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Process Design Manual

Land Application of Sewage Sludge and Domestic Septage

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Land Application of Sewage Sludge and Domestic Septage

U.S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory
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Notice

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Chapter 1
Introduction

1.1 Overview

Land application of sewage sludge[1] generated by domestic sewage treatment is performed in an environmentally safe and cost-effective manner in many communities. Land application involves taking advantage of the fertilizing and soil conditioning properties of sewage sludge by spreading the sewage sludge on the soil surface, incorporating or injecting the sewage sludge into soil, or spraying the sewage sludge. Because sewage sludge disposal practices (e.g., landfilling) are becoming less available and more costly, and because of the increasing desire to beneficially reuse waste residuals whenever possible, land application is increasingly chosen as a sewage sludge use or disposal practice.

Approximately 33 percent of the 5.4 million dry metric tons of sewage sludge generated annually in the United States at publicly owned treatment works (POTWs) is land applied, as shown in Table 1-1. Of the sewage sludge that is land applied, approximately 67 percent is land applied on agricultural lands, 3 percent on forest lands, approximately 9 percent on reclamation sites, and 9 percent on public contact sites; 12 percent is sold or given away in a bag or other container for application to the land (Federal Register, Vol. 58, No. 32, February 19, 1993). In addition, approximately 8.6 billion gallons of domestic septage is generated annually.

Land application of sewage sludge has been practiced in many countries for centuries so that the nutrients (e.g., nitrogen, phosphorus) and organic matter in sewage sludge can be beneficially used to grow crops or other vegetation. Over the years, land application has been increasingly managed to protect human health and the environment from various potentially harmful constituents typically found in sewage sludge, such as bacteria, viruses, and other pathogens; metals (e.g., cadmium and lead); toxic organic chemicals (e.g., PCBs); and nutrients (e.g., nitrogen as nitrate). Management of the land application of sewage sludge has included regulatory measures; voluntary and mandatory pretreatment of wastewater and/or sludge by industry to improve quality (e.g., lower pollutant levels); and use of good management practices at land application sites (e.g., buffer zones, slope restrictions).

[1] The term "biosolids" has recently gained popularity as a synonym for sewage sludge because it perhaps fosters "reuse" potential better than the term "sewage sludge." While this premise may be true, this manual does not use the term "biosolids" because the term is not defined consistently at this time and because the federal Part 503 regulation uses the term "sewage sludge."

1.2 Sewage Sludge Regulations

In 1993, the U.S. Environmental Protection Agency (EPA) promulgated 40 CFR Part 503 to address the Clean Water Act's (CWA) requirement that EPA develop a regulation for the use or disposal of sewage sludge. The CWA required that this regulation protect public health and the environment from any reasonably anticipated adverse effects of pollutants in sewage sludge. The elements of the Part 503 land application standard are illustrated in Figure 1-1. The pollutant limits in the Part 503 rule were based on in-depth risk assessments

Table 1-1. Quantity of Sewage Sludge Generated Annually by Use or Disposal Practice (Federal Register, February 19, 1993)

	POTWs Using a Use/Disposal Practice		Quantity of Sewage Sludge Used or Disposed[a]	
Use/Disposal Practice	**Number**	**Percent of POTWs**	**Quantity (1,000 dmt)**	**Percent of Sewage Sludge**
Land application	4,657	34.6	1,785.3	33.3
Incineration	381	2.8	864.7	16.1
Co-disposal: Landfill	2,991	22.2	1,818.7	33.9
Surface disposal	1,351	10.0	553.7	10.3
Unknown:				
Ocean disposal[b]	133	1.0	335.5	6.3
Other	3,920	29.1	0	0.0
Transfer	25	0.2	N/A	N/A
All POTWs	13,458	100.0	5,357.2	100.0

[a] Numbers may not add up to 100 percent because of rounding.
[b] The National Sewage Sludge Survey, on which these figures are based, was conducted before the Ocean Dumping Ban Act of 1988, which generally prohibited the dumping of sewage sludge into the ocean after December 31, 1991. Ocean dumping of sewage sludge ended in June 1992.

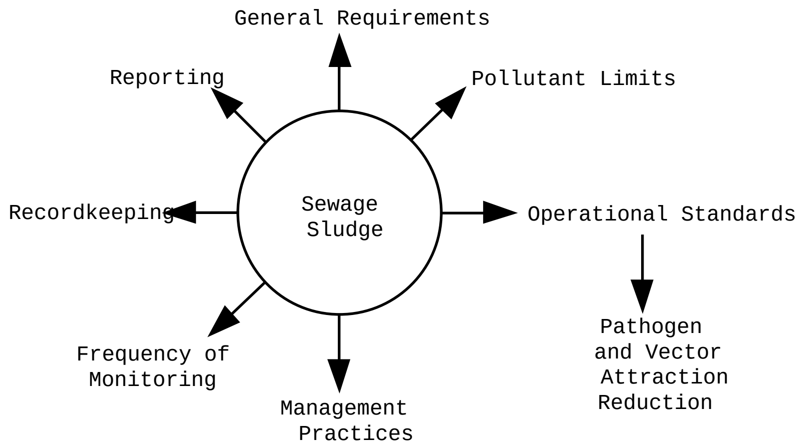

Figure 1-1. Overview of the Part 503 rule's land application requirements.

that investigated the effects on human health and the environment of using or disposing sewage sludge. The pollutant limits and management practices in Part 503 protect human health and the environment, as required by the CWA. Another key component of the rule is the operational standard that requires reduction of pathogens (i.e., disease-causing organisms) and of vector attraction (e.g., insects, rodents) using specified operational processes (e.g., treatment), microbiological monitoring, and physical barriers (e.g., injection or incorporation) for sewage sludge to achieve this reduction. This operational standard, in the judgement of EPA, protects public health and the environment from pathogens and vectors. Other parts of the rule (i.e., general requirements, frequency of monitoring, recordkeeping, and reporting requirements) make the rule self-implementing.

Research has shown that most sewage sludge currently generated in the United States meets the minimum pollutant limits and pathogen reduction requirements set forth in Part 503, and that some sewage sludge already meets the most stringent Part 503 pollutant limits and pathogen and vector attraction reduction requirements.

This manual refers to the Part 503 regulation throughout the document as it relates to the specific topic being discussed (e.g., site selection, design). In addition, this manual provides a summary of the Part 503 land application requirements (Chapter 3).

State agencies may have their own rules governing the use or disposal of sewage sludge or domestic septage. If this is the case, or if a state has not yet adopted the federal rule, the generator or preparer of sewage sludge destined for land application will have to follow the most restrictive portions of both the federal and state rules. Users or disposers of sewage sludge or domestic septage are strongly encouraged to check with the appropriate state sewage sludge coordinator to obtain information on specific and the most up-to-date state requirements.

1.3 Objectives of Manual

The information in this manual is intended for use by municipal wastewater treatment and sewage sludge management authorities, project planners and designers, regional, state, and local governments concerned with permitting and enforcement of federal sewage sludge regulations, and consultants in relevant disciplines such as engineering, soil science, and agronomy. The manual is intended to provide general guidance and basic information on the planning, design, and operation of sewage sludge land application projects for one or more of the following design practices:

- Agricultural land application (crop production, improvement of pasture and rangeland).
- Forest land application (increased tree growth).
- Land application at reclamation sites (mine spoils, construction sites, gravel pits).
- Land application at public contact sites (such as parks and golf courses), lawns, and home gardens.

This manual reflects state-of-the art design information for the land application of sewage sludge. Other EPA manuals that can serve as useful supplements to this guide include:

- *Environmental Regulations and Technology: Control of Pathogens and Vector Attraction in Sewage Sludge.* 1992. Office of Research and Development. EPA/625/R-92/013.
- *Preparing Sewage Sludge For Land Application Or Surface Disposal: A Guide for Preparers of Sewage Sludge on the Monitoring, Record Keeping, and Reporting Requirements of the Federal Standards for*

the Use or Disposal of Sewage Sludge, 40 CFR Part 503. 1993. Office of Water. EPA 831 B-93-002.

- *A Plain English Guide to the EPA Part 503 Biosolids Rule.* 1994. Office of Wastewater Management. EPA/832/R-93/003.
- *Domestic Septage Regulatory Guidance: A Guide to the EPA 503 Rule.* 1993. Office of Water. EPA 832-B-92-005.
- *Technical Support Document for Land Application of Sewage Sludge*. 1992. Vols. I and II. Office of Water. EPA 822/R-93-001a. (NTIS No.: PB93-110583 and PB93-110575).
- *Process Design Manual: Sludge Treatment and Disposal*. 1979. Office of Research and Development. EPA/625/1-79/011.
- *Process Design Manual for Dewatering Municipal Wastewater Sludge*. 1982. Office of Research and Development. EPA/625/1-82/014.

References are made throughout this manual to these and other documents for more detailed information on specific topics relevant to designing land application systems. Full citations for all references are provided at the end of each chapter.

1.4 Scope of Manual

This manual covers both regulatory and non-regulatory aspects of designing and operating sewage sludge land application sites. This manual does not discuss the surface disposal of sewage sludge or codisposal of sewage sludge with municipal solid waste, which is covered in the *Process Design Manual: Surface Disposal of Sewage Sludge and Domestic Septage* (EPA, 1995, EPA/625/R-95/002). This manual also does not discuss incineration of sewage sludge, which is discussed in the *Technical Support Document for Incineration of Sewage Sludge* (EPA, 1992, NTIS PB93-110617). In addition, discussion of industrial sludge, which is regulated by 40 CFR Part 257, is beyond the scope of this manual.

Figure 1-2 presents a suggested sequence to follow when using this manual, which may be varied according to user needs. The manual consists of 16 chapters and 4 appendices. The appendices provide case studies, regional EPA office information, permit requirements, and measurement conversions.

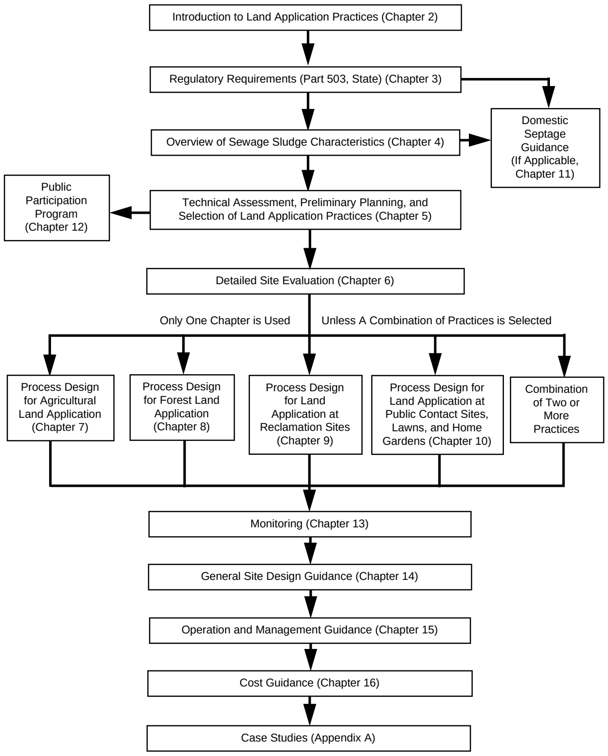

Figure 1-2. Suggested sequence for manual use.

Chapter 2
Overview of Sewage Sludge Land Application Practices

2.1 Introduction

The sewage sludge land application practices listed in the previous chapter are not mutually exclusive. For example, land reclamation may involve the planting of trees on sewage sludge-amended soil, and two or more practices (e.g., land application at agricultural and forest sites) can be used in a single sewage sludge management program. Table 2-1 summarizes the typical characteristics of the sewage sludge land application practices covered in this manual.

Each of these practices has advantages and disadvantages in terms of the quality and quantities of sewage sludge that can be utilized and for application site requirements. This chapter provides an overview of the land application practices and highlights their advantages and disadvantages. Each practice is then discussed in greater detail in the subsequent design chapters. The design chapters present the criteria and limitations that establish sewage sludge application rates in detail.

2.2 Application to Agricultural Lands

2.2.1 Purpose and Definition

Agricultural land application of sewage sludge is practiced in nearly every state, and is especially common in Colorado, New Jersey, Pennsylvania, Ohio, Illinois, Michigan, Missouri, Wisconsin, Oregon, and Minnesota. Hundreds of communities, both large and small, have developed successful agricultural land application programs. These programs benefit the municipality generating the sewage sludge by providing an ongoing, environmentally acceptable, and cost-effective means of managing sewage sludge; the participating farmer also benefits by receiving the nutrients in sewage sludge for crop production, generally at a lower cost than conventional fertilizers.

Sewage sludge applied to agricultural land must be applied at a rate that is equal to or less than the "agronomic rate," defined in Part 503 as the rate designed to provide the amount of nitrogen needed by the crop or vegetation while minimizing the amount of nitrogen in the sewage sludge that will pass below the root zone of the crop or vegetation to the ground water. The amount of available N (or P) applied to the site is based on that required by the crop. This amount of N would otherwise be applied to the site as commercial fertilizer by the farmer. By limiting N loadings to fertilizer recommendations, the impact on ground water should be no greater than in agricultural operations using commercial fertilizers or manure; ground-water impacts may even be less because of Part 503's agronomic rate requirement. Chapter 7 of this manual provides details of agronomic rate calculations for agricultural sites.

2.2.2 Advantages of Agricultural Land Application

Sewage sludge contains several plant macronutrients, principally N and P, and in most cases, varying amounts of micronutrients such as boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn). The exact ratio of these nutrients will not be that of a well-balanced formulated fertilizer; but the nutrients in sewage sludge can be combined with nutrients from other fertilizers to provide the proper amounts of nutrients needed for crop production.

Sewage sludge can also be a valuable soil conditioner. The addition of organic materials like sewage sludge to a fine-textured clay soil can help make the soil more friable and can increase the amount of pore space available for root growth and the entry of water and air into the soil. In coarse-textured sandy soils, organic residues like sewage sludge can increase the water-holding capacity of the soil and provide chemical sites for nutrient exchange and adsorption. In some regions of the country, the water added to the soil during sewage sludge application also is a valuable resource.

The treatment works generating the sewage sludge can benefit because in many cases agricultural land application is less expensive than alternative methods of sewage sludge use or disposal. The general public may benefit from cost savings resulting from agricultural land application of sewage sludge, and the recycling of nutrients is attractive to citizens concerned with the environment and resource conservation.

Table 2-1. Summary of Typical Characteristics of Sewage Sludge Land Application Practices

Characteristics	Agricultural Land Application[a]	Forest Land Application	Land Application at Reclamation Sites	Application to Public Contact Sites, Lawns, and Home Gardens
Application rates	Varies; normal range in dry weight of 2 to 70 t/ha/yr (1 to 30 T/ac/yr) depending on type of crops, sewage sludge characteristics, etc. Typical rate is 10 t/ha/yr (5 T/ac/yr).	Varies; normal range in dry weight of 10 to 220 t/ha/yr (4 to 100 T/ac/yr) depending on soil, tree species, sewage sludge quality, etc. Typical rate is about 18 t/ha/yr (8 T/ac/yr).[b]	Varies; normal range in dry weight of 7 to 450 t/ha/yr (3 to 200 T/ac/yr). Typical rate is 112 t/ha/yr (50 T/ac/yr). Usually a one-time application.	Varies depending on end use (e.g., crops, turf). Typical rate is 18 t/ha/yr (8 T/ac/yr).
Application frequency	Typically repeated annually, usually scheduled between harvesting and planting. Scheduling can be complex with large quantities of sludge.	Usually applied annually or at 3- to 5-year intervals.	Usually a one-time application.	Varies depending on end use.
Ownership of application site(s)	Usually privately owned land. Conditions of application often covered by a contract between farmer(s) and municipality.	Usually owned by private tree-growing firm or governmental agency at state/federal level.	Usually owned by mining firm or governmental agency at state/federal level.	Usually privately owned; some public contact sites (e.g., parks) may be owned by a governmental agency.
Useful life of application site(s)	Unlimited for sludge meeting Part 503 pollutant concentration limits (PCLs, see Chapter 3); limited by accumulated metal loadings from total sludge applied when sludge does not meet PCLs—typically 20-100 or more years.[b]	Usually limited by accumulated metal loadings in total sewage sludge applied. With most sewage sludge, a useful life of 20 to 55 years or more is typical.[b]	Usually a one-time application that helps revegetate site. Cumulative pollutant limits may not be reached for 13 to 50 or more years.[b]	Varies, possibly 32 or more years.b
Sewage sludge transport complexity and cost	Can be expensive if farms are numerous and long transportation distances are involved.	Depends on distance to forest lands and roads within site.	Depends on distance to disturbed lands.	May include conveying sewage sludge from wastewater treatment plant to processing center, transport of bulking materials for composting, and distribution of the finished sewage sludge.
Sewage sludge scheduling	Scheduling can be difficult, because applications must work around planting/ harvesting activities and poor weather conditions.	Scheduling affected by climate and maturity of trees.	Scheduling affected by climate and availability of new sites.	Varies depending on end use.
Application constraints	Usually none when appropriate application vehicles are used. May be limited by cropping pattern and Part 503 agronomic rate management practice requirement.	Can be difficult if limited access roads and uneven terrain. May involve specially designed application equipment. May be limited by Part 503 agronomic rate management practice requirement.	Usually none, but may be complicated by irregular terrain common at disturbed sites.	None; similar to surface application of solid or semisolid fertilizers, lime, or animal manure.
Sludge nutrients beneficially recycled	Yes. Reduces commercial fertilizer use.	Yes. Reduces or eliminates commercial fertilizer use.	Yes. Reduces or eliminates commercial fertilizer use.	Yes. Reduces commercial fertilizer use.
Potential benefits to existing soil condition	Depends on existing soil characteristics and quantity of sludge used.	Depends on existing soil characteristics.	Yes. Allows soil to support vegetation and retards erosion.	Depends on existing soil characteristics and quantity of sludge used.

Table 2-1. Summary of Typical Characteristics of Sewage Sludge Land Application Practices (continued)

Characteristics	Agricultural Land Application[a]	Forest Land Application	Land Application at Reclamation Sites	Application to Public Contact Sites, Lawns, and Home Gardens
Dramatic improvement in vegetative growth response	May improve production; generally replaces some commercial fertilizer nutrients.	Yes. Projects show large positive impact.	Yes. Projects show large positive impact.	Depends on existing soil conditions and quantities of plant nutrients normally applied.
Existing projects using this practice	Hundreds of large and small full-scale projects.	A moderate number of full-scale and demonstration projects.	A moderate number of full-scale and demonstration projects.	A moderate number of full-scale and demonstration projects.
Availability of technical literature pertaining to this practice	Extensive.	Moderate.	Moderate.	Moderate.

[a] t = metric tonnes, T = English tons
[b] Estimates of useful site life from EPA's Technical Support Document for Land Application of Sewage Sludge (U.S. EPA, 1992). Site life may be longer if sludge is not applied every year.

A major advantage of agricultural land application is that usually the treatment works does not have to purchase land. The land utilized for sewage sludge application is kept in production, its value for future uses is not impaired, and it remains on the tax rolls. Finally, agricultural land application usually takes place in a relatively rural setting where the application of sewage sludge is similar to conventional farming operations, such as spreading animal manure, and is not likely to become a public nuisance if properly managed.

2.2.3 Limitations of Agricultural Land Application

Sewage sludge application rates for agricultural land application (dry unit weight of sludge applied per unit of land area) are usually relatively low. Thus, large land areas may be needed, requiring the cooperation of many individual land owners. In addition, sewage sludge transport, as well as application scheduling that is compatible with agricultural planting, harvesting, and possible adverse climatic conditions, will require careful management. If the farms accepting sewage sludge are numerous and widespread, an expensive and complicated sewage sludge distribution system may be required.

2.3 Application to Forest Lands

2.3.1 Purpose and Definition

Except for certain areas in the Great Plains and the southwest, forested lands are abundant and well distributed throughout most of the United States. Many treatment works are located in close proximity to forests; in fact, it is estimated that close to one-third of the land within standard metropolitan areas is forested. Furthermore, approximately two-thirds of all forest land in the United States is commercial timberland (Smith and Evans, 1977). Thus, while currently 3 percent of sewage sludge that is land applied is applied to forest sites, the application of sewage sludge to forest soils has the potential to be a major sewage sludge use practice.

Sewage sludge has been land applied at forest sites in more than ten states, at least on an experimental, field-scale level. The most extensive experience with this practice is in the Pacific Northwest. Seattle, Washington, and a number of smaller towns apply sewage sludge to forests on a relatively large scale.

Three categories of forest land may be available for sewage sludge application:

- Recently cleared land prior to planting
- Newly established plantations (about 3 to 10 years old)
- Established forests

The availability of sites and application considerations for each type of site listed above (as discussed in Chapter 8) will determine which type of site or combination of sites is best for a forest land application program.

2.3.2 Advantages of Forest Land Application

Sewage sludge contains nutrients and essential micronutrients often lacking in forest soils. Demonstration projects have shown greatly accelerated tree growth resulting from sewage sludge application to both newly established plantations and established forests. In addition, sewage sludge contains organic matter that can improve the condition of forest soils by increasing the permeability of fine-textured clay soil, or by increasing the water-holding capacity of sandy soils.

Treatment works located near forest lands may benefit because forest land application may be less expensive than other methods of sewage sludge use or disposal. The general public may benefit from cost savings realized by the treatment works and commercial tree growers using the sewage sludge, and the recycling of nutrients in sewage sludge is attractive to environmentally concerned citizens. Because forests are perennial, the scheduling of sewage sludge applications is not as complex as it may be for agricultural land application programs, for which planting and harvesting cycles must be considered. A final advantage of forest land application is that the treatment works may not have to pay for acquiring land. Sewage sludge application to forest soils is generally performed either annually or at 3- to 5-year intervals.

2.3.3 Limitations of Forest Land Application

Because sewage sludge application to forest lands is not as widely practiced as agricultural application, guidance on this practice is more limited. Chapter 8 provides information on land application at forest sites. The Natural Resource Conservation Service (formerly the Soil Conservation Service) and County Land-Grant University Extension agents may be able to assist with program design and implementation.

It may be difficult to control public access to sewage sludge-amended forest lands. The public is accustomed to free access to forested areas for recreational purposes and may tend to ignore posted signs, fences, etc. Public access restrictions required in Part 503 are discussed in Chapter 3. Forest lands generally are considered to have low potential for public exposure regarding risks associated with the land application of sewage sludge.

Access into some forest lands may be difficult for conventional sewage sludge application equipment. Terrain may be uneven and obstructed. Access roads may have to be built, or specialized sewage sludge application equipment used or developed.

2.4 Land Application at Reclamation Sites

2.4.1 Purpose and Definition

The surface mining of coal, exploration for minerals, generation of mine spoils from underground mines, and tailings from mining operations have created over 1.5 million ha (3.7 million ac) of drastically disturbed land. The properties of these drastically disturbed and marginal lands vary considerably from site to site. Their inability to support vegetation is the result of several factors:

- *Lack of nutrients*. The soils have low N, P, K, or micronutrient levels.
- *Physical properties*. Stony or sandy materials have poor water-holding capacity and low cation exchange capacity (CEC). Clayey soils have poor infiltration, permeability, and drainage.
- *Chemical properties*. The pH of mine soils, tailings, and some drastically disturbed soils range from very acidic to alkaline. Potentially phytotoxic levels of Cu, Zn, Fe, and salts may be present.
- *Organic matter*. Little, if any, organic matter is present.
- *Biological properties*. Soil biological activity is generally reduced.
- *Topography*. Many of these lands are characterized by steep slopes that are subject to excessive erosion.

Historically, reclamation of these lands is accomplished by grading the surface to slopes that minimize erosion and facilitate revegetation. In some cases, topsoil is added. Soil amendments such as lime and fertilizer also are added, and grass, legumes, or trees are planted. Although these methods are sometimes successful, numerous failures have occurred, primarily because of the very poor physical, chemical, or biological properties of these disturbed lands.

Sewage sludge can be used to return barren land to productivity or to provide the vegetative cover necessary for controlling soil erosion. A relatively large amount of sewage sludge must be applied to a land area (7 to 450 t DW/ha) to provide sufficient organic matter and nutrients capable of supporting vegetation until a self-sustaining ecosystem can be established. Because of these typically large, one-time applications of sewage sludge at reclamation sites, the Part 503 rule allows sewage sludge application at reclamation sites to exceed agronomic rates for N if approved by the permitting authority, who may require surface water or groundwater monitoring as a condition for sewage sludge application, if deemed necessary.

Pilot and full-scale demonstration projects have been undertaken in at least 20 states to study the application of sewage sludge to reclaimed lands. The results suggest that sewage sludge can be used effectively to reclaim disturbed sites when the application of sewage sludge is managed properly. The following factors must be considered: the degree to which the sewage sludge is stabilized, sewage sludge application rates, the degree of land slope, and siting issues (e.g., quality of aquifer, depth to ground water).

Because sewage sludge typically is applied only once to land reclamation sites, an ongoing program of sewage sludge application to disturbed lands requires that a planned sequence of additional sites be available for the life of the program. This objective may be achieved through arrangements with land owners and mining firms active in the area or through planned sequential rehabilitation of existing disturbed land areas. Once a reclamation site is reclaimed, sewage sludge can be applied to the site in compliance with the requirements for the type of site it may become (e.g., agricultural or forest land, or a public contact site). For example, reclaimed areas may be used for crop production using agronomic rates of sewage sludge application.

2.4.2 Advantages of Land Application at Reclamation Sites

Land application may be extremely attractive in areas where disturbed and marginal lands exist because of the benefit to the treatment works in using or disposing its sewage sludge and to the environment through reclamation of unsightly, largely useless land areas.

Sewage sludge has several characteristics that makes it suitable for reclaiming and improving disturbed lands and marginal soils. One of the most important is the sewage sludge organic matter which (1) improves soil physical properties by improving granulation, reducing plasticity and cohesion, and increasing water-holding capacity; (2) increases the soil cation exchange capacity; (3) supplies plant nutrients; (4) increases and buffers soil pH; and (5) enhances the rejuvenation of microorganism populations and activity.

The natural buffering capacity and pH of most sewage sludge will improve the acidic or moderately alkaline conditions found in many mine soils. Immobilization of heavy metals is pH-dependent, so sewage sludge application reduces the potential for acidic, metal-laden runoff and leachates. Sewage sludge is also desirable because the nutrients contained in it may substantially reduce commercial fertilizer needs. Furthermore, sewage sludge helps to increase the number and activity of soil microorganisms.

The amount of sewage sludge applied in a single application can often be greater for land reclamation than for agricultural land application, provided that the quantities applied do not pose a serious risk of future plant phytotoxicity or unacceptable nitrate leaching into a potable ground water aquifer, and if regulatory agency approval is granted. In some cases, serious degradation of surface water and ground water may already exist at the proposed site, and a relatively heavy sewage sludge addition with subsequent revegetation can be justified as improving an already bad situation.

The treatment works may not have to purchase land for reclamation projects. In addition, disturbed or marginal lands are usually located in rural, relatively remote areas.

2.4.3 Limitations of Land Application at Reclamation Sites

Plant species for revegetation at reclamation sites should be carefully selected for their suitability to local soil and climate conditions. If crops intended for animal feed or human consumption are planted, the requirements for agricultural land application of sewage sludge have to be met.

Reclamation sites, especially old abandoned mining sites, often have irregular, excessively eroded terrain. Extensive grading and other site preparation steps may be necessary to prepare the site for sewage sludge application. Similarly, disturbed lands often have irregular patterns of soil characteristics. This may cause difficulties in sewage sludge application, revegetation, and future site monitoring.

2.5 Land Application at Public Contact Sites, Lawns, and Home Gardens

2.5.1 Purpose and Definition

Approximately 9 percent of sewage sludge that is land applied annually is used as a soil conditioner or fertilizer on land having a high potential for public contact. These public contact sites include public parks, ball fields, cemeteries, plant nurseries, highway median strips, golf courses, and airports, among others. Another 12 percent of land applied sewage sludge is sold or given away in a bag or other container, most likely for application to public contact sites, lawns, and home gardens. Usually, sewage sludge that is sold or given away in a bag or other container is composted, or heat dried (and sometimes formed into pellets). Composted sewage sludge is dry, practically odorless, and easy to distribute and handle. Bagged or otherwise containerized sewage sludge that is sold or given away often is used as a substitute for topsoil and peat on lawns, golf courses, parks, and in ornamental and vegetable gardens. Yield improvements have been valued at $35 to $50 per dry ton over other potting media (U.S. EPA, 1993).

There have been two basic approaches to sewage sludge use in parks and recreational areas: (1) land reclamation followed by park establishment, and (2) use of sewage sludge as a substitute for conventional fertilizers in the maintenance of established parkland vegetation. Sewage sludge can supply a portion of the nutrients required to maintain lawns, flower gardens, shrubs and trees, golf courses, recreational areas, etc.

2.5.2 Advantages of Land Application at Public Contact Sites, Lawns, and Home Gardens

Programs designed to promote sewage sludge land application to public contact sites, lawns, and home gardens are particularly advantageous for treatment works having limited opportunities for other types of land application (e.g., at forest sites, agricultural land, and reclamation sites).

In some areas of the country, a high demand exists for bagged sewage sludge applied to public contact sites, lawns, and home gardens. This is, in part, due to the fact that sewage sludge often is sold at lower cost than many commercial fertilizers, or is given away free. In addition, although the nutrient content of many sewage sludges is lower than that of commercial fertilizers, sewage sludge contains organic matter that can release nutrients more slowly, minimizing potential "burning" of plants (Lue-Hing et al., 1992).

2.5.3 Limitations of Land Application at Public Contact Sites, Lawns, and Home Gardens

Many of the strictest requirements of the Part 503 rule, in particular the pollutant limits for metals and the pathogen requirements, must be met for sewage sludge applied to lawns, home gardens, and public contact sites. This is because of the high potential for human contact with the sewage sludge at these sites and because it is not possible to impose site restrictions when sewage sludge is sold or given away in a bag or other container for application to the land. While meeting the pollutant limits and pathogen requirements will not be difficult for many sewage sludge preparers, some treatment works have reported problems in meeting certain of these requirements, and corrective measures would involve increased operational costs.

In general, the costs of a program that markets sewage sludge for use on lawns, home gardens, and public contact sites may be greater than the costs of direct land application. Major costs include those for sewage sludge dewatering, processes to achieve adequate pathogen and vector attraction reduction, market development, and transportation.

2.6 References

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Chapter 3
Overview of the Part 503 Regulatory Requirements for Land Application of Sewage Sludge

3.1 General

The federal Part 503 rule (40 CFR Part 503) establishes requirements for land applying sewage sludge (including domestic septage) to ensure protection of public health and the environment when sewage sludge is used for its soil conditioning or fertilizing properties. Promulgated in 1993, Part 503 covers sewage sludge sold or given away in bulk, bags, or other containers for application to agricultural land (e.g., cropland, pastures, and rangelands), forests, reclamation sites (e.g., mine spoils, construction sites, and gravel pits), public contact sites (e.g., parks, plant nurseries), and lawns and home gardens. The rule's land application requirements also pertain to material *derived* from sewage sludge. Such materials include sewage sludge that has undergone a change in quality through treatment (e.g., composting, drying) or mixing with other materials (e.g., wood chips) after it leaves the treatment works where it was generated. Part 503 also covers surface disposal and incineration of sewage sludge, which are beyond the scope of this manual.

This chapter highlights key aspects of the Part 503 rule as they pertain to land application of sewage sludge, including general requirements, pollutant limits, management practices, pathogen and vector attraction reduction, frequency of monitoring, recordkeeping, and reporting, as shown in Chapter 1, Figure 1-1. For a discussion of Part 503 requirements for the land application of domestic septage, see Chapter 11. More detailed discussions of the rule can be found in other EPA documents (U.S. EPA, 1992a; 1992b; 1994).

For most types of sewage sludge other than those specifically excluded (see Table 3-1), the requirements in 40 CFR Part 503 supersede those in 40 CFR Part 257—the previous rule that governed the use or disposal of sewage sludge from 1979 to 1993. Part 503 establishes minimum standards; when necessary to protect public health and the environment, the permitting authority may impose requirements that are more stringent than, or in addition to, those stipulated in the Part 503 rule.

The rule leaves to the discretion of individual states whether to administer a more restrictive sewage sludge use or disposal program than is required by the federal regulation. A state program may even define sewage sludge differently than the federal regulation (see Table 3-2). Also, while state officials are encouraged to submit their sewage sludge programs for review and approval by EPA, they are not required to do so. A disadvantage of an unapproved state program for the regulated community is the added complexity of complying with all applicable federal and state requirements, including the most restrictive requirements of both the state program and the federal rule. Both state and federal operating permits also might be required in a state with a sewage sludge management program that has not been approved by EPA.

For the most part, the requirements of the Part 503 rule are implemented through permits issued by EPA or by a state that administers an EPA-approved sewage sludge management program (see Table 3-3). But the Part 503 rule is "self-implementing," meaning that persons who generate, prepare, or land apply sewage sludge must comply with the rule even if they are not specifically required to obtain a permit.

To ensure compliance with the rule, regulatory officials have the authority to inspect operations, review records, sample applied sewage sludge, and generally respond to complaints concerning public health or public nuisances. EPA also is prepared to pursue enforcement actions when necessary to address violations, whether willful or the result of negligence. In the absence of a government enforcement action, private citizens have standing to pursue civil remedies against a violator under the Clean Water Act.

3.2 Pollutant Limits

Subpart B of the Part 503 rule prohibits the land application of sewage sludge that exceeds pollutant limits termed *ceiling concentrations* in the rule for 10 metals, and places restrictions on the land application of sewage sludge that exceeds additional pollutant limits specified in the rule (*pollutant concentrations, cumulative*

Table 3-1. Types of Sludge, Septage, and Other Wastewater Solids Excluded From Coverage Under Part 503

Sludge Type	Applicable Federal Requirements
Sewage sludge that is hazardous in accordance with 40 CFR Part 261	40 CFR Parts 261-268
Sewage sludge with a PCB concentration equal to or greater than 50 mg/kg total solids (dry weight basis)	40 CFR Part 761
Grit (e.g., small pebbles and sand) and screenings (e.g., large materials such as rags) generated during preliminary treatment of sewage sludge	40 CFR Part 257 (if land applied) 40 CFR Part 258 (if placed in a municipal solid waste landfill)
Commercial septage (e.g., grease from a grease trap at a restaurant) and industrial septage (e.g., liquid or solid material removed from a septic tank that receives industrial wastewater) and mixtures of domestic septage and commerical or industrial septage	40 CFR Part 257 (if land applied) 40 CFR Part 258 (if placed in a municipal solid waste landfill)
Industrial sludge and sewage sludge generated at an industrial facility during the treatment of industrial wastewater with or without combined domestic sewage	40 CFR Part 257 (if land applied) 40 CFR Part 258 (if placed in a municipal solid waste landfill)
Incinerator ash generated during the firing of sewage sludge in a sewage sludge incinerator	40 CFR Part 257 (if land applied) 40 CFR Part 258 (if placed in a municipal solid waste landfill) or 40 CFR Parts 261-268 (if hazardous)
Sewage sludge co-fired in an incinerator with other wastes (other than an auxiliary fuel)	40 CFR Parts 60, 61
Drinking water sludge generated during the treatment of either surface water or ground water used for drinking water	40 CFR Part 257 (if land applied) 40 CFR Part 258 (if placed in a municipal solid waste landfill)
Treatment of sewage sludge prior to final use or disposal (e.g., processes such as thickening, dewatering, storage, heat drying)	None (except for operational parameters used to meet Part 503 pathogen and vector attraction reduction requirements)
Storage of sewage sludge as defined in Part 503	None

Table 3-2. Definitions of Terms Under the Part 503 Rule

Bulk Sewage Sludge	Sewage sludge that is not sold or given away in a bag or other container for application to land.
Domestic Septage	A liquid or solid material removed from a septic tank, cesspool, portable toilet, Type III marine sanitation device, or similar system that receives only domestic sewage. Domestic septage does not include grease-trap pumpings or commercial/industrial wastes.
Domestic Sewage	Waste and wastewater from humans or household operations that is discharged to or otherwise enters a treatment works.
Preparer	The person who generates sewage sludge during the treatment of domesitc sewage in a treatment works, or the person who derives a material from sewage sludge.
Scum, Grit, and Screenings	Scum consists of floatable materials in wastewater and is regulated by Part 503 if it is subject to one of the Part 503 use or disposal practices because it is, by definition, sewage sludge. Grit, which is regulated under 40 CFR Part 257 when applied to the land, consists of heavy, coarse, inert solids (e.g., sand, silt, gravel, ashes, corn grains, seed, coffee ground, and bottle caps) associated with raw wastewater. Screenings, which also are regulated under Part 257 when applied to the land, consist of such solids as rags, sticks, and trash found in the raw wastewater.
Sewage Sludge	A solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Sewage sludge includes scum or solids removed in primary, secondary, or advanced wastewater treatment processes and any material derived from sewage sludge (e.g., a blended sewage sludge/fertilizer product), but does not include grit and screening or ash generated by the firing of sludge in an incinerator. Part 503 considers domestic septage as sewage sludge and sets separate requirements for domestic septage applied to agricultural land, forests, or reclamation sites.
Treatment Works	A federally, publicly, or privately owned device or system used to treat (including recycle and reclaim) either domestic sewage or a combination of domestic sewage and industrial waste of a liquid nature.

pollutant loading rates [CPLRs], or annual pollutant loading rates [APLRs]). For one of the regulated metals, molybdenum, only ceiling concentrations apply while EPA reconsiders the CPLRS, pollutant concentration limits, and APLRs established by the rule. The different types of pollutant limits included in Part 503 are discussed below and are listed in Table 3-4.

3.2.1 Ceiling Concentration Limits

All sewage sludge applied to land must meet Part 503 ceiling concentration limits for the 10 regulated pollutants. Ceiling concentration limits are the maximum allowable concentration of a pollutant in sewage sludge to be land applied. If the ceiling concentration limit for any one of the regulated pollutants is exceeded, the sewage sludge cannot be land applied. The ceiling concentration limits were

Table 3-3. Who Must Apply for a Permit?

Treatment Works Treating Domestic Sewage (TWTDS) Required to Apply for a Permit

- All generators of sewage sludge that is regulated by Part 503 (including all POTWs)
- Industrial facilities that *separately* treat domestic sewage and generate sewage sludge that is regulated by Part 503
- All surface disposal site owner/operators
- All sewage sludge incinerator owner/operators
- Any other person designated by the permitting authority as a TWTDS

TWTDS and Other Persons *Not* Automatically Required To Apply for a Permit[a]

- Any person (e.g., individual, corporation, or government entity) who changes the quality of sewage sludge regulated by Part 503 (e.g., sewage sludge blenders or processers)[b]
- Sewage sludge land appliers, haulers, persons who store, or transporters who do not generate or do not change the quality of the sludge
- Land owners of property on which sewage sludge is applied
- Domestic septage pumpers/haulers/treaters/appliers
- Sewage sludge packagers/baggers (who do not change the quality of the sewage sludge)

[a] EPA may request permit applications from these persons when necessary to protect public health and the environment from reasonably anticipated effects of pollutants that may be present in sewage sludge.
[b] If all the sewage sludge received by a sludge blender or composter is exceptional quality (EQ) sludge, then no permit will be required for the person who receives or processes the EQ sludge.

developed to prevent the land application of sewage sludge containing high concentrations of pollutants.

3.2.2 Pollutant Concentration Limits

Pollutant concentration limits are the most stringent pollutant limits included in Part 503 for land application. These limits help ensure that the quality of land-applied sewage sludge remains at least as high as the quality of sewage sludge at the time the Part 503 rule was developed. Sewage sludge meeting pollutant concentration limits, as well as certain pathogen and vector attraction reduction requirements (see Section 3.7.1), generally is subject to fewer Part 503 requirements than sewage sludge meeting cumulative pollutant loading rates (CPLRs) (discussed below).

3.2.3 Cumulative Pollutant Loading Rates (CPLRs)

A cumulative pollutant loading rate (CPLR) is the maximum amount of a pollutant that can be applied to a site by all bulk sewage sludge applications made after July 20, 1993. CPLRs pertain only to land application of bulk sewage sludge, as defined in Part 503. When the maximum CPLR is reached at the application site for any one of the 10 metals regulated by the Part 503 rule, no additional sewage sludge subject to the CPLRs can be applied to the site. If a CPLR is reached at a site, only sewage sludge that meets the pollutant concentration limits could be applied to that site.

Table 3-4. Part 503 Land Application Pollutant Limits for Sewage Sludge

Pollutant	Ceiling Concentration Limits (milligrams per kilogram)[a,b]	Pollutant Concentration Limits (milligrams per kilogram)[a,c]	Cumulative Pollutant Loading Rate Limits (kilograms per hectare)	Annual Pollutant Loading Rate Limits (kilograms per hectare per 365-day period)
Arsenic	75	41	41	2.0
Cadmium	85	39	39	1.9
Chromium[d]	3,000	1,200	3,000	150
Copper	4,300	1,500	1,500	75
Lead	840	300	300	15
Mercury	57	17	17	0.85
Molybdenum	75	—[d]	—[d]	—[d]
Nickel	420	420	420	21
Selenium	100	36[d]	100	5.0
Zinc	7,500	2,800	2,800	140
Applies to:	All sewage sludge that is land applied	Bulk sewage sludge and bagged sewage sludge[e]	Bulk sewage sludge	Bagged sewage sludge[e]
From Part 503	Table 1, Section 503.13	Table 3, Section 503.13	Table 2, Section 503.13	Table 4, Section 503.13

[a] Dry-weight basis.
[b] All sewage sludge samples must meet the ceiling concentrations, at a minimum, to be eligible for land application (instantaneous values).
[c] Monthly average.
[d] EPA is re-examining these limits.
[e] Bagged sewage sludge is sold or given away in a bag or other container for application to the land.

3.2.4 Annual Pollutant Loading Rates (APLRs)

The annual pollutant loading rate (APLR) is the maximum amount of a pollutant that can be applied to a site within a 12-month period from sewage sludge that is sold or given away in a bag or other container for application to land.[1] To meet the APLRs, the pollutant concentration in sewage sludge, multiplied by the "annual whole sludge application rate," as determined in Appendix A of the Part 503 rule, must not cause any of the APLRs to be exceeded. APLRs rather then CPLRs are used for sewage sludge sold or given away in a bag or other container for application to land because controlling cumulative applications of these types of sewage sludge would not be feasible.

APLRs are based on a 20-year site life, which EPA considers a conservative estimate because sewage sludge sold or given away in small quantities will most likely be applied to lawns, home gardens, or public contact sites. Sewage sludge is not likely to be applied to such types of land for longer than 20 years; indeed, 20 consecutive years of application is unlikely (U.S. EPA, 1992a).

3.2.5 Why Organic Pollutants Were Not Included in Part 503

The Part 503 regulation does not establish pollutant limits for any organic pollutants because EPA determined that none of the organics considered for regulation[2] pose a public health or environmental risk from land application of sewage sludge (U.S. EPA, 1992a). EPA used the following criteria to make this determination:

- The pollutant is banned or restricted in the United States or is no longer manufactured in the United States; or
- The pollutant is not present in sewage sludge at significant frequencies of detection, based on data gathered from the 1990 NSSS; or
- The limit for a pollutant from EPA's exposure assessment is not expected to be exceeded in sewage sludge that is used or disposed, based on data from the NSSS.

[1] "Other containers" are defined in Part 503 as open or closed receptacles, such as buckets, boxes, cartons, or vehicles, with a load capacity of 1 metric ton or less.

[2] Aldrin/dieldrin, benzene, benzo(a)pyrene, bis(2ethylhexyl)phthalate, chlordane, DDT (and its derivatives DDD and DDE), dimethyl nitrosamine, heptachlor, hexachlorobenzene, hexachlorobutadiene, lindane, PCBs, toxaphene, and trichloroethylene.

3.3 Management Practices

As described in Table 3-5, the Part 503 rule specifies management practices that must be followed when sewage sludge is land applied. Management practices required for bulk sewage sludge meeting Part 503 pollutant concentration limits or cumulative pollutant loading rates protect water quality and the survival of threatened or endangered species. For example, bulk sewage sludge that meets these pollutant limits cannot be applied to sites that are flooded or frozen in such a way that the sewage sludge might enter surface waters or wetlands. Also, any direct or indirect action that diminishes the likelihood of a threatened or endangered species' survival by modifying its critical habitat is prohibited. Other Part 503 management practices are listed in Table 3-5.

Table 3-5. Part 503 Land Application Management Practices

For Bulk Sewage Sludge[a]

Bulk sewage sludge cannot be applied to flooded, frozen, or snow-covered agricultural land, forests, public contact sites, or reclamation sites in such a way that the sewage sludge enters a wetland or other waters of the United States (as defined in 40 CFR Part 122.2), except as provided in a permit issued pursuant to Section 402 (NPDES permit) or Section 404 (Dredge and Fill Permit) of the Clean Water Act, as amended.

Bulk sewage sludge cannot be applied to agricultural land, forests, or reclamation sites that are 10 meters or less from U.S. waters, unless otherwise specified by the permitting authority.

If applied to agricultural lands, forests, or public contact sites, bulk sewage sludge must be applied at a rate that is equal to or less than the agronomic rate for the site. Sewage sludge applied to reclamation sites may exceed the agronomic rate if allowed by the permitting authority.

Bulk sewage sludge must not harm or contribute to the harm of a threatened or endangered species or result in the destruction or adverse modification of the species' critical habitat when applied to the land. Threatened or endangered species and their critical habitats are listed in Section 4 of the Endangered Species Act. Critical habitat is defined as any place where a threatened or endangered species lives and grows during any stage of its life cycle. Any direct or indirect action (or the result of any direct or indirect action) in a critical habitat that diminishes the likelihood of survival and recovery of a listed species is considered destruction or adverse modification of a critical habitat.

For Sewage Sludge Sold or Given Away in a Bag or Other Container for Application to the Land[a]

A label must be affixed to the bag or other container, or an information sheet must be provided to the person who receives this type of sewage sludge in another container. At a minimum, the label or information sheet must contain the following information:

- the name and address of the person who prepared the sewage sludge for sale or give-away in a bag or other container;
- a statement that prohibits application of the sewage sludge to the land except in accordance with the instructions on the label or information sheet;
- an AWSAR (see Table 3-18) for the sewage sludge that does not cause the APLR pollutant limits to be exceeded.

[a] These management practices do not apply if the sewage sludge is of "exceptional quality," as defined in section 3.7.

The preparer of sewage sludge that is sold or given away in a bag or other container for application to land must comply with the Part 503 management practice that requires the preparer to provide application rate information, as well as other pertinent data, to the land applier of sewage sludge meeting annual pollutant loading rates (as discussed in Table 3-5 and Section 3.7.4).

3.4 Operational Standards for Pathogens and Vector Attraction Reduction

Subpart D of the Part 503 rule describes requirements for land application of sewage sludge (and domestic septage, as discussed in Chapter 11) that reduce the potential for the spread of disease, thus protecting public health and the environment. The Part 503 Subpart D requirements cover two characteristics of sewage sludge:

- *Pathogens.* Part 503 requires the reduction of potential disease-bearing microorganisms called pathogens (such as bacteria and viruses) in sewage sludge.
- *Vector Attraction.* Part 503 also requires that the potential for sewage sludge to attract vectors (e.g., rodents, birds, insects) that can transport pathogens away from the land application site be reduced.

Compliance with the Part 503 pathogen and vector attraction reduction requirements, summarized below, must be demonstrated separately.

3.4.1 Pathogen Reduction Requirements

The Part 503 pathogen reduction requirements for sewage sludge are divided into two categories: Class A and Class B, as shown in Table 3-6. The implicit goal of the Class A requirements is to reduce the pathogens in sewage sludge (including *Salmonella* sp. bacteria, enteric viruses, and viable helminth ova) to below detectable levels. When this goal is achieved, Class A sewage sludge can be land applied without any pathogen-related restrictions on the site (see Section 3.7).

The implicit goal of the Class B requirements is to ensure that pathogens have been reduced to levels that are unlikely to pose a threat to public health and the environment under specific use conditions. Site restrictions on the land application of Class B sewage sludge minimize the potential for human and animal contact with the sewage sludge until environmental factors have reduced pathogens to below detectable levels. In addition, to further reduce the likelihood of human contact with pathogens, Class B sewage sludge cannot be sold or given away in a bag or other container for land application. Part 503 Class A and B pathogen reduction requirements are summarized below; another EPA document (U.S. EPA, 1992b) provides a detailed discussion of pathogen reduction requirements under Part 503.

Table 3-6. Summary of Class A and Class B Pathogen Alternatives

CLASS A

In addition to meeting the requirements in one of the six alternatives listed below, fecal coliform or *Salmonella* sp. bacterial levels must meet specific densities at the time of sewage sludge use or disposal, when prepared for sale or give-away in a bag or other container for application to the land, or when prepared to meet the requirements in 503.10(b), (c), (e), or (f)

Alternative 1: Thermally Treated Sewage Sludge

Use one of four time-temperature regimes

Alternative 2: Sewage Sludge Treated in a High pH-High Temperature Process

Specifies pH, temperature, and air-drying requirements

Alternative 3: For Sewage Sludge Treated in Other Processes

Demonstrate that the process can reduce enteric viruses and viable helminth ova. Maintain operating conditions used in the demonstration

Alternative 4: Sewage Sludge Treated in Unknown Processes

Demonstration of the process is unnecessary. Instead, test for pathogens—*Salmonella* sp. bacteria, enteric viruses, and viable helminth ova—at the time the sewage sludge is used or disposed, or is prepared for sale or give-away in a bag or other container for application to the land, or when prepared to meet the requirements in 503.10(b), (c), (e), or (f)

Alternative 5: Use of PFRP

Sewage sludge is treated in one of the processes to further reduce pathogens (PFRP)

Alternative 6: Use of a Process Equivalent to PFRP

Sewage sludge is treated in a process equivalent to one of the PFRPs, as determined by the permitting authority

CLASS B

The requirements in one of the three alternatives below must be met in addition to Class B site restrictions

Alternative 1: Monitoring of Indicator Organisms

Test for fecal coliform density as an indicator for all pathogens at the time of sewage sludge use or disposal

Alternative 2: Use of PSRP

Sewage sludge is treated in one of the processes to significantly reduce pathogens (PSRP)

Alternative 3: Use of Processes Equivalent to PSRP

Sewage sludge is treated in a process equivalent to one of the PSRPs, as determined by the permitting authority

Note: Details of each alternative for meeting the requirements for Class A and Class B designations are provided in Section 3.4.

3.4.1.1 Class A Pathogen Requirements

Sewage sludge that must meet the Class A pathogen requirements includes sewage sludge that is sold or given away in a bag or other container for application to land and bulk sewage sludge that is applied to a lawn or home garden. Part 503 Subpart D establishes six alternatives for demonstrating that sewage sludge meets Class A pathogen reduction requirements (Table 3-6). The rule requires that the density of fecal coliforms be less than 1,000 Most Probable Number (MPN) per gram total solids (dry weight) or that *Salmonella* sp. bacteria be less than 3 per 4 grams total solids, as discussed in Table 3-7.

Table 3-7. Pathogen Requirements for All Class A Alternatives

The following requirements must be met for ***all*** six Class A pathogen alternatives. Either:

- the density of fecal coliform in the sewage sludge must be less than 1,000 most probable number (MPN) per gram total solids (dry-weight basis),

or

- the density of *Salmonella* sp. bacteria in the sewage sludge must be less than 3 MPN per 4 grams of total solids (dry-weight basis).

This requirement must be met at one of the following times:

- when the sewage sludge is used or disposed;
- when the sewage sludge is prepared for sale or give-away in a bag or other container for land application; or
- when the sewage sludge or derived material is prepared to meet the Part 503 requirements in 503.10(b), (c), (e), or (f)

Pathogen reduction must take place before or at the same time as vector attraction reduction, except when the pH adjustment or percent solids vector attraction reduction options are met, or if vector attraction reduction is accomplished through injection or incorporation.

Table 3-8. The Four Time-Temperature Regimes for Pathogen Reduction Under Class A, Alternative 1

Regime	Applies to:	Requirement	Time-Temperature Relationship[a]
A	Sewage sludge with 7% solids or higher (except those covered by Regime B)	Temperature of sewage sludge must be 50°C or higher for not less than 20 minutes	$D = \frac{131,700,000}{10^{0.1400T}}$ (Equation 3 of Section 503.32)
B	Sewage sludge with 7% solids or higher in the form of small particles heated by contact with either warmed gases or an immiscible liquid	Temperature of sewage sludge must be 50°C or higher for not less than 15 seconds	$D = \frac{131,700,000}{10^{0.1400T}}$
C	Sewage sludge with less than 7% solids	Heated for more than 15 seconds but less than 30 minutes	$D = \frac{131,700,000}{10^{0.1400T}}$
D	Sewage sludge with less than 7% solids	Temperature of sludge is 50°C or higher with at least 30 minutes contact time	$D = \frac{50,070,000}{10^{0.1400T}}$ (Equation 4 of Section 503.32)

[a] D = time in days; T = temperature in degrees Celsius.

Each of the six alternatives for meeting Class A pathogen reduction requirements includes monitoring requirements to ensure that substantial regrowth of pathogenic bacteria does not occur after the sewage sludge meets the pathogen reduction requirements prior to use or disposal.

The timing of Class A pathogen reduction in relation to vector attraction reduction requirements (see Section 3.4.2) is important when certain vector attraction reduction options are used. Part 503 requires that Class A pathogen reduction be accomplished *before or at the same time as* vector attraction reduction, except when vector attraction reduction is achieved by alkali addition or drying.

The following discussion summarizes the Part 503 Class A pathogen reduction alternatives. For a more complete discussion of these alternatives, see *Environmental Regulations and Technology: Control of Pathogens and Vector Attraction in Sewage Sludge* (U.S. EPA, 1992b).

Alternative 1: Thermally Treated Sewage Sludge

This alternative may be used when the pathogen reduction process relies on specific time-temperature regimes to reduce pathogens (Table 3-8). The approach involves calculating the heating time necessary at a particular temperature to reduce a sewage sludge's pathogen content to below detectable levels. The need to conduct time-consuming and expensive tests for the presence of specific pathogens can be avoided with this approach.

The microbiological density portion of the requirement (i.e., the regrowth requirement) is designed to ensure that the microbiological reductions expected as a result of the time-temperature regimes have actually been attained and that regrowth has not occurred. Equations for each of the four time-temperature regimes takes into account the percent of solids in the sewage sludge and the operating parameters of the treatment process.

Alternative 2: Sewage Sludge Treated in a High pH-High Temperature Process

This alternative may be used when the pathogen reduction process relies on a particular high temperature-high pH process that has been demonstrated to be effective in reducing pathogens to below detectable levels. The high pH (>12 for more than 72 hours) and high temperature (above 52°C [126°F] for at least 12 hours while pH is >12) for prolonged periods allow a less stringent time-temperature regime than the requirements under Alternative 1. After the 72-hour period during which the pH of the sewage sludge is above 12, the sewage sludge must be air dried to achieve a percent solids content of greater than 50 percent. As when thermal processing is used, monitoring for regrowth of pathogenic bacteria (fecal coliforms or salmonellae) must be conducted (Table 3-7).

Alternative 3: Sewage Sludge Treated in Other Processes

This alternative applies to sewage sludge treated by processes that do not meet the process conditions required by Alternatives 1 and 2. Alternative 3 relies on comprehensive monitoring of fecal coliform or *Salmonella* sp. bacteria; enteric viruses; and viable helminth ova to demonstrate adequate reduction of pathogens, as specified in the Part 503 rule.

If no enteric viruses or viable helminth ova are present before treatment (i.e., in the feed sewage sludge), the sewage sludge is Class A with respect to pathogens until the next monitoring episode. Monitoring is continued until enteric viruses or viable helminth ova are detected in the feed sewage sludge, at which point the treated sewage sludge is analyzed to see if these organisms survived treatment. If enteric virus and viable helminth ova densities are below detection limits, the sewage sludge meets Class A requirements and will continue to do so as long as the treatment process is operated under the same conditions that successfully reduced the enteric virus and viable helminth ova densities. Monitoring for fecal coliform and *Salmonella* sp. bacteria, however, must continue to be performed as indicated in Table 3-7.

Alternative 4: Sewage Sludge Treated in Unknown Processes

This alternative is used primarily for stored sewage sludge for which the history is unknown. It also can be used when the process in which sewage sludge is treated does not meet any of the descriptions of a Process to Further Reduce Pathogens (PFRP). In this alternative, a representative sample of the sewage sludge must meet the Part 503 requirements for *Salmonella* sp. or fecal coliform bacteria (as described in Table 3-7); enteric viruses; and viable helminth ova at the time the sewage sludge is used or disposed, prepared for sale or give-away in a bag or other container for application to land, or prepared to meet “exceptional quality” (EQ) land application requirements (as discussed later in this chapter). The number of samples that have to be collected and analyzed for pathogen densities is based on the amount of sewage sludge that is land applied annually (see the requirements for frequency of monitoring in the land application subpart of Part 503).

Alternative 5: Use of a PFRP

This alternative provides continuity with the 40 CFR Part 257 regulation (the predecessor to Part 503). For Alternative 5, sewage sludge qualifies as Class A if it has been treated in one of the processes to further reduce pathogens (PFRPs) (Table 3-9) and meets the regrowth requirement in Table 3-7. The treatment processes must be operated according to the PFRP process descriptions summarized in Table 3-9 at all times. The list of processes in Table 3-9 (which appears as Appendix B in the Part 503 regulation) is similar to the PFRP approaches listed in Part 257, with two major differences:

- All requirements concerning vector attraction have been removed.
- All “add-on” processes listed in Part 257 are now PFRPs because Part 503 contains separate requirements for vector attraction reduction.

Table 3-9. Processes To Further Reduce Pathogens (PFRPs) Listed in the Part 503 Rule

1. Composting

Using either the within-vessel composting method or the static aerated pile composting method, the temperature of the sewage sludge is maintained at 55°C (131°F) or higher for 3 days.

Using the windrow composting method, the temperature of the sewage sludge is maintained at 55°C (131°F) or higher for 15 days or longer. During the period when the compost is maintained at 55°C (131°F) or higher, there shall be a minimum of five turnings of the windrow.

2. Heat Drying

Sewage sludge is dried by direct or indirect contact with hot gases to reduce the moisture content of the sewage sludge to 10% or lower. Either the temperature of the sewage sludge particles exceeds 80°C (176°F) or the wet bulk temperature of the gas in contact with the sewage sludge as the sewage sludge leaves the dryer exceeds 80°C (176°F).

3. Heat Treatment

Liquid sewage sludge is heated to a temperature of 180°C (356°F) or higher for 30 minutes.

4. Thermophilic Aerobic Digestion

Liquid sewage sludge is agitated with air or oxygen to maintain aerobic conditions and the mean cell residence time (i.e., the solids retention time) of the sewage sludge is 10 days at 55°C (131°F) to 60°C (140°F).

5. Beta Ray Irradiation

Sewage sludge is irradiated with beta rays from an electron accelerator at dosages of at least 1.0 megarad at room temperature (ca. 20°C [68°F]).

6. Gamma Ray Irradiation

Sewage sludge is irradiated with gamma rays from certain isotopes, such as Cobalt 60 and Cesium 137, at dosages of at least 1.0 megarad at room temperature (ca. 20°C [68°F]).

7. Pasteurization

The temperature of the sewage sludge is maintained at 70°C (158°F) or higher for 30 minutes or longer.

Under this alternative, treatment processes classified as PFRPs under Part 257 can continue to be operated; however, microbiological monitoring (i.e., for fecal coliform or *Salmonella* sp. bacteria) must now be performed to ensure that pathogen density levels are below detection limits and that regrowth of *Salmonella* sp. bacteria does not occur between treatment and use or disposal of the sewage sludge.

Alternative 6: Use of a Process Equivalent to a PFRP

Under this alternative, sewage sludge is considered to be Class A sewage sludge if it is treated by any process equivalent to a PFRP and meets the regrowth requirement in Table 3-7. To be equivalent, a treatment process must be able to consistently reduce pathogens to levels comparable to the reduction achieved by a listed PFRP. Processes must be operated at all times at the parameters described in the process description. The Part 503 rule gives the permitting authority responsibility for determining equivalency. To assist in making such determinations, the EPA's Pathogen Equivalency Committee (PEC) serves as a resource, providing recommendations on the equivalency of processes; the PEC also provides guidance to the regulated community. Equivalency determinations can be made on a site-specific or national basis. Processes recommended in Part 257 as equivalent (Table 3-10) should yield sewage sludge that meets Class A pathogen reduction requirements, as long as microbiological requirements are also met.

Table 3-10. A Partial List of Processes Recommended as Equivalent to PFRP Under Part 257[1]

Operator	Process Description
Scarborough Sanitary District Scarborough, Maine	Static pile aerated "composting" operation that uses fly ash from a paper company as a bulking agent. The process creates pile temperatures of 60°C to 70°C (140°F to 158°F) within 24 hours and maintains these temperatures for up to 14 days. The material is stockpiled after 7 to 14 days of "composting" and then marketed.
Mount Holly Sewage Authority Mount Holly, New Jersey	Zimpro 50-gpm low-pressure wet air oxidation process. The process involves heating raw primary sewage sludge to 177°C to 204°C (350°F to 400°F) in a reaction vessel under pressures of 250 to 400 psig for 15 to 30 minutes. Small volumes of air are introduced into the process to oxidize the organic solids.
Miami-Dade Water and Sewer Authority Miami, Florida	Anaerobic digestion followed by solar drying. Sewage sludge is processed by anaerobic digestion in two well-mixed digesters operating in series in a temperature range of 35°C to 37°C (95°F to 99°F). Total residence time is 30 days. The sewage sludge is then centrifuged to produce a cake of between 15% to 25% solids. The sewage sludge cake is dried for 30 days on a paved bed at a depth of no more than 46 cm (18 inches). Within 8 days of the start of drying, the sewage sludge is turned over at least once every other day until the sewage sludge reaches a solids content of greater than 70%.

[1]These processes were all recommended for site-specific equivalency.

3.4.1.2 Class B Pathogen Requirements

Bulk sewage sludge that is applied to agricultural land, forests, public contact sites, or reclamation sites must meet the Class B pathogen requirements if it does not meet Class A pathogen requirements. Part 503 Subpart D establishes three alternatives for demonstrating that sewage sludge meets Class B pathogen requirements (Table 3-6). The rule's implicit objective for all three approaches is to ensure that pathogenic bacteria and enteric viruses are reduced in density, as demonstrated by a fecal coliform density in the treated sewage sludge of 2 million Most Probable Number (MPN) or colony-forming units (CFU) per gram total solids sewage sludge (dry-weight basis). Viable helminth ova are not necessarily reduced in Class B sewage sludge.

Table 3-11. Restrictions for the Harvesting of Crops and Turf, Grazing of Animals, and Public Access on Sites Where Class B Sewage Sludge is Land Applied

Restrictions for the harvesting of crops and turf:

1. Food crops with harvested parts that touch the sewage sludge/soil mixture and are totally above ground shall not be harvested for *14 months* after application of sewage sludge.
2. Food crops with harvested parts below the land surface where sewage sludge remains on the land surface for 4 months or longer prior to incorporation into the soil shall not be harvested for *20 months* after sewage sludge application.
3. Food crops with harvested parts below the land surface where sewage sludge remains on the land surface for less than 4 months prior to incorporation shall not be harvested for *38 months* after sewage sludge application.
4. Food crops, feed crops, and fiber crops, whose edible parts do not touch the surface of the soil, shall not be harvested for *30 days* after sewage sludge application.
5. Turf grown on land where sewage sludge is applied shall not be harvested for *1 year* after application of the sewage sludge when the harvested turf is placed on either land with a high potential for public exposure or a lawn, unless otherwise specified by the permitting authority.

Restriction for the grazing of animals:

1. Animals shall not be grazed on land for *30 days* after application of sewage sludge to the land.

Restrictions for public contact:

1. Access to land with a high potential for public exposure, such as a park or ballfield, is restricted for *1 year* after sewage sludge application. Examples of restricted access include posting with no trespassing signs, or fencing.
2. Access to land with a low potential for public exposure (e.g., private farmland) is restricted for *30 days* after sewage sludge application. An example of restricted access is remoteness.

Unlike Class A sewage sludge, which is essentially pathogen-free, Class B sewage sludge contains some pathogens. Therefore, site restrictions (Table 3-11) apply for a certain period when Class B sewage sludge is land applied to allow environmental factors to further reduce pathogens to below detectable levels. Additionally, Class B sewage sludge must meet a vector attraction requirement (see Section 3.4.2). The three alternatives for meeting Part 503 Class B pathogen reduction requirements are summarized below; more detailed information on Class B pathogen requirements can be found in another EPA document (U.S. EPA, 1992b).

Alternative 1: Monitoring of Fecal Coliform

This alternative requires that seven samples of treated sewage sludge be collected at the time of use or disposal, and that the geometric mean fecal coliform density of these sample be less that 2 million CFU or MPN per gram of sewage sludge solids (dry-weight basis). Analysis of multiple samples is required during each monitoring period because the methods used to determine fecal coliform density (i.e., membrane filter methods and the MPN dilution method) have poor precision and because sewage sludge quality tends to vary. Use of at least seven samples is expected to reduce the standard error to a reasonable value.

Alternative 2: Use of a PSRP

Under this alternative, which provides continuity with Part 257, sewage sludge is considered to be Class B if it is treated in one of the processes to significantly reduce pathogens (PSRPs) (Table 3-12). The list of processes (which appears as Appendix B in the Part 503 regulation) is similar to the PSRP approaches listed in Part 257, except that all conditions related to reduction of vector attraction have been removed. Unlike the comparable Class A requirement, this alternative does not require microbiological monitoring because public access to the site is restricted, allowing time for environmental conditions to reduce pathogens to below detectable levels.

Table 3-12. Processes to Significantly Reduce Pathogens (PSRPs) Listed in Part 503

1. Aerobic Digestion

Sewage sludge is agitated with air or oxygen to maintain aerobic conditions for a specific mean cell residence time (i.e., solids retention time) at a specific temperature. Values for the mean cell residence time and temperature shall be between 40 days at 20°C (68°F) and 60 days at 15°C (59°F).

2. Air Drying

Sewage sludge is dried on sand beds or on paved or unpaved basins. The sewage sludge dries for a minimum of 3 months. During 2 of the 3 months, the ambient average daily temperature is above 0°C (32°F).

3. Anaerobic Digestion

Sewage sludge is treated in the absence of air for a specific mean cell residence time (i.e., solids retention time) at a specific temperature. Values for the mean cell residence time and temperature shall be between 15 days at 35°C to 55°C (131°F) and 60 days at 20°C (68°F).

4. Composting

Using either the within-vessel, static aerated pile, or windrow composting methods, the temperature of the sewage sludge is raised to 40°C (104°F) or higher and remains at 40°C (104°F) or higher for 5 days. For 4 hours during the 5-day period, the temperature in the compost pile exceeds 55°C (131°F).

5. Lime Stabilization

Sufficient lime is added to the sewage sludge to raise the pH of the sewage sludge to 12 after 2 hours of contact.

Alternative 3: Use of a Process Equivalent to a PSRP

Alternative 3 states that sewage sludge treated by any process determined to be equivalent to a PSRP by the permitting authority is considered to be a Class B sewage sludge. To assist the permitting authority in making determinations, the EPA's Pathogen Equivalency Committee (PEC) serves as a resource, providing recommendations on the equivalency of processes; the PEC also provides guidance to the regulated community. Equivalency determinations can be made on a site-specific or national basis. Processes recommended in Part 257 as equivalent (a partial list is provided in Table 3-13) should yield sewage sludge that meets Class B pathogen requirements.

Table 3-13. Selected Processes Recommended as Equivalent to PSRP Under Part 257[1]

Operator	Process Description
Town of Telluride, Colorado	Combination oxidation ditch, aerated storage, and drying process. Sewage sludge is treated in an oxidation ditch for at least 26 days and then stored in an aerated holding tank for up to a week. Following dewatering to 18% solids, the sewage sludge is dried on a paved surface to a depth of 2 feet (0.6 m). The sewage sludge is turned over during drying. After drying to 30% solids, the sludge is stockpiled prior to land application. Together, the drying and stockpiling steps take approximately 1 year. To ensure that PSRP requirements are met, the stockpiling period must include one full summer season.
Comprehensive Materials Management, Inc. Houston, Texas	Use of cement kiln dust (instead of lime) to treat sewage sludge by raising sewage sludge pH to at least 12 after 2 hours of contact. Dewatered sewage sludge is mixed with cement kiln dust in an enclosed system.
N-Viro Energy Systems, Ltd. Toledo, Ohio	Use of cement kiln dust and lime kiln dust (instead of lime) to treat sewage sludge by raising the pH. Sufficient lime or kiln dust is added to sewage sludge to produce a pH of 12 for at least 12 hours of contact.
Public Works Department Everett, Washington	Anaerobic digestion of lagooned sewage sludge. Suspended solids had accumulated in a 30-acre (12-hectare) aerated lagoon that had been used to aerate wastewater. The lengthy detention time in the lagoon (up to 15 years) resulted in a level of treatment exceeding that provided by conventional anaerobic digestion. The percentage of fresh or relatively unstabilized sewage sludge was very small compared to the rest of the accumulation (probably much less than 1% of the whole).
Haikey Creek Wastewater Treatment Plant Tulsa, Oklahoma	Oxidation ditch treatment plus storage. Sewage sludge is processed in aeration basins followed by storage in aerated sludge holding tanks. The total sewage sludge aeration time is greater than the aerobic digestion operating conditions specified in the Part 503 regulation of 40 days at 20°C (68°F) to 60 days at 15°C (59°F). The oxidation ditch sludge is then stored in batches for at least 45 days in an unaerated condition or 30 days under aerated conditions.
Ned K. Burleson & Associates, Inc. Fort Worth, Texas	Aerobic digestion for 20 days at 30°C (86°F) or 15 days at 35°C (95°F).

[1] All processes were recommended for site-specific equivalency, except the N-Viro System, which was recommended for national equivalency.

3.4.2 Vector Attraction Reduction Requirements

Subpart D in Part 503 establishes 10 options for demonstrating that sewage sludge that is land applied meets requirements for vector attraction reduction (Table 3-14). The options can be divided into two general approaches for controlling the spread of disease via vectors (such as insects, rodents, and birds):

- Reducing the attractiveness of the sewage sludge to vectors (Options 1 to 8).
- Preventing vectors from coming into contact with the sewage sludge (Options 9 and 10).

Compliance with the vector attraction reduction requirements using one of the options described below must be demonstrated separately from compliance with requirements for reducing pathogens in sewage sludge. Thus, demonstration of adequate vector attraction reduction does not demonstrate achievement of adequate pathogen reduction. Part 503 vector attraction reduction requirements are summarized below; for a detailed discussion of vector attraction requirements, see U.S. EPA (1992b).

3.4.2.1 Option 1: Reduction in Volatile Solids Content

Under this option, vector attraction is reduced if the mass of volatile solids in the sewage sludge is reduced by at least 38 percent during the treatment of the sewage sludge. This percentage is the amount of volatile solids reduction that can be attained by anaerobic or aerobic digestion plus any additional volatile solids reduction that occurs before the sewage sludge leaves the treatment works, such as through processing in drying beds or lagoons, or when sewage sludge is composted.

Table 3-14. Summary of Vector Attraction Reduction Requirements for Land Application of Sewage Sludge Under Part 503 (U.S. EPA 1992b)

Requirement	What Is Required?	Most Appropriate For:
Option 1 503.33(b)(1)	At least 38% reduction in volatile solids during sewage sludge treatment	Sewage sludge processed by: • Anaerobic biological treatment • Aerobic biological treatment • Chemical oxidation
Option 2 503.33(b)(2)	Less than 17% additional volatile solids loss during bench-scale anaerobic batch digestion of the sewage sludge for 40 additional days at 30°C to 37°C (86°F to 99°F)	Only for anaerobically digested sewage sludge
Option 3 503.33(b)(3)	Less than 15% additional volatile solids reduction during bench-scale aerobic batch digestion for 30 additional days at 20°C (68°F)	Only for aerobically digested sewage sludge with 2% or less solids—e.g., sewage sludge treated in extended aeration plants
Option 4 503.33(b)(4)	SOUR at 20°C (68°F) is ≤1.5 mg oxygen/hr/g total sewage sludge solids	Sewage sludge from aerobic processes (should not be used for composted sludges). Also for sewage sludge that has been deprived of oxygen for longer than 1–2 hours.
Option 5 503.33(b)(5)	Aerobic treatment of the sewage sludge for at least 14 days at over 40°C (104°F) with an average temperature of over 45°C (113°F)	Composted sewage sludge (Options 3 and 4 are likely to be easier to meet for sewage sludge from other aerobic processes)
Option 6 503.33(b)(6)	Addition of sufficient alkali to raise the pH to at least 12 at 25°C (77°F) and maintain a pH ≥12 for 2 hours and a pH ≥11.5 for 22 more hours	Alkali-treated sewage sludge (alkalies include lime, fly ash, kiln dust, and wood ash)
Option 7 503.33(b)(7)	Percent solids ≥75% prior to mixing with other materials	Sewage sludges treated by an aerobic or anaerobic process (i.e., sewage sludges that do not contain unstabilized solids generated in primary wastewater treatment)
Option 8 503.33(b)(8)	Percent solids ≥90% prior to mixing with other materials	Sewage sludges that contain unstabilized solids generated in primary wastewater treatment (e.g., any heat-dried sewage sludges)
Option 9 503.33(b)(9)	Sewage sludge is injected into soil so that no significant amount of sewage sludge is present on the land surface 1 hour after injection, except Class A sewage sludge which must be injected within 8 hours after the pathogen reduction process.	Liquid sewage sludge applied to the land. Domestic septage applied to agricultural land, a forest, or a reclamation site
Option 10 503.33(b)(10)	Sewage sludge is incorporated into the soil within 6 hours after application to land. Class A sewage sludge must be applied to the land surface within 8 hours after the pathogen reduction process, and must be incorporated within 6 hours after application.	Sewage sludge applied to the land. Domestic septage applied to agricultural land, forest, or a reclamation site.

3.4.2.2 Option 2: Additional Digestion of Anaerobically Digested Sewage Sludge

Under this option, an anaerobically digested sewage sludge is considered to have achieved satisfactory vector attraction reduction if it loses less than 17 percent additional volatile solids when it is anaerobically batch-digested in the laboratory in a bench-scale unit at 30° to 37°C (86° to 99°F) for an additional 40 days.

Frequently, sewage sludge is recycled through the biological wastewater treatment section of a treatment works or resides for long periods of time in the wastewater collection system. During this time it undergoes substantial biological degradation. If it is subsequently treated by anaerobic digestion for a period of time, it is adequately reduced in vector attraction; however, because sewage sludge enters the digester already partially stabilized, the volatile solids reduction after treatment is frequently less than 38%. The additional digestion test is used to demonstrate that the sewage sludge is indeed satisfactorily reduced in vector attraction.

3.4.2.3 Option 3: Additional Digestion of Aerobically Digested Sewage Sludge

Under this option, an aerobically digested sewage sludge with 2 percent or less solids is considered to have achieved satisfactory vector attraction reduction if it loses less than 15 percent additional volatile solids when it is aerobically batch-digested in the laboratory in a bench-scale unit at 20°C (68°F) or higher for an additional 30 days. This test can be run on sewage sludge with up to 2 percent solids and does not require a temperature correction for sewage sludge not initially digested at 20°C. Sewage sludge with greater than 2 percent solids can be diluted to 2 percent solids with effluent, and the test can then be run on the diluted sludge.

This option is appropriate for aerobically digested sewage sludge, including sewage sludge from extended aeration and oxidation ditch plants where the nominal residence time of sewage sludge leaving the wastewater treatment processes generally exceeds 20 days. In these cases, the sewage sludge may already have been substantially reduced in biological degradability prior to aerobic digestion.

3.4.2.4 Option 4: Specific Oxygen Uptake Rate (SOUR) for Aerobically Digested Sewage Sludge Treated in an Aerobic Process

For sewage sludge treated in an aerobic process (usually aerobic digestion), reduction in vector attraction can also be demonstrated if the SOUR of the sewage sludge to be land applied is equal to or less than 1.5 mg of oxygen per hour per gram of total sewage sludge solids (dry-weight basis) at 20°C (68°F). The basis of this test is that if the sewage sludge consumes very little oxygen, its value as a food source for vectors is very low and thus vectors are unlikely to be attracted to the sewage sludge.

Frequently, aerobically digested sewage sludge is circulated through the aerobic biological wastewater treatment process for as long as 30 days. In these cases, the sewage sludge entering the aerobic digester is already partially digested, which makes it difficult to demonstrate the 38 percent reduction required by Option 1; Option 4 provides an alternative to the percent solids method for demonstrating vector attraction reduction.

The oxygen uptake rate depends on the conditions of the test and, to some degree, on the nature of the original sewage sludge before aerobic treatment. It should be noted that the SOUR method may be unreliable at solids content above 2 percent.

3.4.2.5 Option 5: Aerobic Processes at Greater Than 40°C

Under this option, the sewage sludge must be treated for 14 days or longer, during which time the temperature must be over 40°C (104°) and the average temperature higher than 45°C (113°F). This option applies primarily to composted sewage sludge, which generally contains substantial amounts of partially decomposed organic bulking agents.

This option can be applied to sewage sludge from other aerobic processes, such as aerobic digestion, but other approaches for demonstrating compliance (e.g., those described in Options 3 and 4) are likely to be easier to meet for these types of sewage sludge.

3.4.2.6 Option 6: Addition of Alkali

Under this option, sewage sludge is considered to be adequately reduced in vector attraction if sufficient alkali is added to:

- Raise the pH to at least 12.
- Maintain a pH of at least 12 without addition of more alkali for 2 hours.
- Maintain a pH of at least 11.5 without addition of more alkali for an additional 22 hours.

The conditions required under this option are intended to ensure that the sewage sludge can be stored for at least several days at the treatment works, transported, and then land applied without the pH falling to the point where putrefaction occurs and vectors are attracted.

3.4.2.7 Option 7: Moisture Reduction of Sewage Sludge Containing No Unstabilized Solids

Under this option, sewage sludge vector attraction is considered to be reduced if the sewage sludge does not contain unstabilized solids generated during primary wastewater treatment and if the solids content of the sewage sludge is greater than or equal to 75 percent before the sewage sludge is mixed with other materials. Thus, the reduction must be achieved by removing water, not by adding inert materials.

It is important that the sewage sludge meeting Option 7 not contain unstabilized solids because the partially degraded food scraps likely to be present in such sewage sludge would attract birds, some mammals, and possibly insects, even if the solids content of the sewage exceeded 75 percent. Additionally, steps should be taken to prevent exposure of stored sewage sludge to high humidity, which could cause its outer surface to equilibrate to a lower solids content and attract vectors.

3.4.2.8 Option 8: Moisture Reduction of Sewage Sludge Containing Unstabilized Solids

Vector attraction of any sewage sludge is considered to be adequately reduced if the solids content of the sludge is increased to 90 percent or greater. This extreme desiccation deters vectors in all but the most unusual situations. The solids increase must be achieved by removal of water and not by dilution with inert solids. Drying to this extent severely limits biological activity and strips off or decomposes the volatile compounds that attract vectors.

3.4.2.9 Option 9: Injection of Sewage Sludge

Vector attraction reduction can be demonstrated by injecting the sewage sludge below the ground. Under this option, no significant amount of the sewage sludge can be present on the land surface within 1 hour after injection. If the sludge is Class A with respect to pathogens, it must be injected within 8 hours after discharge from the pathogen-reduction process; special restrictions apply to Class A sewage sludge because it is a medium for regrowth, and after 8 hours pathogenic bacteria may rapidly increase.

Injection of sewage sludge beneath the soil places a barrier of earth between the sewage sludge and vectors. The soil quickly removes water from the sewage sludge, which reduces the mobility and odor of the sewage sludge.

3.4.2.10 Option 10: Incorporation of Sewage Sludge into the Soil

Under this option, sewage sludge applied to the land surface must be incorporated into the soil within 6 hours. If the sewage sludge is Class A with respect to pathogens, the time between processing and application must not exceed 8 hours.

When applied at agronomic rates, the loading of sewage sludge solids typically is approximately 1/200th or less of the mass of soil in the plow layer. If mixing is reasonably good, the dilution of sewage sludge in the soil surface is equivalent to that achieved with soil injection. Initial vector attraction will diminish and be virtually eliminated when the sewage sludge is mixed with the soil.

3.5 Frequency of Monitoring

The Part 503 rule requires that pollutant concentrations (for metals), pathogen densities, and vector attraction reduction be monitored and analyzed when sewage sludge is land applied. Monitoring is intended to ensure that the land-applied sewage sludge meets applicable criteria after its quality has been initially demonstrated.

Part 503 specifies how often sewage sludge must be monitored and lists the analytical methods to be used for analyzing different types of samples. The frequency of monitoring requirements range from 1 to 12 times per year, depending on the amount of sewage sludge (in metric tons, dry-weight basis) applied to a site. Requirements for monitoring must be met regardless of which approaches are used for meeting pollutant limits and pathogen and vector attraction reduction requirements. Frequency of monitoring requirements are summarized in Table 3-15. For frequency of monitoring requirements for stored sewage sludge, contact the permitting authority.

3.6 Recordkeeping and Reporting

The person who prepares sewage sludge for land application must provide information necessary to demonstrate compliance with the Part 503 rule to the land applier, and the person who applies the sewage sludge to the land is responsible for obtaining from the preparer information necessary to demonstrate compliance with the rule. For a discussion of specific Part 503 recordkeeping and reporting requirements, see Chapter 15.

3.7 Sewage Sludge Quality and the Part 503 Requirements

The Part 503 requirements that must be complied with depend on the quality of the sewage sludge, in terms of pollutants, pathogen levels, and vector attraction reduction control. These quality differences are discussed below and are summarized in Table 3-16.

3.7.1 Exceptional Quality (EQ) Sewage Sludge

Sewage sludge that meets the Part 503 ceiling concentration limits, pollutant concentration limits, one of the Class A pathogen reduction alternatives, and one of the vector attraction reduction options described above can be considered “exceptional quality” (EQ) sewage sludge.[3] Sewage sludge meeting these EQ requirements are not

[3] The sewage sludge quality designation “exceptional quality” is based on interpretations of the Part 503 rule, which does not explicitly use this term.

Table 3-15. Frequency of Monitoring for Pollutants, Pathogen Densities, and Vector Attraction Reduction

Amounts of Sewage Sludge[a] (metric tons per 365-day period)	Amount of Sewage Sludge (U.S. tons) Ave. per day	per 365 days	Frequency
Greater than zero but less than 290	>0 to <0.85	>0 to <320	Once per year
Equal to or greater than 290 but less than 1,500	0.85 to <4.5	320 to <1,650	Once per quarter (4 times per year)
Equal to or greater than 1,500 but less than 15,000	4.5 to <45	1,650 to <16,500	Once per 60 days (6 times per year)
Equal to or greater than 1,5000	≥45	≥16,500	Once per month (12 times per year)

[a] Either the amount of bulk sewage sludge applied to the land or the amount of sewage sludge received by a person who prepares sewage sludge for sale or give-away in a bag or other container for application to the land (dry-weight basis).

Table 3-16. Summary of Part 503 Requirements for Different Types of Sewage Sludge

Type of Sewage Sludge[a]	Ceiling Concentration Limit	Other Pollutant Limits	Pathogen Class	Vector Attraction Reduction	Siting Restrictions	General Requirements, Management Practices	Track Added Pollutants
"Exceptional Quality" (Bag or Bulk)	Yes	Pollutant Concentration Limits	A	1 of Options 1-8[b]	No	No[b]	No
Pollutant Concentration (Bulk Only)	Yes	Pollutant Concentration Limits	B	1 of Options 1-10	Yes	Yes	No
CPLR (Bulk Only)	Yes	Cumulative Pollutant Loading Rates (CPLRs)	A or B	1 of Options 1-10	No if Pathogen Class A Yes if Pathogen Class B	Yes	Yes
APLR (Bag Only)	Yes	Annual Pollutant Loading Rates (APLRs)	A	1 of Options 1-8	No	Yes[c]	No

[a] All sewage sludge must also meet Part 503 frequency of monitoring requirements and recordkeeping and reporting requirements.
[b] If sewage sludge instead follows vector attraction reduction options 9 or 10 (incorporation or injection), the sewage sludge must also meet Part 503 general requirements and management practices, and would not be considered "exceptional quality" sewage sludge.
[c] Only two general requirements and a management practice requirement for labeling must be met.

subject to Part 503's land application general requirements and management practices. EQ sewage sludge can be applied as freely as any other fertilizer or soil amendment to any type of land (unless EPA or the director of an EPA-approved state sludge program determines that in a particular case, when bulk sewage sludge is land applied, the Part 503 general requirements or management practices are needed to protect public health and the environment). Although the Part 503 rule does not require EQ sewage sludge to be applied at the agronomic rate for nitrogen (which is a requirement for sewage sludge not meeting EQ requirements), for good management EQ sewage sludge, like any type of fertilizer, also should be applied at the agronomic rate, which supplies the nitrogen needs of the crop or vegetation grown on the site and protects ground water.

To achieve EQ sewage sludge quality, the user or preparer of sewage sludge must:

- Not exceed the Part 503 ceiling concentration limits and pollutant concentration limits for regulated metals (Table 3-4).
- Meet one of the six Part 503 Class A pathogen reduction alternatives (Table 3-6) and required bacterial monitoring (Table 3-7).
- Meet one of the first eight Part 503 vector attraction reduction options (Table 3-14).
- Comply with the Part 503 frequency of monitoring (Table 3-15) and recordkeeping/reporting requirements (see Chapter 15).

The Part 503 general requirements and management practices do not apply to EQ sewage sludge unless they are deemed necessary for bulk sewage sludge, as discussed above.

3.7.2 Pollutant Concentration (PC) Sewage Sludge

"Pollutant Concentration" (PC) sewage sludge meets the same low pollutant limits as EQ sewage sludge, but usually meets Class B rather than Class A pathogen reduction requirements. Sewage sludge meeting Class A pathogen reduction requirements and vector attraction options 9 or 10 (which do not qualify as EQ vector requirements) also is PC sewage sludge. If PC sewage sludge is Class B pathogen status, it must be land applied according to specific site restrictions discussed in Table 3-11 to prevent exposure to the sewage sludge. Sewage sludge that meets PC criteria can be applied to all types of land, except lawns and home gardens, if these site restrictions are observed. To achieve PC sewage sludge quality, the sewage sludge must:

- Not exceed the Part 503 ceiling concentration limits and pollutant concentration limits for regulated metals (Table 3-4).
- Meet one of three Part 503 Class B pathogen reduction alternatives (Table 3-6) and Class B site restrictions (Table 3-11).
- Meet one of 10 applicable Part 503 vector attraction reduction options (Table 3-14).
- Comply with the Part 503 frequency of monitoring (Table 3-15) and recordkeeping/reporting requirements (see Chapter 15).
- Comply with certain Part 503 general requirements (Table 3-17) and management practices (Table 3-5).

3.7.3 Cumulative Pollutant Loading Rate (CPLR) Sewage Sludge

"CPLR" sewage sludge must meet more Part 503 requirements than EQ or PC sewage sludge. These requirements, such as tracking of cumulative metal loadings, ensures adequate protection of public health and the environment. CPLR sewage sludge users or preparers must:

- Not exceed the Part 503 ceiling concentration limits and cumulative pollutant loading rate (CPLR) limits for regulated metals (Table 3-4) when the sewage sludge is land applied in bulk.
- Meet either Part 503 Class A or Class B pathogen reduction requirements (Table 3-6) and related requirements (either Table 3-7 or Table 3-11).
- Meet one of 10 Part 503 vector attraction reduction options (Table 3-14).
- Comply with Part 503 frequency of monitoring (Table 3-15) and recordkeeping/reporting requirements (see Chapter 15).
- Comply with certain Part 503 general requirements (Table 3-17) and management practices (Table 3-5).

3.7.4 Annual Pollutant Loading Rate (APLR) Sewage Sludge

"APLR" sewage sludge, which pertains only to sewage sludge sold or given away in a bag or other container for application to land ("bagged" sewage sludge), must meet Class A pathogen reduction requirements and one of the vector attraction reduction treatment options. These provisions are required because of the high potential for human contact at sites where bagged sewage sludge is likely to be applied (i.e., public contact sites such as parks). APLR sewage sludge users or preparers must:

- Not exceed the Part 503 ceiling concentration limits and annual pollutant loading rate (APLR) limits for regulated metals (Table 3-4) when the sewage sludge is placed in a bag or other container, as defined in Part 503, for sale or given away for application to the land.
- Meet Part 503 Class A pathogen reduction requirements (Table 3-6) and required bacterial monitoring (Table 3-7).
- Meet one of the first eight Part 503 vector attraction reduction options (Table 3-14).
- Meet the Part 503 management practice that requires a label or information sheet that lists data specified in Part 503 (Table 3-5).
- Meet the Part 503 frequency of monitoring (Table 3-15) and recordkeeping/reporting requirements (see Chapter 15).
- Meet the Part 503 general requirements (Part 503.12(a) and (e)(i)).

The Part 503 labelling provision requires that the preparer of APLR sewage sludge provide the applier with allowable application rate information, either on a label or in a handout (usually based on the nutrient content of the sewage sludge). This information is based on the preparer's calculation of the annual whole sludge application rate (AWSAR) (Table 3-18). The preparer/manufacturer also provides the applier with information on the nutrient value of the bagged sewage sludge. The recommended application rate helps ensure that the sewage sludge is applied at the appropriate agronomic rate to minimize the amount of excess nitrogen that passes below the root zone and into ground water.

Table 3-17. Part 503 Land Application General Requirements

For EQ Sewage Sludge

None (unless set by EPA or state permitting authority on a case-by-case basis for bulk sewage sludge to protect public health and the environment).

For PC and CPLR Sewage Sludge

The ***preparer***[a] must notify and provide information necessary to comply with the Part 503 land application requirements to the person who applies bulk sewage sludge to the land.

The ***preparer*** who provides sewage sludge to another person who further prepares the sewage sludge for application to the land must provide this person with notification and information necessary to comply with the Part 503 land application requirements.

The ***preparer*** must provide written notification of the total nitrogen concentration (as N on a dry-weight basis) in bulk sewage sludge to the applier of bulk sewage sludge to agricultural land, forests, public contact sites, or reclamation sites.

The ***applier*** of sewage sludge must obtain information necessary to comply with the Part 503 land application requirements, apply sewage sludge to the land in accordance with the Part 503 land application requirements, and provide notice and relevant information to the owner or lease holder of the land on which sewage sludge is applied.

Out-of-State Use

The ***preparer*** must provide written notification (prior to the initial application of the bulk sewage sludge by the applier) to the permitting authority in the state where sewage sludge is proposed to be land applied when bulk sewage sludge is generated in one state (the generating state) and transferred to another state (the receiving state) for application to the land. The notification must include:

- the location (either street address or latitude and longitude) of each land application site;
- the approximate time period the bulk sewage sludge will be applied to the site;
- the name, address, telephone number, and National Pollutant Discharge Elimination System (NPDES) permit number for both the preparer and the applier of the bulk sewage sludge; and
- additional information or permits in both states, if required by the permitting authority.

Additional Requirements for CPLR Sewage Sludge

The ***applier*** must notify the permitting authority in the state where bulk sewage sludge is to be applied prior to the initial application of the sewage sludge. This is a one-time notice requirement for each land application site each time there is a new applier. The notice must include:

- the location (either street address or latitude and longitude) of the land application site; and
- the name, address, telephone number, and NPDES permit number (if appropriate) of the person who will apply the bulk sewage sludge.

The ***applier*** must obtain records (if available) from the previous applier or landowner that indicate the amount of each CPLR pollutant in sewage sludge that have been applied to the site since July 20, 1993. In addition:

- when CPLR sewage sludge was previously applied since July 20, 1993 to the site and cumulative amounts of regulated pollutants are known, the ***applier*** must use this information to determine the additional amount of each pollutant that can be applied to the site in accordance with the CPLRs in Table 3-4;
- the ***applier*** must keep the previous records and also record the additional **amount of each pollutant he or she is applying to the site**; and
- when CPLR sewage sludge was previously applied to the site and cumulative amounts of regulated pollutants are not known, no additional sewage sludge meeting CPLRs can be applied to that site. However, EQ or PC sewage sludge could be applied.

If sewage sludge meeting CPLRs has not been applied to the site in excess of the limit since July 20, 1993, the CPLR limit for each pollutant in Table 3-4 will determine the maximum amount of each pollutant that can be applied if the applier keeps a record of the amount of each pollutant in sewage sludge applied to any given site.

The ***applier*** must not apply additional sewage sludge under the cumulative pollutant loading concept to a site where any of the CPLRs have been reached.

[a] The preparer is either the person who generates the sewage sludge or the person who derives a material from sewage sludge. This includes the person who prepares sewage sludge for sale or give-away in a bag or other container for application to the land.

Table 3-18. Procedure to Determine the Annual Whole Sludge Application Rate for Sewage Sludge Sold or Given Away in a Bag or Other Container for Application to Land

1. Analyze a sample of the sewage sludge to determine the concentration of each of the 10 regulated metals in the sewage sludge.

2. Using the pollutant concentrations from Step 1 and the APLRs from Table 3-4, calculate an AWSAR for each pollutant using the following equation:

$$AWSAR = \frac{APLR}{C \cdot 0.001}$$

where:

AWSAR = Annual whole sludge application rate (dry metric tons of sewage sludge/hectare/year)

APLR = Annual pollutant loading rate (in Table 3-4) (kg of pollutant/ha/yr)

C = Pollutant concentration (mg of pollutant/kg of sewage sludge, dry weight)

0.001 = A conversion factor

3. The AWSAR for the sewage sludge is the lowest AWSAR calculated for each pollutant in Step 2.

Example:

a. Sewage sludge to be applied to land is analyzed for each of the 10 metals regulated in Part 503. Analysis of the sewage sludge indicates the pollutant concentration in the second column of the table below.

b. Using these test results and the APLR for each pollutant from Table 3-4, the AWSAR for all the pollutants are calculated as shown in the fourth column of the table below.

c. The AWSAR for the sewage sludge is the *lowest* AWSAR calculated for all 10 metals. In our example, the lowest AWSAR is for copper at 20 metric tons of sewage sludge/hectare/year. Therefore, the AWSAR to be used for this sewage sludge is 20 metric tons per hectare/year. The 20 metric tons of sewage sludge/hectare is the same as 410 pounds of sewage sludge/1,000 square feet (20 metric tons × 2,205 lb per metric ton/107,600 square feet per hectare). The AWSAR on the label or information sheet would have to be equal to or less than 410 pounds per 1,000 square feet.

Metal	Sewage Sludge Concentrations (milligrams/kilogram)	APLR[a] (kilograms/ hectare/year)	AWSAR = $\frac{\text{APLR}}{\text{Conc. in Sewage Sludge (0.001)}}$ = metric tons/hectare/year
Arsenic	10	2.0	2/(10 × 0.001) = 200
Cadmium	10	1.9	1.9/(10 × 0.001) = 190
Chromium	1,000	150	150/(1,000 × 0.001) = 150
Copper	3,750	75	75/(3,750 × 0.001) = 20
Lead	150	15	15/(150 × 0.001) = 100
Mercury	2	0.85	0.85/(2 × 0.001) = 425
Molybdenum	—	—	—
Nickel	100	21	21/(100 × 0.001) = 210
Selenium	15	5.0	5/(15 × 0.001) = 333
Zinc	2,000	140	140/(2,000 × 0.001) = 70

[a] Annual pollutant loading rates from Table 3-4 of this guide and Table 4 of the Part 503 rule. The APLR for molybdenum does not have to be met while EPA is reconsidering this value.

3.8 References

When an NTIS number is cited in a reference, that document is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-487-4650

U.S. EPA. 1994. A plain English guide to the EPA Part 503 biosolids rule. EPA/832/R-93/003. Washington, DC.

U.S. EPA. 1992a. Technical support document for land application of sewage sludge, Vol. 1. EPA/822/R-93/018a (NTIS PB93110575). Washington, DC.

U.S. EPA. 1992b. Environmental regulations and technology: Control of pathogens and vector attraction in sewage sludge. EPA/625/R-92/013. Washington, DC.

Chapter 4
Characteristics of Sewage Sludge

4.1 Introduction

Determining the suitability of sewage sludge for land application by characterizing its properties is a necessary first step in planning and designing a land application system. The composition of sewage sludge will have important bearing on the following design decisions:

- Whether the sewage sludge can be cost-effectively applied to land.
- Which land application practice (i.e., application to agricultural, forest, reclamation or public contact sites) is technically feasible.
- The quantity of sewage sludge to be applied per unit area, both annually and cumulatively.
- The degree of regulatory control and system monitoring required.

Important properties of sewage sludge that need to be characterized include:

- Quantity
- Total solids content
- Volatile solids content
- pH
- Organic matter
- Pathogens
- Nutrients
- Metals
- Organic chemicals
- Hazardous pollutants, if any

Sewage sludge composition depends principally on the characteristics of the wastewater influent entering the wastewater treatment works and the treatment processes used. Generally, the more industrialized a community is, the greater the possibility that heavy metals may pose a potential problem for land application of sewage sludge. Industrial pretreatment requirements (40 CFR Part 403) and pollution prevention programs, as well as advances in wastewater and sewage sludge treatment processes, generally have reduced the levels of pollutants in the final sewage sludge leaving a treatment works. Figure 4-1 shows the basic wastewater and sewage sludge generation and treatment process.

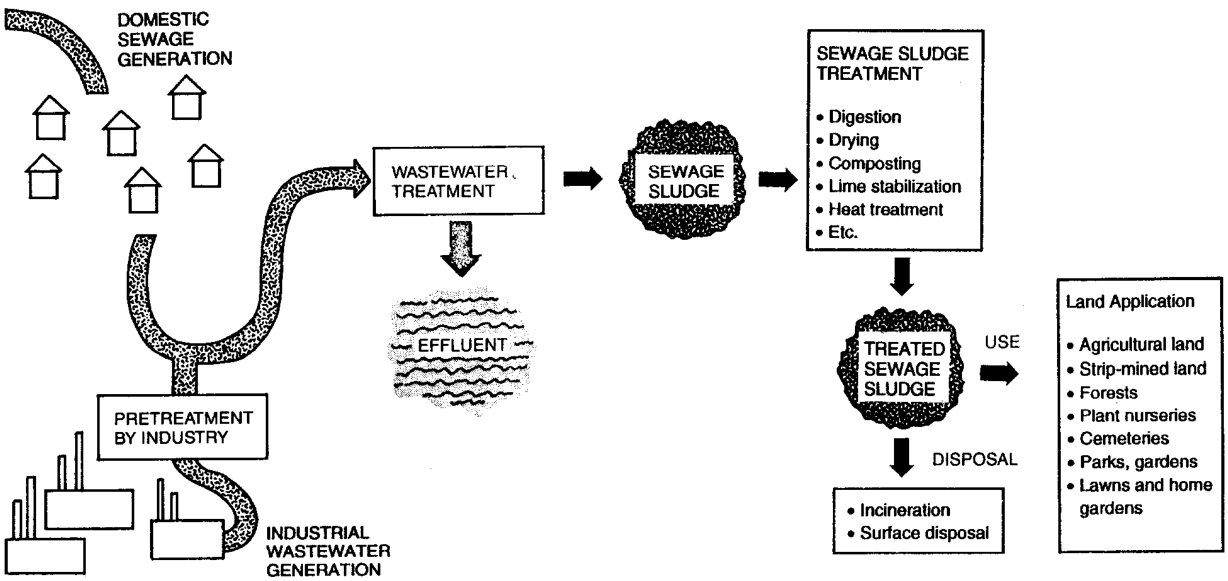
This chapter describes the properties of sewage sludge to be characterized, the different types of sewage sludge (which exhibit different characteristics), and the effects that wastewater and sewage sludge treatment processes and pretreatment have on sewage sludge characteristics. The information provided is intended primarily for illustrative purposes. While the data are useful in preliminary planning, analysis of the actual sewage sludge to be land-applied is necessary for design purposes. The chemical composition of sewage sludge may vary greatly between wastewater treatment works and also over time at a single plant. This variability in sewage sludge composition underscores the need for a sound sampling program (e.g., analysis of a substantial number of sewage sludge samples over a period of 2 to 6 months or longer) to provide a reliable estimate of sewage sludge composition. Sampling is discussed in Chapters 6 and 13.

4.2 Sewage Sludge Quantity

The amount of sewage sludge to be land applied will affect site evaluation and design in several important ways, including land area needs, size of transportation equipment and storage facilities, and cost. Quantities of sewage sludge available also will affect the selection of land application practices (i.e., application at agricultural, forest, reclamation or public contact sites), as well as application rates and operating schedules.

Sewage sludge quantity can be measured in two ways: the volume of the wet sewage sludge, which includes the water content and solids content, or the mass of the dry sewage sludge solids. Sewage sludge volume is expressed as gallons (liters) or cubic meters, while sludge mass usually is expressed in terms of weight, in units of dry metric tons (tonnes). Because the water content of sewage sludge can be high and quite variable, the mass of dry sludge solids is often used to compare sewage sludges with different proportions of water (U.S. EPA, 1984).

SEWAGE SLUDGE



DOMESTIC SEPTAGE

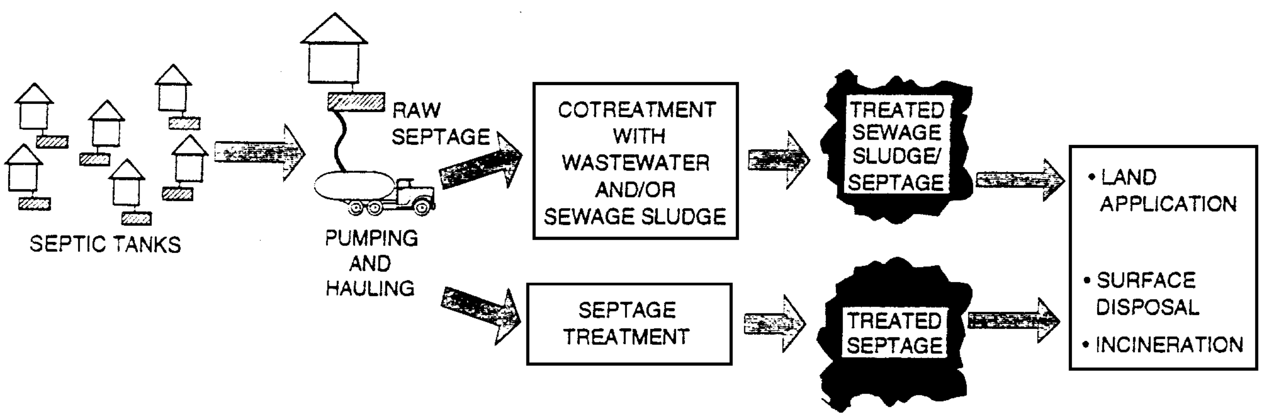


Figure 4-1. Generation, treatment, use, and disposal of sewage sludge and domestic septage.

Key factors affecting sewage sludge volume and mass are wastewater sources and wastewater and sludge treatment processes. For example, industrial contributions to wastewater influent streams can significantly increase the sewage sludge quantity generated from a given amount of wastewater. Also, higher degrees of wastewater treatment generally increase sewage sludge volume. In addition, as shown in Table 4-1, some sewage sludge treatment processes reduce sewage sludge volume, some reduce sewage sludge mass, and some increase sewage sludge mass while improving other sewage sludge characteristics (U.S. EPA, 1984).

4.3 Total Solids Content

The total solids (TS) content of sewage sludge includes the suspended and dissolved solids and is usually expressed as the percent of total solids present in a sewage sludge. TS can affect the potential land application system design in several ways, including:

- Size of transportation and storage systems—The higher the solids content, the lower the volume of sewage sludge that will have to be transported and stored because less water will need to be handled.
- Mode of transport—Different types of transportation to the land application site (e.g., trucks, pipelines) will be used depending on the solids content of the sewage sludge to be applied (see Chapter 14).
- Application method and equipment—The method of sewage sludge application (e.g., surface spreading, injection, spray irrigation) and the type of application equipment needed will vary depending on the solids content of the sewage sludge (see Chapter 14).
- Storage method—Different storage methods will be used depending on solids content (e.g., tanks for liquid sewage sludge versus stockpiles for dewatered sewage sludge).

In general, it is less expensive to transport sewage sludge with a high solids content (dewatered sewage sludge) than to transport sewage sludge with a low solids content (liquid sewage sludge). This cost savings in transport should be weighed against the cost of dewatering the sewage sludge. Typically, liquid sewage sludge has a solids content of 2 to 12 percent solids, while dewatered sewage sludge has a solids content of 12 to 40 percent solids (including chemical additives). Dried or composted sewage sludge typically has a solids content over 50 percent.

TS content depends on the type of sewage sludge (primary, secondary, or tertiary, as discussed in Section 4.12), whether the sewage sludge has been treated prior to land application, and how it was treated. Treatment processes such as thickening, conditioning, dewatering, composting, and drying can lower water content and thus raise the percent solids. The efficiency of these treatment processes, however, can vary substantially from time to time, producing sewage sludge with substantially lower solids content than anticipated. Land application sites, therefore, should be flexibly designed to accommodate the range of variations in sewage sludge solids content that may occur as a result of variations in the efficiency of the wastewater and sewage sludge treatment processes. Without this flexibility, operational problems could result at the site.

4.4 Volatile Solids Content

Sludge volatile solids (VS) are organic compounds that are reduced when the sludge is heated to 550°C (1,022°F) under oxidizing conditions. The VS content of sludge provides an estimate of the organic content of the material. VS content is most often expressed as the percent of total solids that are volatile solids. VS is an important determinant of potential odor problems at land application sites. Reduction of VS is one option in the Part 503 regulation for meeting vector attraction reduction requirements (see Chapter 3). Most unstabilized sewage sludge contains 75 percent to 85 percent VS on a dry weight basis. A number of treatment processes, including anaerobic digestion, aerobic digestion, alkali stabilization, and composting, can be used to reduce sludge VS content and thus the potential for odor. Anaerobic digestion—the most common method of sludge stabilization—generally biodegrades about 50 percent of the volatile solids in a sewage sludge.

4.5 pH

The pH of sewage sludge can affect crop production at land application sites by altering the pH of the soil and influencing the uptake of metals by soil and plants. Pathogen levels and vector control are the major reasons for pH adjustment of sewage sludge. Low pH sludge (less than approximately pH 6.5) promotes leaching of heavy metals, while high pH sludge (greater than pH 11) kills many bacteria and, in conjunction with soils of neutral or high pH, can inhibit movement of heavy metals through soils. Some of the Part 503 pathogen reduction alternatives include raised pH levels (see Chapter 3).

4.6 Organic Matter

The relatively high level of organic matter in sewage sludge allows the sludge to be used as a soil conditioner to improve the physical properties of soil (e.g., increased water infiltration and water-holding capacity). The soil conditioning properties of sewage sludge are especially useful at reclamation sites such as mine spoils.

Table 4-1. Effects of Sewage Sludge Treatment Processes on Land Application Practices (U.S. EPA, 1984)

Treatment Process and Definition	Effect on Sewage Sludge	Effect on Land Application Practices
Thickening: Low-force separation of water and solids by gravity, flotation, or centrifugation. (Sewage sludge thickeners may also be used as flow equalization tanks to minimize the effect of sewage sludge quantity fluctuations on subsequent treatment processes.)	Increase solids concentration of sewage sludge by removing water, thereby lowering sewage sludge volume. May provide a blending function in combining and mixing primary and secondary sewage sludges.	Lowers sewage sludge transportation costs for all practices (e.g, agricultural, forests, reclamation sites, public contact sites).
Digestion (Anaerobic and Aerobic): Biological stabilization of sewage sludge through conversion of some of the organic matter to water, carbon dioxide, and methane. (Digesters may also be used to store sewage sludge to provide greater flexibility for the treatment operation and to homogenize sewage sludge solids to facilitate subsequent handling procedures.)	Reduces the volatile and biodegradable organic content and the mass of sewage sludge by converting it to soluble material and gas. May reduce volume by concentrating solids. Reduces pathogen levels and controls putrescibility and odor.	Reduces sewage sludge quantity.
Alkali Stabilization: Stabilization of sewage sludge through the addition of alkali.	Raises sewage sludge pH. Temporarily decreases biological activity. Reduces pathogen levels and controls putrescibility. Increases the dry solids mass of the sewage sludge. Because pH effects are temporary, decomposition, leachate generation, and release of gas, odors, and heavy metals may occur over time.	High pH of alkali-stabilized sewage sludge tends to immobilize heavy metals in sewage sludge as long as the pH levels are maintained.
Conditioning: Alteration of sewage sludge properties to facilitate the separation of water from sewage sludge. Conditioning can be performed in many ways, e.g., adding inorganic chemicals such as lime and ferric chloride; adding organic chemicals such as polymers; mixing digested sewage sludge with water and resettling (elutriation); or briefly raising sewage sludge temperature and pressure (heat treatment). Thermal conditioning also causes disinfection.	Improves sewage sludge dewatering characteristics. Conditioning may increase the mass of dry solids to be handled without increasing the organic content of the sewage sludge. Conditioning may also improve sewage sludge compactability and stabilization. Generally, polymer-treated sewage sludges tend to be sticky, slick, and less workable than other sewage sludges. Some conditioned sewage sludges are corrosive.	Polymer-treated sewage sludges may require special operational considerations at the land application site.
Dewatering: High-force separation of water and solids. Dewatering methods include vacuum filters, centrifuges, filter presses, belt presses, lagoons, and sand drying beds.	Increases solids concentration of sewage sludge by removing much of the entrained water, thereby lowering sewage sludge volume. Dewatering may increase sewage sludge solids to 15% to 40% for organic sewage sludges and 45% or more for some inorganic sewage sludges. Some nitrogen and other soluble materials are removed with the water. Improves ease of handling by converting liquid sewage sludge to damp cake. Reduces fuel requirements for heat drying.	Reduces land requirements and lowers sewage sludge transportation costs for all practices.
Composting: Aerobic process involving the biological stabilization of sewage sludge in a windrow, aerated static pile, or vessel.	Lowers biological activity. Can destroy most pathogens. Degrades sewage sludge to a humus-like material. Increases sewage sludge mass due to addition of bulking agent.	Excellent soil conditioning properties. Significant storage usually needed. May contain lower nutrient levels than less processed sewage sludge.
Heat Drying: Application of heat to kill pathogens and eliminate most of the water content.	Disinfects sewage sludge. Destroys most pathogens. Slightly lowers potential for odors and biological activity.	Greatly reduces volume of sewage sludge.

4.7 Pathogens

Potential disease-causing microorganisms known as pathogens, including bacteria, viruses, protozoa, and eggs of parasitic worms, are often present in municipal wastewater and raw sewage sludge. Pathogens also are present in domestic septage. Pathogens can present a public health hazard if they are transferred to food crops grown on land to which sewage sludge or domestic septage is applied, contained in runoff to surface waters from land application sites, or transported away from the site by vectors such as insects, rodents, and birds. For this reason, Part 503 specifies pathogen reduction and vector attraction reduction requirements that must be met by sewage sludge applied to land application sites. Table 4-2 illustrates the different types of pathogens typically found in sewage sludge and domestic septage.

Generally, sewage sludge intended for land application is stabilized by chemical or biological processes (see Section 4.13). Table 4-3 shows typical levels of some pathogens in unstabilized and stabilized sewage sludge. Stabilization greatly reduces the number of pathogens in sewage sludge, including bacteria, parasites, protozoa, and viruses (Sagik et al., 1979), as well as odor potential. Nevertheless, even stabilized sewage sludge will usually contain some pathogens; thus the Part 503 regulation requires that specific processes to reduce pathogen levels be undertaken prior to land application and that site restrictions for certain types of sewage sludge be followed. The Part 503 pathogen and vector attraction reduction requirements serve to protect operating personnel, the general public, crops intended for human consumption, ground water, and surface water from potential contamination by unacceptable levels of pathogens. Part 503 requirements also are designed to ensure that regrowth of bacteria does not occur prior to use or disposal. A summary of the Part 503 pathogen and vector attraction reduction requirements is presented in Chapter 3. For more detailed discussions of

Table 4-3. Typical Pathogen Levels in Unstabilized and Anaerobically Digested Liquid Sludges (U.S. EPA, 1979)

Pathogen	Typical Concentration in Unstabilized Sludge (No./100 milliliters)	Typical Concentration in Anaerobically Digested Sludge (No./100 milliliters)
Virus	2,500 - 70,000	100 - 1,000
Fecal Coliform Bacteria[a]	1,000,000,000	30,000 - 6,000,000
Salmonella	8,000	3 - 62
Ascaris lumbricoides-Helminth	200 - 1,000	0 - 1,000

[a] Although not pathogenic, they are frequently used as indicators.

Table 4-2. Principal Pathogens of Concern in Municipal Wastewater and Sewage Sludge

Organism	Disease/Symptoms
Bacteria	
Salmonella sp.	Salmonellosis (food poisoning), typhoid fever
Shigella sp.	Bacillary dysentery
Vibrio cholerae	Cholera
Campylobacter jejuni	Gastroenteritis
Escherichia coli (pathogenic strains)	Gastroenteritis
Enteric Viruses	
Hepatitis A virus	Infectious hepatitis
Norwalk and Norwalk-like viruses	Epidemic gastroenteritis with severe diarrhea
Rotaviruses	Acute gastroenteritis with severe diarrhea
Enteroviruses	
Polioviruses	Poliomyelitis
Coxsackieviruses	Meningitis, pneumonia, hepatitis, fever, cold-like symptoms, diarrhea, etc.
Echoviruses	Meningitis, paralysis, encephalitis, fever, cold-like symptoms, diarrhea, etc.
Reovirus	Respiratory infections, gastroenteritis
Astroviruses	Epidemic gastroenteritis
Calciviruses	Epidemic gastroenteritis
Protozoa	
Cryptosporidium	Gastroenteritis
Entamoeba histolytica	Acute enteritis
Giardia lamblia	Giardiasis (including diarrhea, abdominal cramps, weight loss)
Balantidium coli	Diarrhea and dysentery
Toxoplasma gondi	Toxoplasmosis
Helminth Worms	
Ascaris lumbricoides	Digestive and nutritional disturbances, abdominal pain, vomiting, restlessness
Ascaris suum	May produce symptoms such as coughing, chest pain, and fever
Trichuris trichiura	Abdominal pain, diarrhea, anemia, weight loss
Toxocara canis	Fever, abdominal discomfort, muscle aches, neurological symptoms
Taenia saginata	Nervousness, insomnia, anorexia, abdominal pain, digestive disturbances
Taenia solium	Nervousness, insomnia, anorexia, abdominal pain, digestive disturbances
Necator americanus	Hookworm disease
Hymenolepis nana	Taeniasis

pathogens that may be present in sewage sludge and pathogen and vector attraction reduction processes, see other EPA documents (U.S. EPA, 1992a, 1994).

Following land application, bacterial pathogens generally die off to negligible numbers (99 percent die-off) in 12 days (*Salmonella* sp.) or 18 days (fecal coliform) at a temperature of 15°C (EPA, 1992b, based on EPA, 1987). Viruses commonly survive a maximum of 19 days (surface application) at 15°C (EPA, 1987; U.S. EPA, 1992b). Protozoa will survive for only a few days (Kowal, 1983). Viable helminth ova densities in sewage sludge applied to the surface of grassed plots are reduced by more than 90 percent within 3 to 4 months; viable helminth ova survive longer if sewage sludge is tilled into the soil (Jakubowski, 1988). Generally, none of these microorganisms will leach through the soil system to pollute the receiving ground waters (Edmonds, 1979), but instead will remain in the surface soils for the duration of their survival period. Where surface runoff occurs, buffers should be used to filter out pathogens and prevent entry into receiving water bodies.

4.8 Nutrients

Nutrients present in sewage sludge, such as nitrogen (N), phosphorus (P), and potassium (K), among others, are essential for plant growth and endow sewage sludge with its fertilizing properties. Nutrient levels are key determinants of sewage sludge application rates. Excessive nutrient levels due to high sludge application rates can result in environmental contamination of ground water and surface water and should be avoided. The Part 503 regulation requires that bulk sewage sludge be applied to land at the agronomic rate for nitrogen at the application site.[1]

Table 4-4 shows levels of nutrients typically present in sewage sludge. Nutrient levels, however, particularly nitrogen levels, can vary significantly, and thus analysis should be conducted on the actual sewage sludge being considered for land application. Typically, nutrient levels in sewage sludge are considerably lower than those in commercial fertilizers, especially K, which is usually less than 0.5 percent in sewage sludge (Table 4-4). Thus, supplemental fertilization will usually be needed along with sewage sludge to promote optimum vegetative growth. More sewage sludge can be applied for additional nutrients as long as the Part 503 CPLRs are not exceeded, or the Part 503 pollutant concentration limits are met (see Chapter 3). When the pollutant concentration limits are met, the application rate for the sewage sludge is not impacted by the amount of each pollutant in the sewage sludge.

[1] The agronomic rate is defined in Part 503 as the sewage sludge application rate designed to provide the amount of nitrogen needed by the crop or vegetation grown and to minimize the amount of nitrogen in the sewage sludge that passes below the root zone of the crop to the ground water.

Table 4-4. Nutrient Levels Identified in Sewage Sludge (Sommers, 1977; Furr et al., 1976)[a]

Nutrient	Number of Samples	Percent[b] Range	Median	Mean
Total N	191	<0.1-17.6	3.30	3.90[c]
NH_4^+-N	103	$5x10^{-4}$-6.76	0.09	0.65
NO_3^--N	43	$2x10^{-4}$-0.49	0.01	0.05
P	189	<0.1-14.3	2.30	2.50
K	192	0.02-2.64	0.30	0.40
Na	176	0.01-3.07	0.24	0.57
Ca	193	0.1-25.0	3.9	4.9
Fe	165	<0.1-15.3	1.1	1.3

[a] Data are from numerous types of sludge in 15 states: Michigan, New Hampshire, New Jersey, Illinois, Minnesota, Ohio, California, Colorado, Georgia, Florida, New York, Pennsylvania, Texas, Washington, and Wisconsin.
[b] Dry solids basis.
[c] It is assumed that 82 percent of the total N is organic N. So: organic N + NH_4 + NO_3 = TN, or: 3.2 + 0.65 + 0.05 = 3.90.

4.8.1 Nitrogen

Nitrogen (N) may be present in sewage sludge in an inorganic form, such as ammonium (NH_4) or nitrate (NO_3), or in an organic form. The form in which N is present in sewage sludge is a key factor in determining how much N is available to plants, as well as the potential for N contamination of ground water. Generally, inorganic N as NO_3 is the most water-soluble form of N, and therefore is of the most concern for ground-water contamination because of its high mobility in most soil types. Inorganic N in the form of NH_4 can readily volatilize as ammonia (NH_3) when sewage sludge is applied to the soil surface rather than incorporated or injected, and thus may not be available to plants. Organic N must be decomposed by soil microorganisms, or mineralized to inorganic NH_4 and NO_3, before this form of N is available for plants to use. Therefore, organic N can be considered a slow-release form of N.

The concentrations of organic and inorganic N in sewage sludge are affected by the type of sludge treatment and handling processes used. Most of the organic N in sewage sludge is associated with the sludge solids, and thus organic N levels are not appreciably altered by sludge dewatering or drying procedures. In contrast, the water-soluble inorganic forms of N and their concentrations will decrease dramatically during dewatering (e.g., drying beds, centrifuges, presses). Some heat or air drying processes or lime treatment will reduce NH_4 because of NH_3 volatilization, but will not affect NO_3 levels.

Aerobic conditions facilitate microbial conversion of other N species to the mobile NO_3 form; conversely, anaerobic conditions inhibit conversion of NH_4 to NO_3 by oxidation. Usually, over 90 percent of the inorganic N in sewage sludge will be in the form of NH_4 unless aerobic conditions have prevailed during sludge treatment. For most liquid sewage sludge collected from an anaerobic digester, essentially all the inorganic N will be present as NH_4, constituting from 25 to 50 percent of the total N. The NH_4 concentration in the liquid phase of sludge is relatively constant at a specific treatment plant, although treatment process such as dewatering can substantially lower the NH_4 content to less than 10 percent of the total N.

Because the inorganic N content of sewage sludge is significantly influenced by sludge handling procedures, N analysis should be conducted on the actual sewage sludge that is land applied. The amount of inorganic N mineralized in soils is affected by the extent of sludge processing (e.g., digestion, composting) within the sewage treatment plant and will generally be less for well stabilized sludge.

The organic N content of sewage sludge can range from 1 to 10 percent on a dry weight basis. Organic N compounds found in sludge are primarily amino acids, indicating the presence of proteinaceous materials (Ryan et al., 1973; Sommers et al., 1972). After application to soils, microbes in the soil will decompose the organic N compounds in sewage sludge, resulting in release of NH_4^+, which can then be assimilated by the crop or vegetation being grown.

For a further discussion of nitrogen availability once sewage sludge has been land applied, see Chapters 7, 8, and 9.

4.8.2 Phosphorous, Potassium, and Other Nutrients

Sewage sludge contains varying concentrations of other macro- and micronutrients required for plant growth. Some sludge constituents, such as phosphorous (P), calcium (Ca), magnesium (Mg), and iron (Fe), readily form insoluble compounds with sludge solids and thus remain at relatively high levels in sewage sludge (Table 4-4).

Other sewage sludge constituents, such as potassium (K) and sodium (Na), are water-soluble and are discharged with the treated wastewater, unless special advanced treatment processes are used to remove them. Of the water-soluble constituents that do remain in the sludge, dewatering of sludge (e.g., by centrifuges or presses) will further reduce their concentrations in sludge, while air or heat drying will result in increased levels because these constituents are nonvolatile.

For a discussion of the influence of P, K, and nutrient levels on sewage sludge application rates, see Chapters 7, 8 and 9.

4.9 Metals

Sewage sludge may contain varying amounts of metals; at low concentrations in soil, some of these metals are nutrients needed for plant growth and are often added to inorganic commercial fertilizers. But at high concentrations, some metals may be toxic to humans, animals, and plants. Based on an extensive risk assessment of metals in sewage sludge, the Part 503 rule regulates 10 metals in sewage sludge that is to be land applied, including:

- Arsenic
- Cadmium
- Chromium
- Copper
- Lead
- Mercury
- Molybdenum
- Nickel
- Selenium
- Zinc

The Part 503 risk assessment found that other metals do not pose potential health or environmental risks at land application sites. EPA's 1990 National Sewage Sludge Survey (NSSS) analyzed samples of 412 pollutants or analytes from 177 POTWs using at least secondary treatment processes, including the 10 metals regulated by Part 503 for land application, as shown in Table 4-5. Chapter 3 discusses the Part 503 pollutant limits for these 10 metals. Based on the NSSS survey, EPA estimates that only approximately 2 percent (130 POTWs) of the 6,300 POTWs affected by Part 503

Table 4-5. Mean Concentrations of Metals in Sewage Sludge Compared to Part 503 Ceiling Concentration Limits (Adapted From U.S. EPA, 1990)

Metal	Mean Concentration (mg/kg, DW)	Part 503 Pollutant Ceiling Concentration Limits (mg/kg, DW)
Arsenic	9.9	75
Cadmium	6.94	85
Chromium	119	3,000
Copper	741	4,300
Lead	134.4	840
Mercury	5.2	57
Molybdenum	9.2	75
Nickel	42.7	420
Selenium	5.2	100
Zinc	1,202	7,500

would not meet the regulation's "ceiling concentrations" for metals, the minimal requirement for land application.

Metal concentrations in sewage sludge in large part depend on the type and amount of industrial waste discharged into the wastewater treatment system. Because metals are generally insoluble, they usually are present at higher levels in sewage sludge than in wastewater, and dewatering of sewage sludge has a minimal impact on reducing metal concentrations in sewage sludge destined for land application. Pretreatment of industrial wastewater discharged to a sewerage system has been effective in reducing the metals content of sewage sludge generated at treatment works.

4.10 Organic Chemicals

Sewage sludge may also contain synthetic organic chemicals from industrial wastes, household products, and pesticides. Most sewage sludge contains low levels of these chemicals and does not pose a significant human health or environmental threat. Part 503 does not regulate organic chemicals in sewage sludge because the organic chemicals of potential concern have been banned or restricted for use in the United States; are no longer manufactured in the United States; are present at low levels in sewage sludge based on data from EPA's 1990 NSSS; or because the limit for an organic pollutant identified in the Part 503 risk assessment is not expected to be exceeded in sewage sludge that is used or disposed (U.S. EPA, 1992b).

4.11 Hazardous Pollutants (If Any)

Sewage sludge is not included on a list of specific wastes determined to be hazardous by EPA, nor does available data suggest that sewage sludge is likely to exhibit characteristics of a hazardous waste, which include ignitability, corrosivity, reactivity, or toxicity. The non-hazardous nature of sewage sludge, however, cannot be assumed.

Although sewage sludge conceivably could exhibit the characteristics of ignitability, corrosivity, or reactivity, most concerns about sewage sludge have focused on toxicity. Few, if any, sewage sludges will exhibit the toxicity characteristic (55 FR 11838). If, however, factors are present indicating a possible toxicity problem (e.g., the treatment works receives significant loadings of pollutants covered by the test for toxicity) and the treatment works does not have current data showing that the sludge is not hazardous, it is advisable for the treatment works to test the sewage sludge for toxicity (U.S. EPA, 1990).

The test for toxicity is the Toxicity Characteristic Leaching Procedure (TCLP). This test can be used for both sewage sludge and domestic septage. For the TCLP test, concentrations of pollutants in a TCLP sewage sludge extract are compared to regulatory levels for toxicity. Table 4-6 lists the toxicity characteristic

Table 4-6. Analytical Classification and Limits for TCLP Constituents

Constituent	Limit, mg/L
Pesticides	
Chlordane	0.03
Endrin	0.02
Heptachlor	0.008
Lindane	0.4
Methoxychlor	10.0
Toxaphene	0.5
Herbicides	
2,4-D	10.0
2,4,5-TP Silvex	1.0
Volatiles	
Benzene	0.5
Carbon tetrachloride	0.5
Chlorobenzene	100.0
Chloroform	6.0
1,2-Dichloroethane	0.5
1,1-Dichloroethylene	0.7
Methyl ethyl ketone	200.0
Tetrachloroethylene	0.7
Toluene	1000.0
Trichloroethylene	0.5
Vinyl chloride	0.2
Semivolatiles	
o-Cresol	200.0
m-Cresol	200.0
p-Cresol	200.0
1,2-Dichlorobenzene	300.0
1,4-Dichlorobenzene	7.5
2,4-Dinitrotoluene	0.1
Hexachlorobenzene	0.02
Hexachlorobutadiene	0.5
Hexachloroethane	3.0
Nitrobenzene	2.0
Pentachlorophenol	1.0
2,4,5-Trichlorophenol	400.0
2,4,6-Trichlorophenol	2.0
Metals	
Arsenic	5.0
Barium	100.0
Cadmium	1.0
Chromium	5.0
Lead	5.0
Mercury	0.2
Selenium	1.0
Silver	5.0

pollutants and their regulatory levels. If the concentrations of pollutants in the extract meet or exceed these regulatory levels, the wastes are classified as hazardous. If a sewage sludge or domestic septage extract is deemed hazardous, land application would not be allowed. Studies conducted by EPA's Office of Solid Waste in 1985-86 found that none of the sewage sludge samples tested had TCLP extract concentrations that exceeded the (then proposed) regulatory levels. For most pollutants, except metals, levels were non-detectable (U.S. EPA, 1993a).

4.12 Types of Sewage Sludge

The characteristics of sewage sludge described above will vary depending on the type of sewage sludge generated, as discussed below.

4.12.1 Primary Sewage Sludge

Primary sewage sludge—sludge that is the result of primary wastewater treatment and has not undergone any sludge treatment process—usually contains from 93 to 99.5 percent water, as well as solids and dissolved substances that were present in the wastewater or were added during the wastewater treatment process (U.S. EPA, 1984). Primary wastewater treatment removes the solids (sludge) that settle out readily from the wastewater. Usually the water content of this sludge can be easily reduced by thickening or dewatering.

4.12.2 Secondary Sewage Sludge

Secondary wastewater treatment generally involves a primary clarification process followed by biological treatment and secondary clarification (U.S. EPA, 1990). Sewage sludge generated by secondary wastewater treatment processes, such as activated biological systems and trickling filters, has a low solids content (0.5 percent to 2 percent) and is more difficult to thicken and dewater than primary sewage sludge.

4.12.3 Tertiary Sewage Sludge

Tertiary sewage sludge is produced by advanced wastewater treatment processes such as chemical precipitation and filtration. Chemicals used in advanced wastewater treatment processes, such as aluminum, iron, salts, lime, or organic polymers, increase sludge mass and usually sludge volume. Generally, if lime or polymers are used, the thickening and dewatering characteristics of sludge will improve, whereas if iron or aluminum salts are used, the dewatering and thickening capacity of the sludge will usually be reduced.

4.12.4 Domestic Septage

Domestic septage is considered sewage sludge by the Part 503 regulation and is defined and discussed in Chapter 11. Table 4-7 shows some of the characteristics of domestic septage. Domestic septage may foam and generally has a strong odor (U.S. EPA, 1978). Settling properties are highly variable. Some domestic septage settles readily to about 20 to 50 percent of its original volume, while others show little settling (U.S. EPA, 1979).

Table 4-7. Chemical and Physical Characteristics of Domestic Septage (U.S. EPA, 1993b)

Parameter	Concentration, mg/kg (dry weight basis)
Arsenic	4
Cadmium	3
Chromium	14
Copper	140
Lead	35
Mercury	0.15
Molybdenum	-
Nickel	15
Selenium	2
Zinc	290
Nitrogen as N	2%
Phosphorus as P	<1%
pH	6-7
Grease	6-12%
Biochemical oxygen demand (BOD_5)	6,480 mg/L
Total solids (as normally spread)	3.4%

4.13 Effects of Wastewater and Sludge Treatment Processes on Sewage Sludge Characteristics

The effects of wastewater and sludge treatment processes on sewage sludge characteristics have been discussed above as they pertain to specific sludge parameters. This section focuses on the broader effects of treatment on sewage sludge characteristics, highlighting the variable nature of treated sludge and thus the need for site-specific sludge characterization. Table 4-1 lists the various types of treatment processes, a number of which can be used to meet the Part 503 pathogen or vector attraction reduction requirements (see Chapter 3). Table 4-8 shows nutrient levels found in sewage sludge subjected to different treatment processes. EPA's *Process Design Manual for Sludge Treatment and Disposal* (U.S. EPA, 1979) provides further information on sludge treatment technologies.

Sewage sludge is virtually always treated by a stabilization process prior to land application. Stabilization reduces the volume of raw sludge by 25 to 40 percent because much of the volatile solids are degraded to

Table 4-8. Nutrient Levels in Sewage Sludge From Different Treatment Processes (Sommers, 1977)[a]

Nutrient	Sludge Treatment Process[b]	No. of Samples	Range	Median	Mean
Organic C (%)	Anaerobic	31	18-39	26.8	27.6
	Aerobic	10	27-37	29.5	31.7
	Other	60	6.5-48	32.5	32.6
	All	101	6.5-48	30.4	31.0
Total N (%)	Anaerobic	85	0.5-17.6	4.2	5.0
	Aerobic	38	0.5-7.6	4.8	4.9
	Other	68	<0.1-10.0	1.8	1.9
	All	191	<0.1-17.6	3.3	3.9
NH_4^+-N (mg/kg)	Anaerobic	67	120-67,600	1,600	9,400
	Aerobic	33	30-11,300	400	950
	Other	3	5-12,500	80	4,200
	All	103	5-67,600	920	6,540
NO_3^--N (mg/kg)	Anaerobic	35	2-4,900	79	520
	Aerobic	8	7-830	180	300
	Other	3	—	—	780
	All	45	2-4,900	149	490
Total P (%)	Anaerobic	86	0.5-14.3	3.0	3.3
	Aerobic	38	1.1-5.5	2.7	2.9
	Other	65	<0.1-3.3	1.0	1.3
	All	189	<0.1-14.3	2.3	2.5
K (%)	Anaerobic	86	0.02-2.64	0.30	0.52
	Aerobic	37	0.08-1.10	0.39	0.46
	Other	69	0.02-0.87	0.17	0.20
	All	192	0.02-2.64	0.30	0.40
Na (%)	Anaerobic	73	0.01-2.19	0.73	0.70
	Aerobic	36	0.03-3.07	0.77	1.11
	Other	67	0.01-0.96	0.11	0.13
	All	176	0.01-3.07	0.24	0.57
Ca (%)	Anaerobic	87	1.9-20.0	4.9	5.8
	Aerobic	37	0.6-13.5	3.0	3.3
	Other	69	0.12-25.0	3.4	4.6
	All	193	0.1-25.0	3.9	4.9

[a] Concentrations and percent composition are on a dried solids basis.
[b] "Other" includes lagooned, primary, tertiary, and unspecified sludges. "All" signifies data for all types of sludges.

carbon dioxide, methane, or other end products. This decomposition of the organic matter in the sludge and the subsequent release of carbon dioxide, ammonium, hydrogen sulfide, and phosphate result in lower levels of organic carbon (C), nitrogen (N), sulfur (S), and phosphorous in the stabilized sludge than was present in the raw sludge entering the stabilization unit. Stabilization processes include aerobic and anaerobic digestion and composting, among others. The actual amounts of stabilized sludge produced in a treatment works depends on operational parameters (e.g, temperature, mixing, detention time) of the stabilization process used.

Composting of sewage sludge results in further decreases in the organic constituents. If the sludge is mixed with a bulking agent (e.g., wood chips) during composting to facilitate aeration and rapid stabilization, some of the bulking agent will remain in the compost (even if screened), resulting in dilution of sludge components (e.g., nutrients, metals). The extensive biological activity that occurs during composting results in further decreases in the organic N, C, and S content of the sludge. In general, the organic N content of sludge decreases in the following order: raw, primary or waste activated, digested, and composted.

Wastewater and sewage sludge treatment processes often involve the addition of ferric chloride, alum, lime, or polymers. The concentration of these added elements increase their concentration in the resultant sludge. In addition, the added compound can have other indirect effects on sludge composition. For example, alum precipitates as aluminum hydroxides, which can subsequently adsorb phosphorus and coprecipitate with trace metals such as cadmium. Lime (calcium oxide or hydroxide) used as a sludge stabilization agent will ultimately precipitate in sludge as calcium carbonate, which also can retain phosphorus and metals. Lime addition also may result in losses of ammonia through volatilization.

4.14 Effects of Pretreatment and Pollution Prevention Programs on Sewage Sludge Characteristics

EPA first established pretreatment requirements (40 CFR Part 403) in 1978. Pretreatment programs require industries to limit the concentrations of certain pollutants in wastewater discharged to a treatment works, including heavy metals and organic chemicals.

In addition to pretreatment programs, pollution prevention programs designed to reduce or eliminate pollution are often developed as a joint effort by industry and government and are undertaken voluntarily by a company. The quality of sewage sludge has continually improved over the years, and many regulators, researchers, and treatment works managers believe that pretreatment and pollution prevention programs have been significant factors in achieving this improvement. For example, levels of cadmium, chromium, and lead have decreased since the 1970s, as shown by data from EPA's 1982 "40 City Study" (U.S. EPA, 1982) and 1990 NSSS (Shimp et al., 1994).

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When an NTIS number is cited in a reference, that document is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-487-4650

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Chapter 5
Site Evaluation and Selection Process

5.1 General

The process of planning a sewage sludge land application project begins with the collection and assessment of basic data on sludge characteristics. The sludge characteristics in conjunction with estimated application rates can then be compared to applicable federal, state, and local regulations for an initial assessment of sewage sludge suitability for any of the land application practices discussed in Chapter 2. The public's perception and acceptance of such a proposed project, as well as land availability, transportation modes, and climatic conditions, must all be considered and evaluated to determine the feasibility of the proposed program.

The careful identification, evaluation, and ultimate selection of land application sites can prevent future environmental problems, reduce monitoring requirements, minimize overall program costs, and moderate or eliminate adverse public reaction. Poor site selection and management practices in the past have resulted in environmental problems and public resistance.

Section 5.2 gives an overview of key requirements in the Part 503 regulation that affect site selection for land application of sewage sludge. Figure 5-1 provides an overview of a six-step process for identifying the best sewage sludge land application practice and the best site(s) for land application of sewage sludge. Sections 5.4 though 5.8 describe each of the six steps in more detail, and Section 5.9 provides an example of the site selection procedures that can be used for a typical medium-sized community.

5.2 Part 503 Requirements

The Part 503 rule contains several provisions that must be considered during site selection for land application of sewage sludge. These provisions are discussed briefly below and are explained further in Chapter 3. Some state and local governments have developed additional or more stringent regulations; therefore, it is important to check with state and local regulatory and permitting agencies where the proposed project is located to determine what requirements apply.

5.2.1 Protection of Surface Water and Wetlands

Part 503 specifies that sewage sludge cannot be applied to flooded, frozen, or snow-covered agricultural land, forests, public contact sites, or reclamation sites in such a way that it enters a wetland or other waters of the United States, except as provided in a Section 402 (NPDES) or Section 404 (dredge and fill) permit. In addition, sewage sludge cannot be applied to agricultural land, forests, or reclamation sites that are 10 meters or less from waters of the United States, unless otherwise specified by the permitting authority.

Other federal regulations also may apply to sewage sludge application in wetlands. These include:

- Sections 401, 402, and 404 of the Clean Water Act
- The Rivers and Harbors Act of 1989
- Executive Order 11990, Protection of Wetlands
- The National Environmental Policy Act
- The Migratory Bird Conservation Act
- The Fish and Wildlife Coordination Act
- The Coastal Zone Management Act
- The Wild and Scenic Rivers Act
- The National Historic Preservation Act

Additional published information that may be useful includes USGS topographic maps, National Wetland Inventory maps, Soil Conservation Service (SCS) soil maps, and wetland inventory maps prepared locally. Some of the local U.S. Army Corps of Engineers District Offices can provide a wetland delineation to indicate whether all or some portion of a potential or actual land application site is in a wetland. The state agency regulating activities in wetlands should also be asked to inspect the area in question. The definition of a wetland and the regulatory requirements for activities in wetlands may be different at the state level.

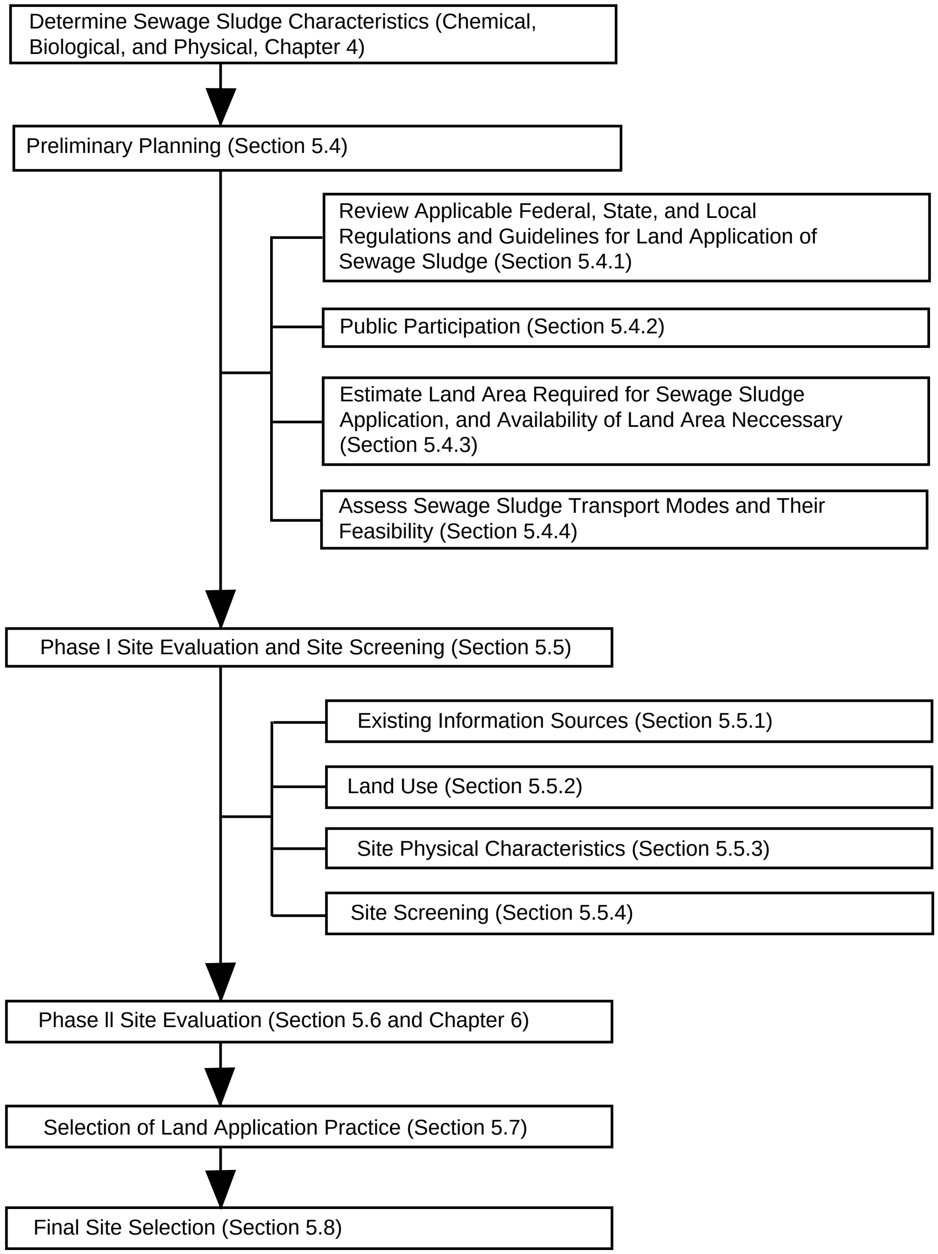

Figure 5-1. Simplified planning steps for a sewage sludge land application system.

5.2.2 Protection of Threatened and Endangered Species

Under Part 503, sewage sludge may not be applied to land if it is likely to adversely affect a threatened or endangered species listed under Section 4 of the Endangered Species Act or the designated critical habitat of such a species. The Threatened and Endangered Species List can be obtained from the U.S. Fish and Wildlife Service's (FWS's) Publications Office in Washington, DC. Critical habitat is defined as any place where a threatened or endangered species lives and grows during any stage of its life cycle.

Any direct or indirect action (or the result of any direct or indirect action) in a critical habitat that diminishes the likelihood of survival and recovery of a listed species is considered destruction or adverse modification of a critical habitat. Individuals may contact the Endangered Species Protection Program in Washington, DC. or Fish and Wildlife Service Field Offices for more information about threatened and endangered species considerations in their area. State departments governing fish and game also should be contacted for specific state requirements.

5.2.3 Site Restrictions

Restrictions for the harvesting of crops and turf, grazing of animals, and public access (see Chapter 3) also must be met when sewage sludge that meets the Part 503 Class B pathogen requirements is land applied.

5.3 Planning and Selection Process

As shown in Figure 5-1, this manual suggests a phased, six-step planning and site selection approach.

5.4 Preliminary Planning

Careful preliminary planning will help minimize delays and expenses later on in the process by identifying legal constraints (Section 5.4.1) and obtaining public input early in the process (Section 5.4.2). A preliminary estimate of land area requirements for different land application practices (Section 5.4.3) and a preliminary identification of feasible sewage sludge transportation options (Section 5.4.4) helps focus the Phase I site evaluation and site screening process (Section 5.5). The transportation assessment is especially important for defining the geographic search area for potential land application sites.

5.4.1 Institutional and Regulatory Framework

All current federal, state, county, and municipal regulations and guidelines should be reviewed during the preliminary planning process. Depending on local procedure, permits may be required from both state and local regulatory agencies. Figure 5-2 shows the agencies that have jurisdiction over land application of sewage sludge. Federal requirements under the Part 503 rule are described in detail in Chapter 3 of this manual.

5.4.2 Public Participation

Public participation is critical during the early stages of planning a land application project. Most involvement should come at the beginning of the planning process when public input has the greatest potential to shape the final plan. This early involvement helps determine the limits to public and political acceptability of the project. During this phase, the public plays a constructive, as opposed to a reactive, role in decision-making.

Site selection generally involves a preliminary screening of numerous potential sites after which several sites are selected for more detailed investigation. These selected sites should be subjected to intense public scrutiny. It is at this point that public participation can play a particularly formative role in determining the final site and design and operation procedures.

Most public interest and involvement—including the most vocal and organized protests—occur during the site selection stage. Therefore, the major thrust of the public participation program should come during this stage, with a particular emphasis on two-way communication using such avenues as public meetings, workshops, and radio talk shows.

Chapter 12 provides a detailed discussion of how to design and implement a public participation program for a land application project.

5.4.3 Preliminary Land Area Requirements

A precise estimate of the land area required for sewage sludge application should be based on design calculations provided in Chapters 7, 8, and 9 for the land application practice under consideration. However, for preliminary planning, a rough estimate of the land application area which might be necessary can be obtained from Table 5-1. (Note that different practices may not necessarily involve repeated annual applications.)

As an example, assume that the project is intended to land apply 1,000 t (1,100 T), dry weight, of sewage sludge annually. Using the typical rates shown in Table 5-1, a very rough estimate of the area required for agricultural land application would be 90 ha (220 ac), plus additional area required, if any, for buffer zones, sludge storage, etc. For a one-time application of 1,000 t of sewage sludge at a land reclamation site, the typical values shown in Table 5-1 indicate that 9 ha (22 ac) would be required.

5.4.4 Sewage Sludge Transport Assessment

Transport can be a major cost of a land application project, and requires a thorough analysis. This section is intended only to provide a brief summary of the alternatives that may be considered during the preliminary planning phase.

Sewage sludge can be transported by truck, pipeline, or rail. In certain instances, combined transport methods (e.g., pipeline-truck) are also used. The choice of a transportation method depends on the type of land selected, the volume and solids content of the sewage sludge, and the distance to and number of destination points.

The first consideration is the nature of the sewage sludge itself. As shown in Table 5-2, sewage sludge is classified for handling/transport purposes as either liquid, sludge cake, or dried, depending on its solids content. Only liquid sludge can be pumped and transported by pipeline. Pipeline transport can be cost effective for long-distance pumping of liquid sludge (usually less than 8 percent solids) but has been used for sludge up to 20 percent solids over very short distances. If liquid sludge is transported by truck or rail, closed vessels must be used, e.g., tank truck, railroad tank cars, etc. Sludge cake can be transported in watertight boxes, and dry sludge can be transported in open boxes (e.g., dump trucks).

Trucks and pipelines are the most common form of transport. Rail transport also is used in the United States. An example is rail shipment of sludge from New York to Texas.

Agencies With Jurisdiction Over Land Application

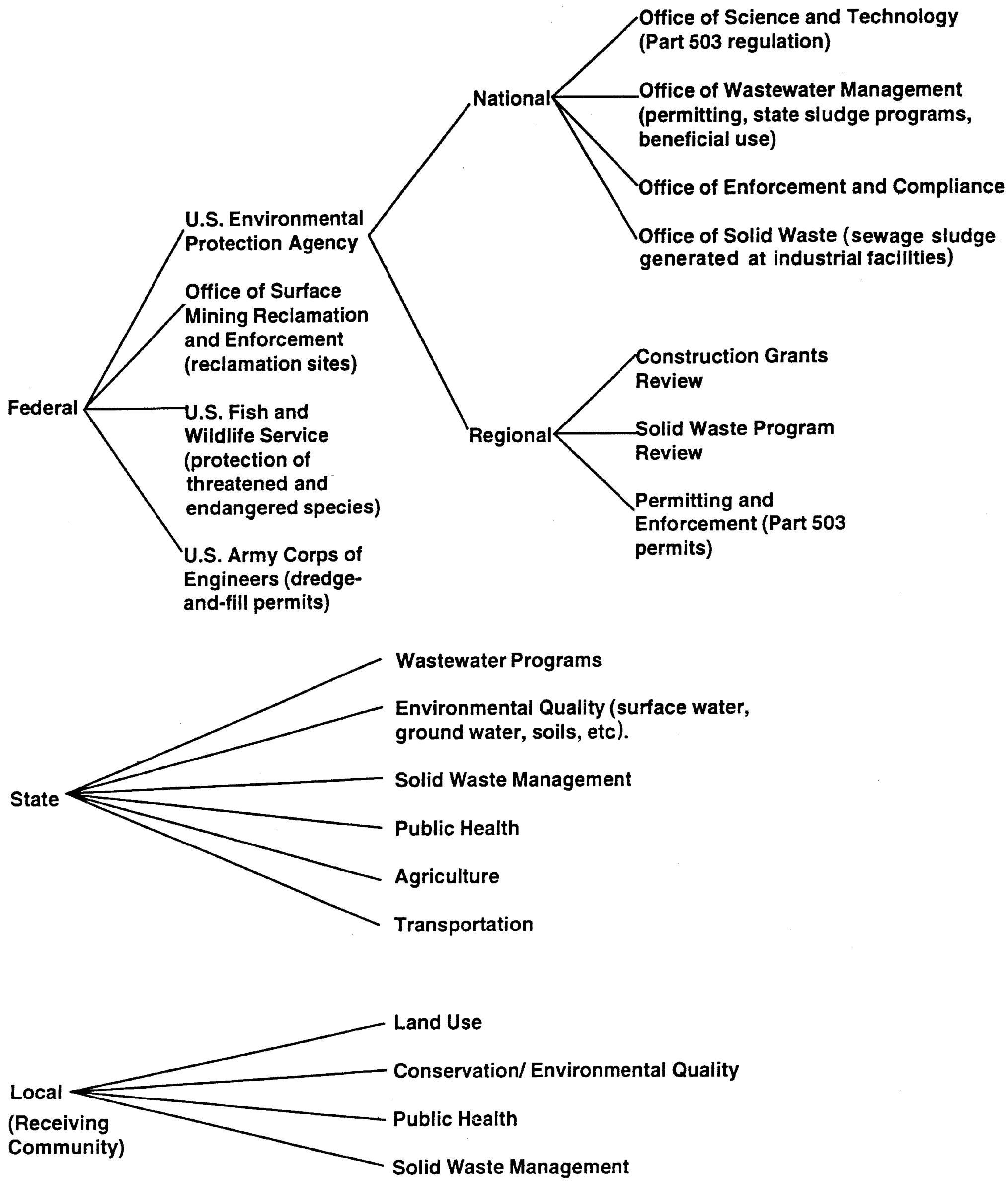

Figure 5-2. Institutional framework (adapted from Deese et al., 1980).

Truck transport allows greater flexibility than any other transport method. Destinations can be changed with little advance notice, and the sludge can be distributed to many different destinations. If trucks must be routed along residential or secondary streets, public concern about congestion and the risk of sludge spills must be considered. Most land application systems use truck transport, either alone or after sludge transport by pipeline or rail to an intermediate storage facility. Liquid sludge of up to 10 percent solids concentration (depending on its viscosity) can be transported in tank trucks. Dewatered sludge with a greater than 10 percent solids concentration can usually be transported in open trucks with watertight seals if precautions are taken to prevent spillage. Dried and composted sludge with approximately 50 percent or greater solids concentration can be transported without watertight seals or splash guards (U.S. EPA, 1984).

The desirable limit for a truck haul distance is about 25 to 40 km (15 to 25 mi) one way. For low cost land application of liquid sludge, the land must generally be within about a 16-km (10-mi) radius of the treatment plant. Mechanically dewatered sludge can generally be economically transported to a site up to about 22 km (20 mi). Air-dried sludges, which have solids concentrations in excess of 55 to 60 percent, can be economically transported a greater distance. In evaluating transportation costs,

Table 5-1. Preliminary Estimates of Sewage Sludge Applications (Dry Weight) for Different Types of Land

Land Type	Time Period of Application	Reported Range of Application Rates		Typical Rate	
		t/ha	T/ac	t/ha	T/ac[a]
Agricultural Land	Annual or twice annually	2-70	1-30	10	5
Forest Land	Annually, or at 3-5 year intervals	10-220	4-100	18	8
Land Reclamation Site	One time	7-450	3-200	112	50

[a]t = metric tonnes
T = English tons (short)

Table 5-2. Sewage Sludge Solids Content and Handling Characteristics

Sludge Type	Typical Solids Content (%)	Handling/ Transport Methods
Liquid	1 to 10	Gravity flow, pump, pipeline, tank transport
Sludge cake ("wet" solids)	10 to 30	Conveyor, auger, truck transport (watertight box)
Dried	50 to 95	Conveyor, bucket, truck transport (box)

the cost of dewatering must be weighed against the cost savings that can result from transporting a drier sludge (U.S. EPA, 1984).

Tables 5-3 and 5-4 present some practical considerations for hauling sludge. Table 5-5 provides a rating of transport modes in terms of reliability, staffing needs, energy requirements, and costs. For a detailed discussion of sludge transport, see Chapter 14.

5.5 Phase I Site Evaluation and Site Screening

A Phase I site evaluation uses the information obtained during preliminary planning, namely the estimate of preliminary land area requirements (Section 5.4.3) and the results of the transportation assessment (Section 5.4.4), to identify potential land application sites. Existing information sources (Section 5.5.1) are used to identify multiple sites considering land use (Section 5.5.2) and physical characteristics (Section 5.5.3) within the area that sewage sludge can feasibly be transported. Site screening allows elimination of unsuitable areas due to physical, environmental, social, or political reasons (Section 5.5.4), and identification of sites for more detailed Phase II site evaluation (Section 5.6 and Chapter 6).

5.5.1 Existing Information Sources

Sources of information on land characteristics, cropping patterns, and other relevant data in the geographic search area include:

- U.S. Department of Agriculture - Consolidated Farm Service Agency, Natural Resources Conservation

Table 5-3. Transport Modes for Sewage Sludge

Sewage Sludge Type	Transportation Considerations
Liquid Sludge	
Vehicles:	
Tank Truck	Capacity - up to maximum load allowed on road, usually 6,600 gal maximum. Can have gravity or pressurized discharge. Field trafficability can be improved by using flotation tires at the cost of rapid tire wear on highways.
Farm Tank Wagon and Tractor	Capacity - 800 to 3,000 gal. Principal use would be for field application.
Pipeline	Need minimum velocity of 1 fps to keep solids in suspension; friction decreases as pipe diameter increases (to the fifth power); buried pipeline suitable for year-round use. High capital costs.
Rail Tank Car	100-wet-ton (24,000-gal) capacity; suspended solids will settle while in transit.
Semisolid or Dried Sludge	
Truck	Commercial equipment available to unload and spread on ground; need to level sludge piles if dump truck is used. Spreading can be done by farm manure spreader and tractor.
Farm Manure Spreader	Appropriate for small systems where nearby farmlands are accessible by a manure spreader.
Rail Hopper Car	May need special unloading site and equipment for field application, although in many cases can use conventional unloading equipment.

Table 5-4. Auxiliary Facilities for Sewage Sludge Transport (Culp et al., 1980)

	Transport Mode			
	Truck	Railroad	Barge	Pipeline
Liquid				
Loading storage	No*	Yes	Yes	Yes
Loading equipment	Yes	Yes	Yes	Yes
Dispatch office	Yes	Yes	Yes	NA†
Dock and/or control building	NA	NA	Yes	Yes
Railroad siding(s)	NA	Yes	NA	NA
Unloading equipment	Yes	Yes	Yes	NA
Unloading storage#	No	Yes	Yes	Yes
Dewatered				
Loading storage	Yes**	Yes	NA	NA
Loading equipment	Yes	Yes	NA	NA
Dispatch office	Yes	Yes	NA	NA
Dock and/or control building	NA	NA	NA	NA
Railroad siding(s)	NA	Yes	NA	NA
Unloading equipment	Yes	Yes	NA	NA
Unloading storage	No	No	NA	NA

* Storage required for one or two truckloads is small compared with normal plant sludge storage.
† Not applicable.
\# Storage assumed to be a part of another unit process.
** Elevated storage for ease of gravity transfer to trucks.

Service, Forest Service, and Cooperative State Research Education and Extension Service.

- U.S. Geological Survey.
- U.S. EPA.
- U.S. Army Corps of Engineers.
- Private photogrammetry and mapping companies.
- State agricultural mining and geologic agencies.
- State water resource agencies.
- State universities and local colleges.
- Local planning and health departments.
- Local water conservation districts.
- Ground water users (municipalities, water companies, individuals, etc.).
- State land grant universities and water resource centers.

Section 5.5.3.5 identifies major sources for climatic data.

Table 5-5. Evaluation of Sewage Sludge Transport Modes (Culp et al., 1980)

	Transport Mode Alternatives		
Characteristics	Truck	Pipeline	Railroad
Reliability and Complexity[1]	1	3	1
Staffing Skills[2]	1	3	2
Staff Attention (Time)[3]	3	2	1
Applicability and Flexibility[4]	1	3	2
Energy Used[5]	8	6	2
Costs			
Capital Investment	Low	High	—
Operation, Maintenance, and Labor	Fairly High	Low	—
Overall[6]	—	—	Generally High[7]

[1] 1 = most reliable, least complex; 2 = intermediate; 3 = least reliable, most complex.
[2] 1 = least skills; 2 = intermediate; 3 = highest skills.
[3] Attention time increases with magnitude of number.
[4] 1 = wide applicability (all types of sludge); 3 = limited applicability, relatively flexible.
[5] 1 = lowest; 8 = highest.
[6] Overall costs are a function of sludge quantities and properties (percent solids), distance transported, and need for special storage loading and unloading equipment.
[7] Rail costs would generally be in the form of freight charges; costs could be lower for large volumes of sludge, or if long-distance rail is less expensive than truck transport.

5.5.2 Land Use and Availability

Prevailing or projected land use often exerts a significant influence on site selection, as well as on acceptance of a particular sewage sludge land application practice. It is necessary to determine both current and future land use in assessing the land area potentially suitable and/or available for sewage sludge application. Important considerations include zoning compliance, aesthetics, and site acquisition.

5.5.2.1 Current Land Use

Current land use patterns will help identify areas where land application of sewage sludge may be acceptable. The local SCS and Agricultural Extension Service representatives have knowledge of local farming, forestry, mining, and other land use practices. The SCS will, in many cases, have a comprehensive county soil survey with aerial photo maps showing the land area.

- **Agricultural Lands.** To a great extent, prevailing farming practices dictate the acceptability of agricultural land application. Small land holdings in a nonagricultural community may limit application to this type of land. An area devoted almost exclusively to production of human food crops restricts the periods when sewage sludge can be applied to land. Areas with a mixture of row crops, small grains, hay crops, and pastures may allow sewage sludge application throughout much of the year, depending on farming cycles.

- **Forest Lands.** A consideration in sewage sludge application to forest lands is the potential need to control public access for a period of time after sludge application. Therefore, the most desirable sites are often those owned by or leased to commercial growers, which already control public access. Publicly owned forest land has been used for sewage sludge application, but may require interagency negotiations and greater public education efforts than the use of privately owned land.
- **Reclamation Sites.** Potential reclamation sites are relatively easy to identify in a particular local area. Sewage sludge land application design is influenced by the potential future use of the reclaimed land (i.e., agriculture, silviculture, parks, greenbelts, etc.). The application of sewage sludge is often a one-time operation at reclamation sites rather than a repetitive series of applications on the same site. It is therefore necessary that (1) the mining or other operations will continue to generate disturbed land to which sludge can be applied, or (2) the reclamation area is of sufficient size to allow a continuing sludge application program over the design life of the project. State and federal guidelines may dictate the criteria for sludge applications and subsequent management.
- **Public Contact Sites.** Public contact sites such as parks, golf courses, and cemeteries are good candidates for land application of sewage sludge. Because municipalities often own these sites, a land application program may be easier to arrange at these sites than at privately owned sites. Bagged sewage sludge is often used at public contact sites having a small land area. Regulatory requirements and other considerations for the use of sewage sludge at public contact sites are explained in Chapter 10.
- **Lawns and Home Gardens.** Bagged sewage sludge can be used like other fertilizers for lawns and home gardens. Regulatory and other considerations for use of sewage sludge on lawns and home gardens are discussed in Chapter 10.

5.5.2.2 Future Land Use

Projected land use plans, where they exist, should be included when considering sewage sludge land application. Regional planners and planning commissions should be consulted to determine the projected use of potential land application sites and adjacent properties. If the site is located in or near a densely populated area, extensive control measures may be needed to overcome concerns and minimize potential aesthetic problems that may detract from the value of adjacent properties. Master plans for existing communities should be examined. The rate of industrial and/or municipal expansion relative to prospective sites can significantly affect long-term suitability.

5.5.2.3 Zoning Compliance

Zoning and land use planning are closely related, and zoning ordinances generally reflect future land use planning. Applicable zoning laws, if any, which may affect potential land application sites should be reviewed concurrently with land use evaluations. Since it is unusual that a community will have a specific area zoned for sludge/waste storage, project proponents may need to seek a zoning change for separate sewage sludge storage facilities.

5.5.2.4 Aesthetics

Selection of a land application site and/or sewage sludge land application practice can be affected by community concern over aesthetics, such as noise, fugitive dust, and odors. In addition to application site area concerns, routes for sludge transport vehicles must be carefully evaluated to avoid residential areas, bridge load limitations, etc. Disruption of the local scenic character and/or recreational activities, should they occur, may generate strong local opposition to a sewage sludge management program. Every attempt must be made to keep the application site compatible with its surroundings and, where possible, enhance the beauty of the landscape. Buffer zones are usually required to separate sewage sludge application sites from residences, water supplies, surface waters, roads, parks, playgrounds, etc.

5.5.2.5 Access

The preliminary sewage sludge transportation feasibility assessment (Section 5.4.4) will narrow the geographic search area for potential sites by focusing attention on areas that are adjacent to or in the vicinity of existing transportation corridors (e.g., roads, rail lines) for the selected sewage sludge transportation modes. Areas that are too distant for economic transport, or to which access is restricted for other reasons (such as physical barriers), can be eliminated from further consideration.

5.5.2.6 Site Acquisition

Application of sewage sludge to agricultural land can often be accomplished without direct purchase or lease of the land. Well-prepared educational and public participation programs early in the planning stages often identify numerous farmers willing to participate in a land application program. This type of arrangement may be more acceptable to the public in some cases than purchasing land for sewage sludge land application.

Several different contractual arrangements between municipalities and landowners for agricultural land application have been successfully employed, including:

- The municipality transports and spreads the sludge at no expense to the landowner.
- The municipality transports and spreads the sludge and pays the landowner for the use of his land.
- The landowner pays a nominal fee for the sewage sludge and for the municipality to transport and spread the sludge. This is most common for agricultural sites where local demand for sewage sludge as a fertilizer or soil conditioner exists.
- The municipality hauls the sludge and the landowner spreads it.
- The landowner hauls and spreads the sludge.

A written contract between the landowner and the sewage sludge preparer and/or applier is highly recommended. In some instances, the preparer/applier will be the municipality; in other cases, it will be a private preparer/applier who is transporting and spreading for the municipality. The Part 503 rule contains requirements for both preparers and appliers (see Chapter 3).

The principal advantage of a written contract is to ensure that both parties understand the agreement prior to applying the sewage sludge. Often, oral contracts are entered with the best of intentions, but the landowner and preparer/applier have differing notions of the rights and obligations of each party. In some cases, the contract may serve as evidence in disputes concerning the performance of either the preparer/applier or the landowner. Suggested provisions of contracts between the applier and landowner are shown in Table 5-6.

The use of land without purchase or lease may also be applicable for land application of sewage sludge to forested lands and reclamation sites. Direct purchase or lease, however, may be necessary for large-scale sewage sludge management systems regardless of the type of land at which sewage sludge is applied. In these instances, site acquisition represents a major cost in the implementation of the land application program.

5.5.3 Physical Characteristics of Potential Sites

The physical characteristics of concern are:

- Topography
- Soil permeability, infiltration, and drainage patterns
- Depth to ground water
- Proximity to surface water

The planner/designer should review federal and state regulations or guidelines that place limits on these physical characteristics of application sites. Chapter 6 addresses site physical characteristics in more detail. This section focuses on information that can usually be obtained from existing topographic and soil maps for the purpose of identifying sites where more detailed investigations may be justified.

5.5.3.1 Topography

Topography influences surface and subsurface water movement, which affects the amount of potential soil erosion and surface water runoff containing applied sewage sludge. These considerations have been factored into the pollutant limits established in the Part 503 regulation. Topography also can indicate the kinds of soil to be found on a site.

Quadrangle maps published by the U.S. Geological Survey may be useful during preliminary planning and screening to estimate slope, local depressions or wet areas, rock outcrops, regional drainage patterns, and water table elevations. These maps, however, usually are drawn to a scale that cannot be relied on for evaluating small parcels and do not eliminate the need for field investigation of potential sewage sludge land application sites. The use of regional and soil survey maps can help eliminate potentially unsuitable areas. Table 5-7 summarizes important criteria; see Section 5.2.1 for related Part 503 regulatory requirements.

Soils on ridge tops and steep slopes are typically well drained, well aerated, and usually shallow. But steep slopes, except on very permeable soils, increase the possibility of surface runoff of sewage sludge. Soils on concave land and broad flat lands frequently are poorly drained and may be waterlogged during part of the year. Soils between these two extremes will usually have intermediate properties with respect to drainage and runoff. Application to steep slopes (from 30 to over 50 percent) in forested areas may be possible under specific conditions (e.g., properly buffered slopes with good forest floor/understory vegetation, depending on the type of soil, vegetation, and sewage sludge) if it can be shown that the risk from runoff is low. Forest sites, which generally have a very permeable forest floor, and new technology for applying dewatered sewage sludge in forests greatly reduce the potential for overland flow.[1]

The steepness, length, and shape of slopes influence the rate of runoff from a site. Rapid surface water runoff accompanied by soil erosion can erode sewage sludge soil mixtures and transport them to surface waters. Therefore, state regulations/guidelines often stipulate the maximum slopes allowable for sewage sludge land application sites under various conditions regarding sludge physical characteristics, application techniques, and application rates. Specific guidance should be

[1] Henry, C. 1995. Personal communication, Dr. Charles Henry, Pack Forest Research Center, University of Washington, Eatonville, WA.

Table 5-6. Suggested Provisions of Contracts Between Sewage Sludge Preparer, Sludge Applier, and Private Landowners (Sagik et al., 1979)

Identification of the landowner, the preparer, and the applier spreading the sludge.

Location of land where application is to occur and boundaries of the application sites.

Entrance and exit points to application sites for use by spreading equipment.

Specification of the range of sludge quality permitted on the land. Parameters identified might include percent of total solids; levels of trace elements and pathogens in the sludge, and vector attraction reduction, as regulated by Part 503; additional state and local parameters required. The contract would specify who is to pay for the analysis, and frequency of analysis.

Agreement on the timing of sludge application during the cropping season. Application rates and acceptable periods of application should be identified for growing crops, as well as periods when the soil is wet.

Agreements on the application rate (agronomic rate). This rate might vary through the year depending on the crop, the sludge analyses, and when and where application is occurring.

Restrictions on usage of land for growing root crops or fresh vegetables, or for grazing livestock.

Conditions under which either party may escape from provisions of the contract or be subject to indemnification or liability issues.

Table 5-7. Potentially Unsuitable Areas for Sewage Sludge Application

Areas bordered by ponds, lakes, rivers, and streams without appropriate buffer areas.

Wetlands and marshes without a permit.

Steep areas with sharp relief.

Undesirable geology (karst, fractured bedrock) (if not covered by a sufficiently thick soil column).

Undesirable soil conditions (rocky, shallow).

Areas of historical or archeological significance.

Other environmentally sensitive areas such as floodplains or intermittent streams, ponds, etc., as specified in the Part 503 regulation.

obtained from appropriate regulatory agencies; for general guidance, suggested limits are presented in Table 5-8.

5.5.3.2 Soils and Geology

Soil survey reports can be obtained from local SCS offices and are suitable for preliminary planning. When potential sites are identified, field inspections and investigations are necessary to confirm expected conditions (Section 5.4.2). The SCS mapping units cannot represent areas smaller than 0.8 to 1.2 ha (approximately 2 to 3 acres). Thus, there is a possibility that small areas of

Table 5-8. Recommended Slope Limitations for Land Application of Sewage Sludge

Slope	Comment
0-3%	Ideal; no concern for runoff or erosion of liquid or dewatered sludge.
3-6%	Acceptable for surface application of liquid or dewatered sludge; slight risk of erosion.
6-12%	Injection of liquid sludge required in most cases, except in closed drainage basin and/or areas with extensive runoff control. Surface application of dewatered sludge is usually acceptable.
12-15%	No liquid sludge application without effective runoff control; surface application of dewatered sludge is acceptable, but immediate incorporation is recommended.
Over 15%	Slopes greater than 15% are only suitable for sites with good permeability (e.g., forests), where the steep slope length is short (e.g., mine sites with a buffer zone downslope), and/or the steep slope is a minor part of the total application area.

soils with significantly different characteristics may be located within a mapping unit but not identified. SCS soil surveys provide information on typical characteristics of soil map units that are very useful for identifying the most favorable soils within a potential site and for comparing relative suitability of different possible sites. Section 5.9.8 (Table 5-15) illustrates how relevant information on soil types can be compiled.

The texture of the soil and parent geologic material is one of the most important aspects of site selection because it influences permeability, infiltration, and drainage. It is important that a qualified soil scientist be involved in the assessment of soils at potential land application sites.

With proper design and operation, sewage sludge can be successfully applied to virtually any soil. However, highly permeable soil (e.g., sand), highly impermeable soil (e.g., clay; although the addition of organic material in sewage sludge may help reduce impermeability), or poorly drained soils may present special design requirements. Therefore, sites with such conditions should generally be given a lower priority during the preliminary site selection process. Table 5-9 summarizes typical guidelines for soil suitability. In some cases, the favorable aspects (i.e., location, municipal ownership, etc.) may outweigh the costs of mitigation measures.

Soil Permeability and Infiltration

Permeability (a property determined by soil pore space, size, shape, and distribution) refers to the ease with which water and air are transmitted through soil. Fine-textured soils generally possess slow or very slow permeability, while the permeability of coarse-textured soils ranges from moderately rapid to very rapid. A medium-

Table 5-9. Soil Limitations for Sewage Sludge Application to Agricultural Land at Nitrogen Fertilizer Rates in Wisconsin (Keeney et al., 1975)

	Degree of Soil Limitation		
Soil Features Affecting Use	**Slight**	**Moderate**	**Severe**
Slope[a]	Less than 6%	6 to 12%	More than 12%
Depth to seasonal water table	More than 1.2 m	0.6 to 1.2 m	Less than 1 m
Flooding and ponding	None	None	Occasional to frequent[b]
Depth to bedrock	More than 1.2 m	0.6 to 1.2 m	Less than 0.61 m
Permeability of the most restricting layer above a 1-m depth	0.24 to 0.8 cm/hr	0.8 to 2.4 cm/hr 0.08 to 0.24 cm/hr	Less than 0.08 cm/hr More than 2.4 cm/hr
Available water capacity	More than 2.4 cm	1.2 to 2.4 cm	Less than 1.2 cm

[a] Slope is an important factor in determining the runoff that is likely to occur. Most soils on 0 to 6% slopes will have slow to very slow runoff; soils on 6 to 12% slopes generally have medium runoff; and soils on steeper slopes generally have rapid to very rapid runoff.
[b] Land application may be difficult under extreme flooding or ponding conditions.

Metric conversions: 1 ft = 0.3048 m, 1 in = 2.54 cm.

textured soil, such as a loam or silt loam, tends to have moderate to slow permeability.

Soil Drainage

Soils classified as (1) very poorly drained, (2) poorly drained, or (3) somewhat poorly drained by the Soil Conservation Service may be suitable for sewage sludge application if runoff control is provided. Soils classified as (1) moderately well-drained, (2) well drained, or (3) somewhat excessively drained are generally suitable for sewage sludge application. Typically, a well-drained soil is at least moderately permeable.

5.5.3.3 Surface Hydrology, Including Floodplains and Wetlands

The number, size, and nature of surface water bodies on or near a potential sewage sludge land application site are significant factors in site selection due to potential contamination from site runoff and/or flood events. Areas subject to frequent flooding have severe limitations for sewage sludge application. Engineered flood control structures can be constructed to protect a land application site against flooding, but such structures can be prohibitively expensive.

5.5.3.4 Ground Water

For preliminary screening of potential sites, it is recommended that the following ground-water information for the land application area be considered:

- Depth to ground water (including historical highs and lows).
- An estimate of ground water flow patterns.

When a specific site or sites has been selected for sewage sludge application, a detailed field investigation may be necessary to determine the above information. During preliminary screening, however, published general resources may be located at local USGS or state water resource agencies.

Generally, the greater the depth to the water table, the more desirable a site is for sewage sludge application. Sewage sludge should not be placed where there is potential for direct contact with the ground-water table. The actual thickness of unconsolidated material above a permanent water table constitutes the effective soil depth. The desired soil depth may vary according to sludge characteristics, soil texture, soil pH, method of sludge application, and sludge application rate. Table 5-10 summarizes recommended criteria for the various land application practices.

The type and condition of consolidated material above the water table is also of major importance for sites where high application rates of sewage sludge are desirable. Fractured rock may allow leachate to move rapidly. Unfractured bedrock at shallow depths will restrict water movement, with the potential for ground water mounding, subsurface lateral flow, or poor drainage. Limestone bedrock is of particular concern where sinkholes may exist. Sinkholes, like fractured rock, can accelerate the movement of leachate to ground water. Thus, potential sites with potable ground water in areas underlain by fractured bedrock, by

Table 5-10. Recommended Depth to Ground Water

Type of Site	Drinking Water Aquifer[a]	Excluded Aquifer[b]
Agricultural	1-2 m	0.5 m
Forest	2 m[c]	0.7 m
Reclamation	1-2 m	0.5 m

[a] States may have other depth-to-ground water requirements.
[b] Clearances are to ensure trafficability of surface, not for ground water protection; excluded aquifers are not used as potable water supplies.
[c] Seasonal (springtime) high water and/or perched water less than 1 m are not usually a concern.

Metric conversion: 1 m = 3.28 ft.

unfractured rock at shallow depths, or with limestone sinkholes should be avoided.

5.5.3.5 Climate

Analysis of climatological data is an important consideration for the preliminary planning phase. Rainfall, temperature, evapotranspiration, and wind may be important climatic factors affecting land application of sewage sludge, selection of land application practices, site management, and costs. Table 5-11 highlights the potential impacts of some climatic regions on the land application of sewage sludge.

Meteorological data are available for most major cities from three publications of the National Oceanic and Atmospheric Administration (NOAA):

- The Climatic Summary of the United States.
- The Monthly Summary of Climatic Data, which provides basic data, such as total precipitation, maximum and minimum temperatures, and relative humidity, for each day of the month, and for every weather station in the area. Evaporation data are also given, where available.
- Local Climatological Data, which provides an annual summary and comparative data for a relatively small number of major weather stations.

This information can be obtained by written request from NOAA, 6010 Executive Boulevard, Rockville, Maryland 20852. Another excellent source is the National Climatic Center in Asheville, North Carolina 28801. Weather data may also be obtained from local airports, universities, military installations, agricultural and forestry extension services and experiment stations, and agencies managing large reservoirs.

Table 5-11. Potential Impacts of Climatic Regions on Land Application of Sewage Sludge (Culp et al., 1980)

	Climatic Region		
Impact	**Warm/Arid**	**Warm/Humid**	**Cold/Humid**
Operation Time	Year-round	Seasonal	Seasonal
Operation Cost	Lower	Higher	Higher
Storage Requirement	Less	More	More
Salt Buildup Potential	High	Low	Moderate
Leaching Potential	Low	High	Moderate
Runoff Potential	Low	High	High

5.5.4 Site Screening

Site screening is an integral part of the Phase I site evaluation process. Initially, development of land area, transportation distance, topographic, soils, hydrologic and other site screening criteria helps focus efforts on collecting relevant information. One practical screening technique involves the use of transparent (mylar) overlays with concentric rings drawn around the wastewater treatment facility. The distance represented by the initial ring will vary depending on facility location, sewage sludge quantity, proximity of nearby communities, local topography, and the land application practices being considered. A small community might start with an area 20 km (12.5 miles) in diameter, while a large system may initially screen a much larger study area. Shaded areas representing unsuitable locations are marked on the map or the transparency. If the initial ring does not have suitable sites, then the next ring with a larger diameter should be considered. It should be remembered that areas that are unsuitable in their existing state can often be modified to make them acceptable for sewage sludge application. The necessary modifications (e.g., extensive grading, drainage structures, flood control, etc.) may be cost-effective if the site is otherwise attractive in terms of location, low land cost, etc.

5.5.4.1 Contact with Owners of Prospective Sites

When potential sites are identified, ownership should be determined. Often the City Hall, County Courthouse, or a real estate broker will have community or areawide maps indicating the tracts of land, present owners, and property boundaries. The County Recorder and title insurance companies are also useful sources of information on property ownership, size of tracts, and related information. Contacting landowners prematurely without adequate preparation may result in an initial negative reaction which is difficult to reverse. A public information program should be prepared (see Chapter 12), and local political support secured. The individuals involved in making the initial owner contacts should be knowledgeable about potential program benefits and constraints.

Initial contacts concerning the proposed project should be made with the prospective landowners/site managers through personal interviews. Initial contacts via telephone are not recommended to avoid misunderstandings regarding the benefits of a land application program.

Ideally, the Phase I site evaluation and screening process will identify two or three sites that merit a more detailed Phase II site evaluation, discussed below.

5.6 Phase II Site Evaluation: Field Investigation

The Phase II site evaluation step involves field investigations of one or more sites to determine whether soil survey and other map information used in the Phase I site evaluation and screening process is accurate and to obtain additional, more detailed information required for final selection of the land application practice (Section 5.7) and final site selection (Section 5.8). Chapter 6 covers the following aspects of Phase II investigations:

- Preliminary field site surveys.
- Procedures for detailed site investigations.
- Special considerations for detailed site evaluations for different land application practices: agricultural, forest land, reclamation sites, and public contact sites.

5.7 Selection of Land Application Practice

When the most feasible land application practices have been identified (e.g., application to agricultural land, forests, reclamation sites, public contact sites, or lawns and home gardens), preliminary estimates of site life and costs (capital and O&M) for the individual practices should be made (see Section 5.8.1). Potential social and environmental impacts resulting from each practice also should be assessed. Comparing these data should reveal the most suitable land application practice that fits both the needs of the wastewater treatment facility and local conditions. The facility might also consider adopting more than one land application practice (e.g., agricultural and forest land application) if the combined practices appear to be cost-effective. The flow chart shown in Figure 5-3 summarizes the procedure for selecting a land application practice.

A checklist of relevant design features for each land application site is usually helpful for compiling information and provides baseline data for cost estimates (Table 5-12). Individual practices can be compared and evaluated based on both quantitative and qualitative factors:

- Estimated costs
- Reliability
- Flexibility
- Land area requirements and availability
- Land use effects
- Public acceptance
- Regulatory requirements (federal, state, and local)

A qualitative comparison of each land application practice is based on the experience and judgment of the project planners and designers. This is more difficult than a cost comparison, because the level of each impact is more ambiguous and subject to differences of opinion.

5.8 Final Site Selection

The final selection of the site(s) is often a simple decision based on the availability of the best site(s). This is frequently the case for small communities. If, however, the site selection process is complex, involving many potential sites and/or several sewage sludge use and/or disposal practices, a weighted scoring system may be useful.

The use of a quantitative scoring system for site selection is demonstrated in the *Process Design Manual for Surface Disposal of Sewage Sludge and Domestic Septage* (U.S. EPA, in preparation). While the criteria for selecting site(s) for the land application practices discussed in this manual differ somewhat from those provided in the surface disposal design manual, the weighting and scoring system may be useful. Table 5-13 presents another example of a ranking system for forest sites, based on consideration of topography, soils and geology, vegetation, water resources, climate, transportation, and forest access.

Several other considerations should be integrated into the decision-making process, including:

- Compatibility of sewage sludge quantity and quality with the specific land application practice selected.
- Public acceptance of both the practice(s) and site(s) selected.
- Anticipated design life, based on assumed application rate, land availability (capacity), projected heavy metal loading rates (if Part 503 cumulative pollutant loading rates are being met, as defined in Chapter 3), and soil properties.

5.8.1 Preliminary Cost Analysis

A preliminary estimate of relative costs should be made as part of the site selection process. These estimates are necessary for comparing alternative sites and/or land application practices.

Proximity of the sewage sludge land application site to the wastewater treatment facility is very important in the decision-making process because of transportation costs. Further, the cost of sludge dewatering equipment should be evaluated in view of estimated fuel savings through decreased total loads and/or shorter haul distances. For ease of comparison, all costs can be expressed in dollars per dry weight of sewage sludge. Capital costs should be estimated over the life of the site, whereas operating costs should be estimated annually. Cost factors that are of prime importance are summarized in Table 5-14. These assessments should be based on experience and best engineering judgment. Chapter 16 discusses cost estimations in more detail.

5.8.2 Final Site Selection

The Phase I and Phase II site evaluation process should result in detailed information on two or more sites that have been identified as suitable for the selected land application practice. This information, combined with the preliminary cost analysis (Section 5.8.1) should provide

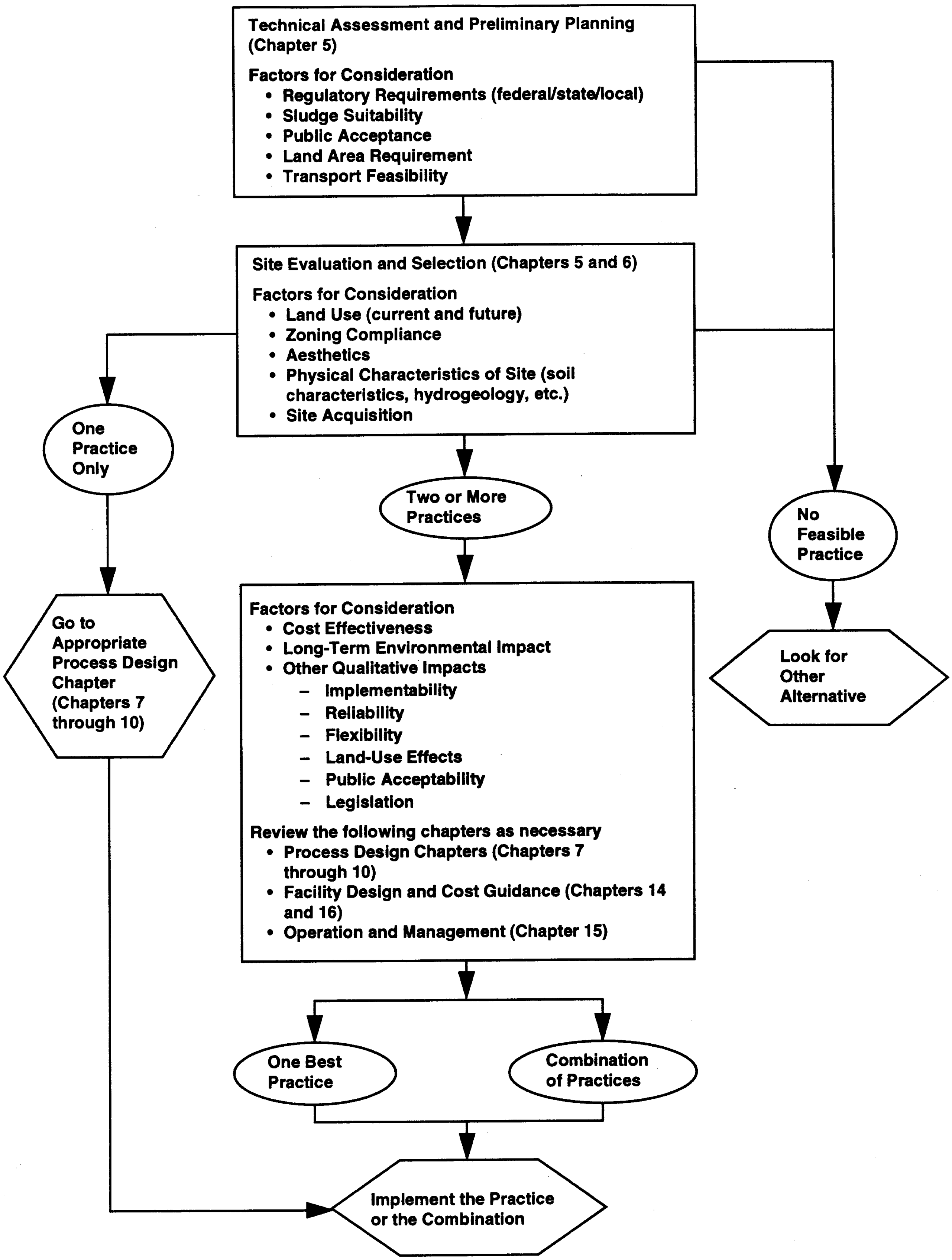

Figure 5-3. Planning, site selection, and land application practice selection sequence.

Table 5-12. Example Design Features Checklist/Comparison of Candidate Land Application Practices

	Candidate Practice or Combination of Practices		
Subject	**Agriculture**	**Forest**	**Reclamation**
1. Distance and travel time from POTW to the candidate site			
2. Distance and travel time from the storage facility to the candidate site			
3. Distance from the nearest existing development, neighbors, etc., to the candidate site			
4. Sludge modification requirements, e.g., dewatering			
5. Mode of sludge transportation			
6. Land area required			
7. Site preparation/construction needs:			
a. None			
b. Clearing and grading			
c. Access roads (on-site and off-site)			
d. Buildings, e.g., equipment storage			
e. Fences			
f. Sludge storage and transfer facilities			
g. On-site drainage control structures			
h. Off-site runoff diversion structures			
i. On-site runoff storage			
j. Flood control structure			
k. Ground water pollution control structure, e.g., subsurface drain system			
l.Soil modification requirements, e.g., lime addition, etc.			
8. Equipment needs:			
a. Sludge transport vehicle			
b. Dredge			
c. Pumps			
d. Crawler tractor			
e. Subsurface injection unit			
f. Tillage tractor			
g. Sludge application vehicle			
h. Nurse tanks or trucks			
i. Road sweeper			
j. Washing trucks			
k. Irrigation equipment			
l. Appurtenant equipment			
9. Monitoring requirements:			
a. Soil			
b. Sludge analysis			
10. Operational needs			
a. Labor			
b. Management			
c. Energy			
d. Repair			

Table 5-13. Relative Ranking for Forest Sites for Sewage Sludge Application[a]

Factor	Relative Rank
Topography	
Slope	
less than 10%	High
10-20%	Acceptable
20-30%	Low
over 30%	Low
Site continuity (somewhat subjective)	
no draws, streams, etc., to buffer	High
1 or 2 requiring buffers	Acceptable
numerous discontinuities	Low
Transportation	
Distance	Low-High
Condition of the roads	Low-High
Travel through sensitive areas	Low-High
Forest Access System	
Percent of forest system in place	Low-High
Ease of new construction	
easy (good soils, little slope, young trees)	High
difficult	Low-Acceptable
Erosion hazard	
little (good soils, little slope)	High
great	Low-Acceptable
Soil and Geology	
Soil type	
sandy gravel (outwash, Soil Class I)	High
sandy (alluvial, Soil Class II)	High
well graded loam (ablation till, Soil Class IV)	Acceptable
silty (residual, Soil Class V)	Acceptable
clayey (lacustrine, Soil Class IV)	Low
organic (bogs)	Low
Depth of soil	
deeper than 10 ft	High
3-10 ft	High
1-3 ft	Acceptable
less than 1 ft	Low
Geology (subjective, dependent upon aquifer)	
sedimentary bedrock	Acceptable-High
andesitic basalt	Acceptable-High
basal tills	Low-Acceptable
lacustrine	Low
Vegetation	
Tree species	
Hybrid cottonwood (highest N uptake rates)	High
Douglas-fir	High
other conifers	High
other mixed hardwoods	Acceptable
red alder	Low

a basis for selecting the most cost-effective site or sites. The next section provides an example of the site evaluation and selection process.

5.9 Site Selection Example

Each of the process design chapters (Chapters 7 through 9) provides a detailed example of the design of a specific land application system for agricultural, forest, and reclamation sites. This section provides a brief example of the site selection procedure that could be used for a typical medium-sized community.

Table 5-14. Cost Factors To Be Considered During Site Selection

Capital Costs
- Land acquisition—purchase, lease, or use of private land.
- Site preparation—grading, roads, fences, drainage, flood control, and buildings (if needed).
- Equipment—sludge transport and application.
- Sludge storage facilities.

Operating Costs
- Fuel for sludge transport and application.
- Labor (transport, application, maintenance, sampling, etc.)
- Equipment repair.
- Utilities.
- Monitoring, if required (laboratory analysis, sample containers, shipping).
- Materials and miscellaneous supplies.

5.9.1 City Characteristics

- Population–34,000.
- Wastewater volume–0.18 m^3/s (4 mgd).
- Wastewater treatment facility description–conventional activated sludge, with anaerobic digestion of primary and waste-activated sludges.

5.9.2 Sewage Sludge and Soil Characteristics

- Daily sludge generation–2.36 dry t/day (2.6 dry T/day).
- Average solids content–4 percent.
- Average chemical properties (dry weight basis):
  - Total N–3 percent
  - NH_4-N–1 percent
  - Total P–2 percent
  - Total K–0.5 percent
- Metal regulated by Part 503 (in mg/kg):
  - As–10
  - Cd–19
  - Cr–800
  - Cu–700
  - Pb–500
  - Hg–7
  - Mo–12
  - Ni–150
  - Se–19
  - Zn–2,000
- Soil is maintained at pH 6.5 or above when required for optimum crop production.

5.9.3 Regulations Considered

Assume that agricultural land application is the only practice being considered, and that special permits are not required for sewage sludge application, provided that:

1. Annual sewage sludge applications do not exceed either the agronomic rate or the Part 503 limits for metals.
2. Annual program for routine soil testing (N, P, K) and lime requirement (pH) is implemented.
3. Wastewater treatment plant measures the chemical composition of sludge.
4. Records are maintained on the location and the amount of sludge applied.
5. The site is not 10 meters or less from waters classified as waters of the United States.

5.9.4 Public Acceptance

Assume that public acceptance of land application of sewage sludge is judged to be very good. Several nearby communities have previously established agricultural land application programs with excellent results. Sewage sludge characteristics from these communities were similar, as were farm management and cropping patterns involving corn, oats, wheat, and pastureland. Several articles had appeared in the local newspaper indicating that escalating landfill costs were causing the city to study various sewage sludge use and disposal alternatives. No public opposition groups are known to exist.

5.9.5 Preliminary Feasibility Assessment

The above preliminary information was sufficiently encouraging to warrant further study of agricultural land application.

5.9.6 Estimate Land Area Required

An application rate of 22.4 t/ha/year (10 T/ac/year) was used as a first approximation (see Table 5-1). The acreage required for the city was estimated as follows:

$$\text{Acreage needed} = \frac{2.36 \text{ t/day} \times 365 \text{ days/yr}}{22.4 \text{ t/ha/yr}} = 38.4 \text{ ha}$$

Thus, assume 40 ha (100 ac) for the preliminary search.

5.9.7 Eliminate Unsuitable Areas

Figure 5-4 shows a general area map containing the city and surrounding communities. Three concentric rings of 10, 20, and 30 km (6.2, 12.4, and 18.6 mi) were drawn around the wastewater treatment facility. Areas directly south of the facility were immediately excluded because of the city boundaries. Similarly, areas east and southeast were excluded because of the city's projected growth pattern, the encroachment of a neighboring city, and the municipal airport. Further investigations to identify potential land application sites were thus concentrated to the west and northwest.

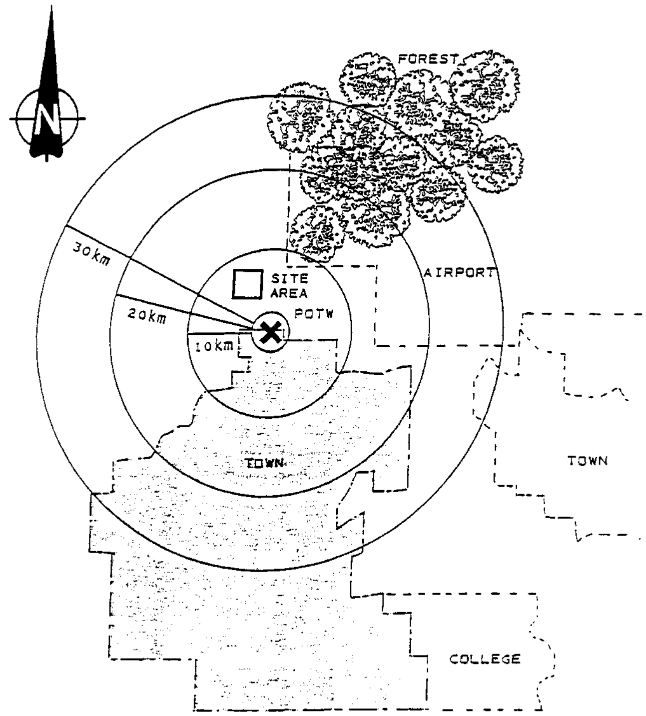

Figure 5-4. General area map with concentric rings.

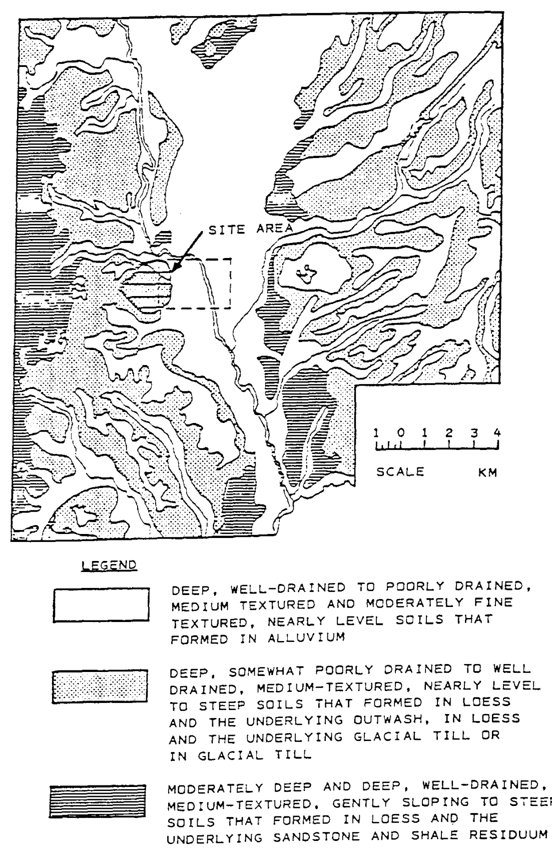

Figure 5-5. General soil map showing area selected for sewage sludge land application.

5.9.8 Identify Suitable Areas

Soil maps obtained from the local SCS office were examined within the three radii selected. Areas within the 10-km (7-mi) ring were given first priority because of their proximity to the wastewater treatment facility. Sufficient land was located within this distance, and the areas contained within the second and third radii were not investigated.

Figure 5-5 is a general soil map showing one potential area available for sewage sludge land application. A detailed soil map of the area is shown in Figure 5-6, and the map legend is presented in Table 5-15.

Information presented in the soil survey report included: slope, drainage, depth to seasonal water table, and depth to bedrock. Cation exchange capacities (CEC) were estimated

Table 5-15. Ranking of Soil Types for Sewage Sludge Application

Soil Type	Slope Percent	Depth to Seasonal High Water Table (ft)	Depth to Bedrock (ft)	Texture*	Drainage Class†	Approximate CEC	Relative Ranking#
AvA**	0-2	1-3	>15	sil	P	10-15	3
Ca**	0.2	>6	>15	sil	W	10-15	1
CnB2**	2-6	>6	>15	sil	W	10-15	1
CnC2	6-12	>6	>15	sil	W	10-15	2
CnC3	6-12	>6	>15	sil	W	10-15	2
Cn02	12-18	>6	>15	sil	W	10-15	3
Cn03	12-18	>6	>15	sil	W	10-15	3
Fe**	0-2	3-6	>15	sil	W	10-15	2
FoA**	0-2	>6	>15	l	W	10-15	1
FoB2	2-4	>6	>15	l	W	10-15	1
FoC3	6-12	>6	>15	l	W	10-15	2
Ge	0-2	>6	>15	l	W	10-15	1
Hh	0-2	1-3	>10	sil	SP	10-15	3
La	0-2	>6	>15	gsal	W	>5	1
MbA	0-2	>6	>15	l	W	10-15	1
MbB2	2-6	>6	>15	l	W	10-15	1
Md	0-2	3-6	>15	sicl	MW	>15	2
NgA**	0-2	>6	>15	l	W	10-15	1
NgB2**	2-6	>6	>15	l	W	10-15	1
NnA	0-2	>6	>15	l	W	10-15	1
RnF	0-2	>6	>15	gl	E	>5	1
Ro**	0-2	>6	>15	sicl	W	>15	1
Rp	0-2	>6	>15	sicl	W	>15	1
RsB2	2-6	3-6	>15	sil	MW	10-15	2
Sc	0-2	0-1	>15	sicl	VP	>15	3
Sh**	0-2	1-3	>15	sil	SP	10-15	3
Sm	0-2	1-3	>15	l	SP	10-15	3
Sz	0-2	>6	>15	sal	W	5-10	1
Wc**	0-2	0-1	>15	cl	VP	>15	3
Wh**	0-2	1-3	>15	l	SP	10-15	3

* l, loam; gsal, gravelly sandy loam; sil, silt, loam; sicl, silty clay loam; cl, clay loam; sal, sandy loam; gl, gravelly loam.
† E, excessively drained; W, well drained; MW, moderately well drained, SP, somewhat poorly drained; P, poorly drained; VP, very poorly drained.
\# 1, 0-6 percent slope, >6 ft to water table and >15 to bedrock. 2, 6-12 percent slope or 3-6 ft to water table. 3, 12-18 percent slope or 0-3 ft to water table.
** Soil types present on potential site (see Figure 5-6). Soil type information from SCS county soil survey.

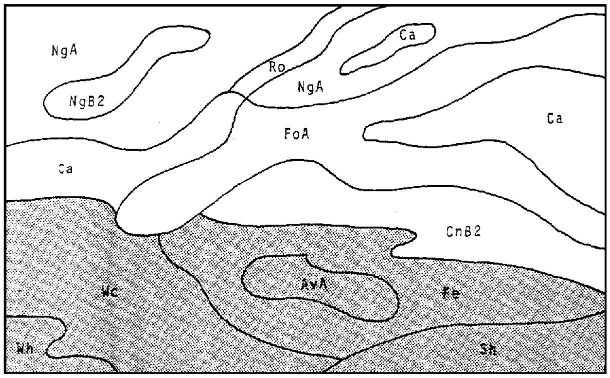

Figure 5-6. Detailed soil survey map of potential site for sewage sludge land application. (Areas not suitable for use are shaded; see Table 5-17 for ranking of soil types.)

from texture, and a ranking was developed to estimate soil suitability for sewage sludge application.

Since the detailed soil map was based on an aerial photo, farm buildings, houses, etc., were usually identifiable. Certain portions within this area were excluded, including:

- Areas in close proximity to houses, schools, and other inhabited buildings.
- Areas immediately adjacent to ponds, lakes, rivers, and streams.

The excluded areas were shaded (Figure 5-6), using a mylar overlay. The remaining unshaded areas, covering about 930 ha (2,300 ac), were generally pastureland with some fields of corn and oats. Within this area was about 175 ha (432 ac) which ranked in Category 1 in Table 5-15.

The land in the site area was owned by three individuals. Since the 175 ha (432 ac) was far in excess of the 40 ha (100 ac) required, no further sites were investigated. Soils present in the area were generally silt loams. Representative soil analysis was as follows:

- CEC - 10 meq/100 g.
- Soil pH - 6.0 (1:1 with water).
- Available P - 16.8 kg/ha (15 lb/ac).
- Available K - 84 kg/ha (75 lb/ac).
- Lime necessary to raise pH to 6.5 - 5.4 t/ha (2.4 T/ac).

The three landowners were contacted individually to determine their willingness to participate. All expressed considerable interest in participating in the program.

5.9.9 Phase II Site Survey and Field Investigation

These efforts confirmed the suitability of the site selected. Agreements were thus made with each landowner to land apply municipal sewage sludge.

5.9.10 Cost Analysis

No land costs were incurred since the landowners agreed to accept the sewage sludge. Capital costs included: transportation vehicle, application vehicle, sludge-loading apparatus with pumps, pipes, concrete pad, electrical controls, and storage facilities. Annual costs for this system were estimated to be $110/dry t ($98/dry T), as compared to $128/dry t ($116/dry T) for landfilling the sludge at a site 25 km (15.5 m) from the wastewater treatment facility.

5.9.11 Final Site Selection

The 175 ha (432 ac) of best quality land were distributed over seven individual fields, several of which were not serviced by all-weather roads. These fields would only be used if complicating factors (e.g., field or crop conditions) rendered the other fields unusable. The contractual agreement with the three individuals specified that sewage sludge would be land applied to certain fields (to be determined at owner discretion) at rates commensurate with crop nitrogen requirements and in compliance with the Part 503 pollutant limits for metals and other Part 503, state, and local regulatory requirements.

5.10 References

When an NTIS number is cited in a reference, that document is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-487-4650

Culp, G., J. Faisst, D. Hinricks, and B. Winsor. 1980. Evaluation of sludge management systems: Evaluation checklist and supporting commentary. EPA/430/9-80/001 (PB81108805). Cul/Wesner/Culp, El Dorado Hills, CA.

Deese, P., J. Miyares, and S. Fogel. 1980. Institutional constraints and public acceptance barriers to utilization of municipal wastewater and sludge for land reclamation and biomass production: A report to the president’s council on environmental quality. (EPA 430/9-81-013; July 1981).

Keeney, D., K. Lee, and L. Walsh. 1975. Guidelines for the application of wastewater sludge to agricultural land in wisconsin. Technical Bulletin 88, Wisconsin Department of Natural Resources, Madison, WI.

Sagik, B., B. Moore, and C. Forber. 1979. Public health aspects related to the land application of municipal sewage effluents and sludges. In: Sopper, W.E., and S.M. Kerr, eds. Utilization of municipal sewage effluent and sludge on forest and disturbed land. Pennsylvania State University Press, University Park, PA. pp. 241-263.

U.S. EPA. 1995. Process design manual: Surface disposal of sewage sludge and domestic septage. EPA/625/R-95/002. Cincinnati, OH.

U.S. EPA. 1984. Environmental regulations and technology: Use and disposal of municipal wastewater sludge. EPA/625/10-84-003. Washington, DC.

Chapter 6
Phase II Site Evaluation

6.1 General

The Phase I site evaluation and screening process described in Chapter 5 will usually identify a number of candidate sites for land application of sewage sludge that require more detailed investigation before final site selection. The extent and type of information gathered in field investigations for a Phase II site evaluation will vary depending on:

- Land application practice being considered, e.g., agricultural, forest, or land reclamation.
- Regulatory requirements.
- Completeness and suitability of information on soils, topography, and hydrogeology obtained from other sources (e.g., the SCS, USGS, etc).

General site characteristics can be obtained from a combination of soil survey maps and site visits. The principal soil chemical analyses required are soil tests which are routinely conducted to develop recommendations for application of conventional fertilizer materials. Table 6-1 provides a summary of the site-specific information required for different land application practices. This information is of a general nature and can usually be obtained from site visits without field sampling and testing. Review of this information may eliminate some potential sites from further consideration.

Table 6-1. Basic Site-Specific Information Needed for Land Application of Sewage Sludge

Property Ownership

Physical Dimensions of Site
- a. Overall boundaries
- b. Portion usable for sludge land application under constraints of topography, buffer zones, etc.

Current Land Use

Planned Future Land Use

If Agricultural Crops Are To Be Grown:
- a. Cropping patterns
- b. Typical yields
- c. Methods and quantity of fertilizer application
- d. Methods of soil tillage
- e. Irrigation practices, if any
- f. Final use of crop grown (animal/human consumption, non-food chain, etc.)
- g. Vehicular access within site

If Forest Land:
- a. Age of trees
- b. Species of trees
- c. Commercial or recreational operation
- d. Current fertilizer application
- e. Irrigation practices
- f. Vehicular access within site

If Reclamation Site:
- a. Existing vegetation
- b. Historical causes of disturbance (e.g., strip mining of coal, dumping of mine tailings, etc.)
- c. Previous attempts at reclamation, if any
- d. Need for terrain modification

Surface/Ground Water Conditions
- a. Location and depth of wells, if any
- b. Location of surface water (occasional and permanent)
- c. History of flooding and drainage problems
- d. Seasonal fluctuation of ground water level
- e. Quality and users of ground water

6.2 Preliminary Field Site Survey

A field site survey should be conducted after potential sites have been identified in the map study performed during the Phase I site evaluation. A drive or walk through the candidate areas should verify or provide additional information on:

- Topography. Estimate of slope both on prospective site and adjacent plots.
- Drainage. Open or closed drainage patterns.
- Distance to surface water.
- Distance to water supply well(s).
- Available access roads. All-weather or temporary.
- Existing vegetation/cropping.

A field survey form similar to the one shown in Table 6-2 that records the current condition of all critical factors is recommended. The data collected from various sites can then be used to update the map overlay (see Chapter 5). The appropriate additional information for different land uses in Table 6-1 (agricultural crops, forest land, reclamation sites) should also be gathered.

Table 6-2. Sample Form for Preliminary Field Site Survey

A. PROPERTY LOCATION ____________ PROPERTY OWNER ____________

B. TOPOGRAPHY
1. Relief (sharp, flat, etc.) ____________
2. Slope Estimate ____________
3. Drainage Patterns
- Open/Closed ____________
- Drainage Class No.* ____________
- Any Underdrains ____________

C. DISTANCE FROM SITE BOUNDARY TO:
1. Surface Water ____________
2. Water Supply Well ____________

D. ESTIMATE OF SITE DIMENSIONS
1. Area ____________
2. Natural Boundaries ____________
3. Fences ____________

E. AVAILABLE ACCESS
1. Road Types ____________
2. Other ____________

F. EXISTING VEGETATION/CROPS AND COMMONLY USED CROP ROTATIONS
1. On-Site ____________
2. Neighboring Properties ____________

G. SOIL
1. Texture ____________
2. Variability ____________

*Refer to Soil Conservation Service drainage classes.

6.3 Site-Specific Field Investigations

This section focuses on basic field investigation methods applicable to agricultural and forest land application sites, which typically encompass areas of tens to hundreds of hectares, but for which detailed maps (1:6,000 or less) generally are not available. In general, active reclamation sites often have detailed maps and extensive environmental data that have been prepared and collected as part of the permitting process, so specific additional information for determining sewage sludge application rates may not be required. Section 6.5 discusses special considerations related to investigation of reclamation sites involving abandoned land.

Where land application of bulk sewage sludge is being considered for public contact sites, such as parks, detailed site maps may be available that can be used for the type of investigations described here. Otherwise, field investigation procedures described in this section are applicable. Application of bagged sewage sludge on public contact sites, lawns, and home gardens will not require site-specific field investigations.

6.3.1 Base Map Preparation

Major types of commonly available maps that contain useful information for site field investigations include (1) U.S. Geological Survey (USGS) 7.5 minute topographic maps (scale 1:24,000), (2) published Soil Conservation Service (SCS) soil survey maps (which usually range in scale from 1:15,000 to 1:20,000), (3) Federal Emergency Management Agency (FEMA) floodplain maps, and (4) U.S. Fish and Wildlife Service National Wetland Inventory Maps.

Site boundaries from a recent survey or County records should be located as accurately as possible on all maps that have been collected for the site. The accuracy of points on a USGS 7.5 minute quadrangle map (about plus or minus 50 feet) is generally not sufficient for detailed site evaluation for sewage sludge land application, but the expense of preparing a larger scale topographic base map will usually not be justified. Enlarging the area of a topographic map that includes the site of interest using a copy machine is the simplest way to obtain a larger scale working map for field investigations. The same can be done for a soil map of the area, if available. The original scale bars of the map should be included or enlarged separately so that the actual scale of the enlarged map can be determined. Information from other maps, such as flood plain boundaries, should also be transferred to the working base map. Another way to obtain a larger scale topographic base map, if the computer equipment and software are available, is to obtain the appropriate USGS map in digital format, which then can be used to print a base map of the desired area and scale.

6.3.2 Field Checking of Surface Features and Marking Buffer Zones on the Base Map

Key point and linear surface features on the base map that should be added or checked in the field include: (1) location of surface water features (springs, intermittent and perennial surface streams, ponds and streams); (2) location of ground water wells, and (3) location of residences, other buildings, public roads, fencelines and other man-made features. Accuracy of surface features on the enlarged base map can be checked by first measuring distances between points on the map that can be easily located in the field, and then measuring the actual distance. For example, measuring the distance of a site corner by a roadway from the point that a stream crosses the site boundary at the road is relatively easy to measure in the field by pacing or using a 100-ft tape measure. Any major features that are not within about 10 feet of the marked location on the enlarged topographic base map should be redrawn. Also, any significant surface features that are not on the base map should be added.

The field-checked and revised base map allows reasonably accurate delineation of any buffer zones where sewage sludge should not be applied. The Part 503 rule specifies a minimum buffer of 10 meters from surface waters at a land application site unless otherwise specified by the permitting authority. Many states specify larger buffers to surface waters and may specify buffers to wells, dwellings, property lines, and other features. Any applicable setback distances should be marked on the field-checked base map.

6.3.3 Identifying Topographic Limitations

Many state regulatory programs define slope grade limits for land application of sewage sludge that may vary according to the type of land use (e.g., agricultural, forest, or reclamation site) and method of application (Table 5-8). The appropriate regulatory authority should be contacted to identify any slope limitations that might apply to the site. An SCS soil survey (see Section 6.3.4) is the easiest way to identify areas with similar slope ranges because soil map units are usually differentiated according to slope classes. Soil map units with slopes that exceed the applicable limitations should be marked as potentially unsuitable areas before going into the field. Depending on the type of soil or application method (e.g., surface application, incorporation, or injection), different slopes may be appropriate. Areas with differing slope limits should be identified on the same map; alternatively, separate maps may be developed that identify potentially unsuitable areas because of differing slope limitations.

The above map(s) needs to be taken into the field to check the accuracy of the boundaries separating suitable and unsuitable areas based on slope. In most situations, spot checking of actual slope gradients using a clinometer and a surveyor's rod will be adequate (Boulding, 1994 and U.S. EPA, 1991 describe this procedure in more detail). Such field checking is likely to result in slight to moderate adjustments to the boundaries delineating areas with unsuitable slopes. The field-checked topographic boundaries should be marked on the enlarged topographic base map described in Section 6.3.1.

6.3.4 Field Soil Survey

If available, a county soil survey published by the SCS is the best single source of information about a site because it also provides an indication of subsurface geologic and hydrogeologic conditions and contains a wealth of information on typical soil physical and chemical characteristics. If a soil survey is not available, check to see if the current or previous property owners have worked with the local Soil and Water Conservation District. If so, an unpublished farm survey may be on file in the District SCS office. If an unpublished soil survey is available, SCS soil series descriptions and interpretation sheets should be obtained for all soil series that have been mapped in the area (see Table 6-3). Estimated soil properties are typically given as ranges or values for different soil horizons; direct field observation and sampling are required for more accurate definition of soil properties. Even if a published soil survey is available,

Table 6-3. Types of Data Available on SCS Soil Series Description and Interpretation Sheets

Soil Series Description Sheet

Taxonomic Class
Typical soil profile description
Range of characteristics
Competing series
Geographic setting
Geographically associated soils
Drainage and permeability
Use and vegetation
Distribution and extent
Location and year series was established
Remarks
Availability of additional data

Soil Survey Interpretation Sheet*

Estimated Soil Properties (major horizons)
- *Texture class* (USDA, Unified, and AASHTO)
- *Particle size distribution*
- Liquid limit
- Plasticity index
- Moist bulk density (g/cm^3)
- *Permeability (in/hr)*
- *Available water capacity (in/in)*
- Soil reaction (pH)
- Salinity (mmhos/cm)
- Sodium absorbtion ratio
- *Cation exchange capacity (Me/100g)*
- Calcium carbonate (%)
- Gypsum (%)
- *Organic matter (%)*
- Shrink-swell potential
- Corrosivity (steel and concrete)
- Erosion factors (K, T)
- Wind erodability group
- *Flooding (frequency, duration, months)*
- *High water table (depth, kind, months)*
- *Cemented pan (depth, hardness)*
- *Bedrock (depth, hardness)*
- Subsidence (initial, total)
- *Hydrologic group*
- Potential frost action

Use/Suitability Ratings
- Sanitary facilities
- Source material
- Community development
- Water management
- Recreation
- Crop/pasture capability and predicted yields
- Woodland suitability
- Windbreaks (recommended species for planting)
- Wildlife habitat suitability
- Potential native plant community (rangeland or forest)

* Units indicated are those used by SCS.

Note: Italicized entries are particularly useful for evaluating contaminant transport.

these sheets provide a convenient reference for characteristics of soil series occurring within a site. The same information on individual soil series can be found in the text portion of an SCS soil survey, but is scattered through different sections and tables in the report.

Although published soil surveys provide much useful information for preliminary site selection, they may not be adequate for site-specific evaluation for land application of sewage sludge. For example, areas of similar soils that cover less than 4 or 5 acres are generally not shown on published SCS county soil surveys. For site-specific evaluation and design purposes, it is desirable to identify areas of similar soil characteristics that are as small as an acre. The SCS may be able to prepare a more detailed soil survey of a site that has been selected for land application of sewage sludge. If SCS has a large backlog of requests, however, obtaining a more detailed soil survey can take months. A detailed soil survey prepared by consulting soil scientists will be more expensive, but will usually involve less delay. If a private consultant conducts the soil survey, the person or persons actually carrying out the survey should be trained in soil mapping and classification methods used by SCS for the National Cooperative Soil Survey.

Field checking of soil map unit boundaries and delineation of smaller units omitted from an existing SCS soil survey can be done using an enlarged soil map, as described for the topographic base map in Section 6.3.1. Alternatively, revised soil map unit delineations or new mapping can be done directly on the working topographic base map. An added benefit of more detailed soil mapping at a site is that it will also provide additional site-specific information for delineation of floodplains and wetlands (Section 6.3.5), and for hydrogeologic interpretations where ground-water is relatively shallow (Section 6.3.6). The soil survey will also be helpful in planning soil sampling for designing agronomic rates of sewage sludge application (Section 6.4).

6.3.5 Delineation of Floodplains and Wetlands

Some state regulatory programs place restrictions or limitations on land application of sewage sludge on or near floodplains and wetlands. State floodplain restrictions vary, ranging from prohibition of application on the 10-year or 100-year floodplain, to conditions on placement within a floodplain (e.g., incorporation within 48 hours, use of diversion dikes or other protective measures). Floodplains can be easily identified as low-lying areas adjacent to streams on topographic maps and as alluvial soils adjacent to streams on soil maps. FEMA maps should be consulted to determine whether a site includes a 100-year floodplain. Accurate delineation of floodplain boundaries requires detailed engineering and hydrologic studies. The appropriate regulatory agency should be consulted to determine whether such detailed investigations are required, and, if so, to identify recommended procedures.

Wetlands include swamps, marshes, bogs, and any areas that are inundated or saturated by ground water or surface water at a frequency and duration to support a dominant vegetation adapted to saturated soil conditions. As with floodplains, an SCS soil survey will indicate whether “hydric” soils are present at a site (e.g., soils that are wet long enough to periodically produce anaerobic conditions). If wetlands are present at a site, the appropriate regulatory agency should be contacted to determine whether their boundaries should be accurately delineated.

Accurate wetland delineation typically requires assessment by a qualified and experienced expert in soil science and botany/biology to identify: (1) the limits of the wetland boundary based on hydrology, soil types, and plants types; (2) the type and relative abundance of vegetation, including trees; and (3) rare, endangered, or otherwise protected species and their habitats, if present. Many methods have been developed for assessing wetlands. The main guidance manuals for wetland delineation for regulatory purposes are the *Corps of Engineers Wetlands Delineation Manual* (U.S. Army Corps of Engineers, 1987) and the *Federal Manual for Identifying and Delineating Jurisdictional Wetlands* (Federal Interagency Committee for Wetland Delineation, 1989). The latter manual places greater emphasis on assessment of the functional value of wetlands, along the lines of earlier work by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service, 1984).

6.3.6 Site Hydrogeology

The Part 503 rule does not explicitly require investigations to characterize ground-water hydrology at sewage sludge land application sites but does require that sewage sludge be land applied at the agronomic rate for N for the crop or vegetation being grown. As discussed in Section 6.4.1 on agronomic rates, some knowledge of depth to ground water is useful when selecting appropriate sites. Tables 5-9 and 5-10 contain general guidelines for depth to ground water at land application sites. Most states have established their own requirements for minimum depths to ground water for sewage sludge land application sites, which range from 1 ft to 6 ft. Also, a number of states restrict application on highly permeable and/or very slowly permeable soils.

The field soil survey described in Section 6.3.4 will provide the necessary information on depth to ground water for most sites. The published soil survey report or soil series interpretation sheet will indicate typical depths to seasonal high water table and also expected ranges of permeability for each major soil horizon. If significant areas of the site have relatively shallow water tables (<3 feet), it may be desirable to prepare a more detailed depth-to-water-table map based on soil morphology, as described below. Soils with very high or very slow permeability, as indicated by the soil survey, should be eliminated as areas for land application of sewage sludge, if possible. If elimination of such areas places too great a restriction on suitable areas for land application, it may be necessary to conduct field infiltration and permeability tests to determine whether areas of these soils may be suitable.

6.4 Soil Sampling and Analysis to Determine Agronomic Rates

6.4.1 Part 503 Definition of Agronomic Rate

Designing the agronomic rate for land application of sewage sludge is one of the key elements in the Part 503 rule for ensuring that land application does not degrade ground water quality through nitrate contamination. The Part 503 rule defines *agronomic rate* as:

> the whole sludge application rate (dry weight basis) designed: (1) to provide the amount of nitrogen needed by the food crop, feed crop, fiber crop, cover crop, or vegetation grown on the land and (2) to minimize the amount of nitrogen in the sewage sludge that passes below the root zone of the crop or vegetation grown on the land to the ground water. (40 CFR 503.11(b))

Designing the agronomic rate for a particular area requires knowledge of (1) soil fertility, especially available N and P; and (2) characteristics of the sewage sludge, especially amount and forms of N (organic N, NH_4, and NO_3). The complex interactions between these factors and climatic variability (which affects soil-moisture related N transformations) make precise prediction of crop N requirements difficult.

Nitrogen fertilizer recommendations have historically been based primarily on experience from replicated field trials of crop response on different soil types and management practices. Nitrogen fertilizer recommendations based on such studies often vary regionally. The high organic N content of sewage sludge, which becomes available for plant uptake over a period of years as it is gradually mineralized, requires an approximate mass balance that accounts for N needs of the crop, availability of N in the sewage sludge and the soil, and losses (such as volatilization and denitrification).

Chapter 7 and Chapter 8 address in detail mass balance methods for designing agronomic rates at agricultural and forest sites.

6.4.2 Soil Sampling

Soil sampling and analysis will usually not be needed at land application sites until the site has been selected and it is time to calculate sewage sludge application rates. Soil sample collection procedures are described in Chapter 13. The types of analyses performed on soil samples will vary somewhat depending on the crop and state regulatory requirements. Major constituents that may need to be tested include:

- NO_3-N as an indicator of plant-available N in the soil. NO_3 root zone profiles are widely used in states west of the Missouri River where precipitation and leaching are relatively low (Keeney, 1982). The pre-sidedress nitrate test (PSNT), where soil NO_3-N is sampled to a depth of 0.3 to 0.6 m prior to corn planting or in early June, has been found to be a good indicator of plant-available N in humid areas (Magdoff et al., 1984; Sander et al., 1994). Where applicable, these tests should be made for calculating initial sewage sludge application rates, and can possibly be used in subsequent years as a more accurate alternative to the equations in Chapters 7 and 8 for estimating N mineralization rates. Chapter 13 discusses these tests in more detail.
- C:N ratio, which provides an indication of the potential for immobilization of N in sewage sludge as a result of decomposition of plant residues in the soil and at the soil surface. This is especially relevant for forest land application sites, as discussed in Chapter 8.
- Plant-available P. Where sewage sludge is applied at rates to supply plant N needs, this test is less critical. This test is essential, however, if sewage sludge application rates are to be based on plant P requirements (see Chapter 7).
- Plant-available K. This is required to determine supplemental K fertilization needs for optimum plant growth.
- Soil pH and pH (e.g., lime) adjustments. A soil pH of approximately 6.5 maximizes the availability of soil nutrients to plants and immobilization of trace metals. Where soil pH is lower than 6.5, lime or other alkali amendments are often added to the soil to bring pH to the desired level.

6.5 Special Considerations for Reclamation Sites

At reclamation sites involving abandoned mined land, field investigations to characterize ground-water distribution and quality are usually required. The detailed site investigation should determine the following:

- Depth to ground water, including seasonal variations
- Quality of existing ground water
- Present and potential future use of ground water
- Existence of perched water
- Direction of ground water flow

6.5.1 Sampling and Analysis of Disturbed Soils

Sampling and analysis of soils at reclamation sites are necessary to:

- Establish sewage sludge application rates (typically for a single or several [e.g., three] application(s) at reclamation sites).
- Determine amounts of supplemental fertilizer, lime, or other soil amendment required to obtain desired vegetative growth.
- Determine the infiltration and permeability characteristics of the soil.
- Determine background soil pH, metals, nutrients, etc., prior to sewage sludge application.

Soil survey maps will usually provide only an idea of the type of soil present prior to the disturbance. Often, the only soil profile present on a surface-mined site is the mixture of soil and geologic materials, and the physical and chemical characteristics of the mixture can vary greatly over relatively short distances. A field inspection will need to be made to determine the number and location of samples necessary to characterize the materials. The specific analyses needed may vary from location to location based on state and local regulations covering both the reclamation and sewage sludge land application aspects. Chapter 13 describes disturbed soil sampling procedures further.

Nitrogen and phosphorus are generally deficient on disturbed lands, and phosphorus is often the most limiting fertility factor in plant establishment on drastically disturbed land (Berg, 1978). Soil tests used for P analysis reflect the chemistry of soils, and thus are more regionalized than tests for other major nutrients. A number of soil tests have been developed for use on acid soils in the eastern United States and on neutral and calcareous soils in the west. Drastically disturbed lands, however, do not always reflect the local soils. Thus, if disturbed spoil material is going to be analyzed for P, the local routine analysis procedure may not be appropriate, and other P analyses might be required. Recommendations should be obtained from the local agricultural experiment station. Testing for pH requires sufficient sampling of surface soils to characterize variations in pH; coring may be required to identify any subsurface distribution of toxic or acid-forming spoil material.

6.6 References

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Chapter 7
Process Design for Agricultural Land Application Sites

7.1 General

Agricultural land is the type of land most widely used for the application of sewage sludge. This chapter presents detailed design information for the application of sewage sludge to agricultural land, placing primary emphasis on the growing of crops such as corn, soybeans, small grains, cotton, sorghum, and forages. The design example presented at the end of this chapter assumes that the designer has (1) selected agricultural land application; (2) completed preliminary planning (see Chapter 5); and (3) chosen a transportation system to convey sewage sludge to the application site (see Chapter 14).

The design approach presented in this chapter is based on the use of sewage sludge as a low-nutrient fertilizing material that can partially replace commercial fertilizers. The goal of this approach is to optimize crop yields through applications of both sewage sludge and supplemental fertilizers, if needed. The sewage sludge application rate is typically designed for either the nitrogen (N) or phosphorus (P) needs of the crop grown on a particular soil. In addition, the sewage sludge application rate must be consistent with federal, state, and local regulations relative to pathogens, metals, and organics contained in the sewage sludge and related requirements for vector attraction reduction.

The design example presented at the end of this chapter also assumes that basic sewage sludge and crop production information has been collected. The sewage sludge composition data needed to meet regulatory requirements and ensure good design are described in Chapter 4.

Other concerns regarding agricultural land application include the possibility of odors or potential exposure to pathogens due to inadequate sewage sludge treatment or poor site management. The design approach described in this chapter assumes that the sludge has been properly stabilized to meet pathogen and vector attraction reduction requirements and reduce odor potential.

Community acceptance of a land application project will be more readily forthcoming if local participation is assured. The initial task for obtaining public support begins with the selection of a project team whose members can offer technical service and expertise (see Chapter 12).

Information must also be available on the types of crops to be grown, attainable yield level, and the relationship between soil fertility tests and recommended fertilizer application rates. The overall goal is to develop a nutrient management plan for the use of sewage sludge and fertilizer to meet the nutrient needs of the crop to be grown.

7.2 Regulatory Requirements and Other Considerations

Chapter 3 presents the requirements specified by the federal Part 503 regulation. When designing a land application system, check with state and local agencies to learn about any other requirements that must be met. Information on other key design considerations, such as nutrients, pH, and land application of sewage sludge on arid lands, is discussed below.

7.2.1 Nitrogen and Other Nutrients

7.2.1.1 Nitrogen

Nitrogen is the nutrient required in the largest amounts by all crops. The addition of N to soils in excess of crop needs results in the potential for NO_3-N contamination of ground water because NO_3-N is not readily adsorbed by soil particles and will move downward as water percolates through the soil profile. Whether excess N is applied by sewage sludge or from excessive applications of animal manures or conventional N fertilizer materials, an increased risk of NO_3-N loss to ground water may occur, depending on climate or crop production practices. High NO_3-N levels in water supplies may result in health problems for both infants and livestock (Reed et al., 1994). The maximum allowable concentration of NO_3-N in drinking water has been established at 10 mg/L NO_3-N.

To prevent ground-water contamination by NO_3-N, the Part 503 rule requires that bulk sewage sludge be applied to a site at a rate that is equal to or less than the agronomic rate for N at the site. This is the rate that is designed to provide the amount of N needed by the crop while minimizing the amount of N in the sewage sludge that will pass below the root zone of the crop to the ground water. The factors that must be considered in deriving the agronomic application rate for a crop site include, but are not limited to:

- The amount of N needed by the crop or vegetation grown on the land.
- The amount of plant-available N remaining from previous applications of N-containing materials (e.g., fertilizers, irrigation water, animal manure, sewage sludge).
- The amount of organic N that is mineralized and becomes available each year from previous applications of N-containing materials (e.g., sewage sludge, animal manure).
- The amount of N left from biological N fixation by leguminous crops that is mineralized and becomes available for crops to use (i.e., legume credit).
- The type of soil at the site and the amount of N mineralized from soil organic matter.
- Denitrification losses of NO_3-N and/or volatilization losses of ammonia.
- Any other identifiable sources or losses of N.

The design example in Section 7.5 illustrates the process for calculating the agronomic rate.

7.2.1.2 Phosphorus

For most sewage sludge, applying sufficient sludge to meet all the crop's N needs will supply more P than needed (Jacobs et al., 1993). Phosphorus does not usually present a ground-water pollution concern. Some states limit sludge application to cropland based on P loading to protect surface water quality. Section 7.4.4.2 and 7.5.3 discuss sewage sludge application rates limited by P.

7.2.1.3 Other Nutrients

Sewage sludge application can be a source of micronutrients that are important for plant growth, such as iron (Fe), manganese (Mn), and zinc (Zn). But because sewage sludge does not contain balanced amounts of nutrients, an understanding of agronomy and crop production practices is important to prevent possible disruption of soil fertility and plant nutrition when sludge is applied to crops (Jacobs et al., 1993). For example, at an agricultural site in Virginia, addition of lime-treated sludge raised the soil pH to 7.5, resulting in manganese deficiency in soybeans. The problem was corrected by application of Mn to foliage, and the POTW eliminated lime conditioning to prevent excessive elevation of soil pH caused by sewage sludge applications (Jacobs et al., 1993).

7.2.2 Soil pH and Requirements for pH Adjustment

Some states require that soils treated with sludge be maintained at a pH of 6.5 or above to minimize the uptake of metals by crops based on previous EPA guidance. The federal Part 503 regulation does not require a minimum pH of soil because pH was factored into the risk assessment on which the regulation was based (U.S. EPA, 1992). In addition, at least one review of the literature on how soil pH influences the uptake of metals suggests that the recommendation of pH 6.5 should be reconsidered for food-chain agricultural soils, based on reports that indicate adequate control of metals uptake at pH 6.0 (Sommers et al., 1987). As discussed above (Section 7.2.1.3), proper management of soil pH also is important for good nutrient availability and crop growth.

Soil pH control has been practiced routinely in those areas of the United States where leguminous crops (e.g., clover, alfalfa, peas, beans) are grown. Fortunately, limestone deposits are normally abundant in these regions, resulting in minimal costs associated with liming soils. Considerable cost, however, may be associated with liming soils in other areas of the United States (e.g., eastern and southeastern states). Soils in these regions tend to be naturally acidic, and may require relatively large amounts of limestone (12 to 20 t/ha, or 5 to 8 tons/ac [T/ac]) to maintain a proper soil pH. In addition, the trend toward increased growth of cash grain crops (corn, small grains) has resulted in greater commercial fertilizer use, which generates acidity that can decrease soil pH.

While maintaining soil pH between 6.5 and 7.0 often is desirable for optimum availability of essential plant nutrients, liming soils is not always necessary to achieve desired crop growth. For example, excellent yields of corn, soybeans, and wheat can be obtained at a soil pH of 5.5 to 6.0. Many soils in most of the western United States contain free calcium carbonate, which naturally maintains a pH of about 8.3. For these types of soils, trace element deficiencies rather than toxicities are a major concern. Therefore, the best advice is to involve agronomic expertise to help manage soil pH at the recommended levels for soils and crops in your state or area.

Soil pH is buffered by inorganic and organic colloids. Thus, it does not increase immediately after limestone applications, nor does it decrease soon after sewage sludge or N fertilizer additions. If soil pH is less than the desired level, a lime requirement test can be used to estimate the amount of agricultural limestone required to adjust the pH. Soil pH monitoring is discussed further in Chapter 13.

7.2.3 Special Considerations for Arid Lands

7.2.3.1 Crop Land

In arid regions (all U.S. lands west of the 100th meridian, with less than 20 inches of rain annually), sewage sludge additions can be a significant source of nutrients and organic matter. Sludge application can often improve soil physical properties such as water-holding capacity, infiltration, and aeration (Burkhardt et al., 1993). Sludge application can also increase the protein content of crops such as winter wheat compared to sites receiving commercial N fertilizer (Ippolito et al., 1992).

In arid and semi-arid climates, evapotranspiration exceeds precipitation, minimizing downward migration of NO_3-N. In low-rainfall and irrigated areas, sewage sludge constituents such as soluble salts and boron (B) should also be considered when determining sludge application rates. High concentrations of salt in the plow layer can impair germination and early seedling growth (Jacobs et al., 1993). Excessive salt can also cause soil dispersion, reducing water infiltration rates and soil aeration and causing soil structure changes that make tilling more difficult (Jacobs et al., 1993).

Generally, additions of salts by sewage sludge applications at agronomic rates will be low enough to avoid any salt injury to crops. In dry climates, however, sewage sludge can be a source of additional salts to the soil-plant system, as can other fertilizers, manures, etc. Salt sources must be properly managed if optimum crop growth is to be achieved. Therefore, guidance from land grant universities or other local sources of agronomic information should be sought to help manage soluble salt levels in soils.

7.2.3.2 Rangeland

Application of sewage sludge to rangeland (open land with indigenous vegetation) is considered agricultural land application under the Part 503 regulation. Much of the arid and semiarid rangelands in the western and southwestern United States have been degraded by overgrazing, fires, wind erosion, and single resource management practices. Sewage sludge application to these lands can enhance the soil and vegetation (Aguilar et al., 1994). Benefits can include increased rangeland productivity; improved forage quality; increased rainfall absorption and soil moisture; reduced runoff; increased germination and populations of favorable grasses; less competition from invading shrubs and weeds; and decreased erosion potential (Fresquez et al., 1990; Pierce et al., 1992; Peterson and Madison, 1992). In addition, the remote locations of most arid rangeland sites minimizes public concerns about odors, vectors, and traffic. Table 7-1 describes projects in which sewage sludge was applied to arid rangelands.

As Table 7-1 shows, various studies concur that sewage sludge application to rangelands can improve plant productivity without adversely impacting the environment. The studies vary, however, regarding what application rates of sewage sludge are optimum to use. A study in Fort Collins, Colorado, reported that an application rate of 4.5 mg/ha (2 dry T/ac) would enhance vegetative growth with minimum excess NO_3-N concentrations in soil (RDB and CDM, 1994), and also indicated that N levels in soil did not increase at a soil depth of 12 inches as application rates increased (Gallier et al., 1993). A study in the Rio Puerco Watershed in New Mexico indicated that leaching from saturated flow would not be expected to occur below 1.5 m (5 ft) in similar soils in this semiarid environment (Aguilar and Aldon, 1991). Another study in Wolcott, Colorado, reported potential NO_3-N in surface water runoff at application rates above 20 mg/ha (9 dry T/ac), while a study at the Sevilleta National Wildlife Refuge in New Mexico reported a reduction in surface water runoff at an application rate of 45 mg/ha (20 dry T/ac), with NO_3-N, copper (Cu), and cadmium (Cd) concentrations in the runoff below state limits for ground water and for livestock and wildlife watering areas (Aguilar and Aldon, 1991).

A key to successful sewage sludge application on arid rangelands is minimizing the disturbance of soil and vegetation. Once the plant cover is disturbed, recovery is very slow in the arid conditions, leaving the rangeland vulnerable to erosion and weed invasion (Burkhardt et al., 1993). Section 7.3.1 below discusses sludge application methods suitable for arid rangelands.

7.3 Application Methods and Scheduling

7.3.1 Application Methods

Methods of sewage sludge application chosen for agricultural land depend on the physical characteristics of the sludge and soil, as well as the types of crops grown. Liquid sewage sludge can be applied by surface spreading or subsurface injection. Surface application methods include spreading by farm tractors, tank wagons, special applicator vehicles equipped with flotation tires, tank trucks, portable or fixed irrigation systems, and ridge and furrow irrigation.

Surface application of liquid sludge by tank trucks and applicator vehicles is the most common method used for agricultural croplands, particularly when forage crops are grown. Surface application of liquid sludge is normally limited to soils with less than a 6 percent slope. After the sludge has been applied to the soil surface and allowed to partially dry, it is commonly incorporated by plowing or other tillage options prior to planting the crop (i.e., corn, soybeans, small grains, cotton, other row crops), unless minimum or no-till systems are being used. Ridge and furrow irrigation systems can be designed to

Table 7-1. Summary of Research on Sewage Sludge Application to Rangeland (Adapted From U.S. EPA, 1993)

Geographic Location	Plant Community	Mean Precip. (cm/yr)	Sludge Loading (mg/ha, dry)	Significant Results of Study
Wolcott, CO	western wheatgrass, alkali bluegrass, Indian ricegrass	25	0, 4.5, 9, 13, 18, 22, 27, 31, 36	Increase in species diversity with sewage sludge application. Increase in nitrogen concentration in soil profile with increasing application rates, but did not penetrate below 90 cm (about 3 ft). Application rates above 20 mg/ha (9 T/ac) pose a potential hazard for surface water contamination by nitrates (Gallier et al., 1993; Pierce, 1994).
Meadow Springs Ranch, Fort Collins, CO	blue grama, buffalo grass, western wheatgrass, fringed sage	38	0, 2.2, 4.5, 11, 22, 34	Maximum vegetative growth was obtained at an application rate of 11 mg/ha (5 T/ac). An application rate of 4.5 mg/ha (2 T/ac) of sewage sludge would increase vegetative growth and minimize excess nitrate concentrations in soil (RDB and CDM, 1994). Nitrogen levels in soil ceased to increase below 1 ft (Gallier et al., 1993).
Sevilleta National Wildlife Refuge, NM	blue grama, hairy grama	20-25	45	Reduction in runoff volumes due to increased water absorption and surface roughness resulting from sewage sludge application. Nitrate concentrations in runoff were well below recommended NM standard of 10 mg-N/l (Aguliar and Loftin, 1991; Aguilar et al, 1992).
Rio Puerco Watershed, NM	blue grama, snakeweed	25	0, 22.5, 45, 90	An increase of 2 to 3 fold in blue grama forage production was found for sludge applications of 45 and 90 mg/ha (20 and 40 T/ac). A decrease in snakeweed yield was found, allowing forage to increase (Fresquez et al., 1991). Sludge applications of 22.5 and 45 mg/ha (10 and 20 T/ac) produced the most favorable vegetative growth responses, whereas applications of 90 mg/ha (40 T/ac) did not significantly increase yield (Fresquez et al., 1990).

apply sewage sludge during the crop growing season. Spray irrigation systems generally should not be used to apply sludge to forages or to row crops during the growing season, although a light application to the stubble of a forage crop following a harvest is acceptable. The adherence of sludge to plant vegetation can have a detrimental effect on crop yields by reducing photosynthesis. In addition, spray irrigation tends to increase the potential for odor problems and reduces the aesthetics at the application site, both of which can lead to public acceptability problems.

Liquid sewage sludge can also be injected below the soil surface, and injection generally is the preferred method when gaining public acceptance. Available equipment includes tractor-drawn tank wagons with injection shanks (originally developed for liquid animal manures) and tank trucks fitted with flotation tires and injection shanks (developed for sludge application). Both types of equipment minimize odor problems and reduce ammonia volatilization by immediate mixing of soil and sludge. Sludge can be injected into soils with up to 12 percent slopes. Injection can be used either before planting or after harvesting most crops but is likely to be unacceptable for forages and sod production. Some injection shanks can damage the sod or forage stand and leave deep ruts in the field. Equipment with specialized injection shanks has been developed that will not damage the growth of forage and sod crops.

Dewatered sewage sludge can be applied to cropland by equipment similar to that used for applying animal manures, but more sophisticated equipment has been developed with high flotation tires and improved application design. Typically, the dewatered sludge will be surface-applied and then incorporated by plowing or another form of tillage. Incorporation, however, is not used when dewatered sludge is applied to growing forages or to minimum- or no-till land. Sewage sludge application methods, some of which can be used to meet Part 503 vector attraction reduction requirements (i.e., incorporation and injection), are discussed in greater detail in Chapter 14.

A number of agricultural land application programs using private farmland have found that soil compaction is an important concern of farmers (Jacobs et al., 1993). Therefore, care should be taken to manage the application equipment and methods (e.g., use wide-flotation tires, deep till the staging area following application) to prevent soil compaction (Jacobs et al., 1993).

Table 7-2. General Guide to Months Available for Sewage Sludge Application for Different Crops in North Central States[a]

Month	Corn	Soybeans	Cotton[c]	Forages[d]	Small Grains[b]	
					Winter	Spring
January	S[e]	S	S/I	S	C	S
February	S	S	S/I	S	C	S
March	S/I	S/I	S/I	S	C	S/I
April	S/I	S/I	P, S/I	C	C	P, S/I
May	P, S/I	P, S/I	C	C	C	C
June	C	P, S/I	C	H, S	C	C
July	C	C	C	H, S	H, S/I	H, S/I
August	C	C	C	H, S	S/I	S/I
September	C	H, S/I	C	S	S/I	S/I
October	H, S/I	S/I	S/I	H, S	P, S/I	S/I
November	S/I	S/I	S/I	S	C	S/I
December	S	S	S/I	S	C	S

[a] Application may not be allowed due to frozen, flooded, or snow-covered soils.
[b] Wheat, barley, oats, or rye.
[c] Cotton, only grown south of southern Missouri.
[d] Established legumes (alfalfa, clover, trefoil, etc.), grass (orchard grass, timothy, brome, reed canary grass, etc.), or legume-grass mixture.
[e] S = surface application
S/I = surface/incorporation application
C = growing crop present; application would damage crop
P = crop planted; land not available until after harvest
H = after crop harvested, land is available again; for forages (e.g., legumes and grass), availability is limited and application must be light so regrowth is not suffocated

On arid rangelands, it is important to minimize the disturbance of the soil surface and existing perennial plant cover. Examples of sewage sludge application to rangeland are shown in Table 7-1. Carlile et al. describe the following application method as one that can be used for arid rangelands:[1]

- Shred brush species with an agricultural shredder at a height that does not disturb underlying grass vegetation.
- Apply the sewage sludge uniformly over the soil surface with a tractor-drawn agricultural manure spreader.
- Pass over the land with a range dyker and roller to make small pits and slits in the soil without significantly disturbing the grass cover.

7.3.2 Scheduling

The timing of sewage sludge land applications must be scheduled around the tillage, planting, and harvesting operations for the crops grown and also can be influenced by crop, climate, and soil properties. Sewage sludge cannot be applied during periods of inclement weather. Table 7-2 presents a general guide regarding when surface and subsurface applications of sludge are possible for crops in the North Central States. Local land-grant universities, extension personnel, or others with agronomic expertise can provide similar information for each state or locality.

Under the Part 503 regulation, application of sewage sludge to agricultural land that is flooded, frozen, or snow-covered is not prohibited, but the applier must ensure that no sludge enters wetlands or surface waters (except as allowed in a Clean Water Act Section 402 or 404 permit). Soil moisture is a major consideration affecting the timing of sludge application. Traffic on wet soils during or immediately following heavy rainfalls may result in compaction and may leave deep ruts in the soil, making crop production difficult and reducing crop yields. Muddy soils also make vehicle operation difficult and can create public nuisances by carrying mud out of the field and onto roadways.

Split applications of sewage sludge may be required for rates of liquid sludge in excess of 4 to 7 t/ha (2 to 3 dry T/ac), depending on the percent solids content. Split application involves more than one application, each at a relatively low rate, to attain a higher total rate, when the soil cannot receive the volume of the higher rate at one time. For example, if a sludge contains 4 percent solids, the volume of sludge applied at a rate of 11 t/ha (5 dry T/ac) is approximately 114,000 L/ha (30,000 gal/ac, or about 1.1 acre inch [ac-in]). Application rates much above 0.3 ac-in at one time will likely result in runoff or ponding, depending on soil conditions (e.g., infiltration rate, water-holding capacity) and slopes.

[1] Carlile, B.L., R.E. Sosebee, B.B. Wester, and R. Zartman. Beneficial use of biosolids on arid and semi-arid rangeland. Draft report.

Thus, if rates such as 1.1 ac-in are desired, three or four separate applications will probably be needed.

Subsurface injection will minimize runoff from all soils and can be used on greater slopes. Injection application rates in one pass, however, are not much greater than rates with surface application. Injection should be made perpendicular to slopes to avoid having liquid sludge run downhill along the injection slits and pond at the bottom of the slopes. As with surface application, the drier the soil, the more liquid it will be able to absorb, thereby minimizing any movement downslope.

7.3.3 Storage

Storage facilities are required to hold sewage sludge during periods of inclement weather, equipment breakdown, frozen or snow-covered ground, or when land is unavailable due to growth of a crop. Liquid sewage sludge can be stored in digesters, tanks, lagoons, or drying beds; dewatered sewage sludge can be stockpiled. Volume requirements will depend on individual systems and climate and can be estimated from the following data:

- Sewage sludge volume and physical characteristics
- Climatic data
- Cropping data

Chapter 14 contains additional information on evaluating sludge storage needs.

Some states specify climatic restrictions when sewage sludge applications are prohibited (e.g., on days when more than 2.5 mm [0.1 in.] of rainfall occurs). For a specific site, the average number of days in each month with these or other weather conditions can be obtained from the National Climatic Center, NOAA, Asheville, North Carolina 28801, or from local sources.

Except for forages, sewage sludge application to cropland usually is limited to those months of the year when a crop is not present. The application schedule shown in Table 7-2 is a general guide for common crops in the North Central States; similar information can be obtained for other states, as discussed in Section 7.3.2. The availability of sites used to grow several different crops will help facilitate the application of sewage sludge throughout the year. For example, a number of fields containing forages, corn, and winter wheat would allow sludge application during nearly all months of the year.

7.4 Determining Sewage Sludge Application Rates for Agricultural Sites

Sewage sludge application rates are calculated from data on sludge composition, soil test information, N and P fertilizer needs of the crop grown, and concentrations of trace elements. In essence, this approach views sewage sludge as a substitute for conventional N or P fertilizers in crop production. The number of years that sewage sludge application may be limited, based on Part 503 cumulative pollutant loading rate limits for metals, is discussed below in Section 7.4.4.3.

The general approach for determining sewage sludge application rates on agricultural cropland can be summarized as follows:

- Nutrient requirements for the crop selected are based on yield level and soil test data. If sewage sludge has been applied in previous years, fertilizer recommendations are corrected for carry-over of nutrients added by previous sludge additions.
- Annual sewage sludge application rates are calculated based on N crop needs, P crop needs, and Part 503 annual pollutant loading rate limits, where applicable (bagged sludge).
- Supplemental fertilizer is determined from N, P, and K needed by the crop and amounts of N, P, and K provided by sewage sludge application.
- Sewage sludge applications are terminated when a Part 503 cumulative pollutant loading rate limit is reached if applicable (see Section 7.4.4.3 and Chapter 3).

The majority of sewage sludge contains roughly equal amounts of total N and P, while crop requirements for N are generally two to five times greater than those for P. A conservative approach for determining annual sewage sludge application rates would involve applying sewage sludge to meet the P rather than N needs of the crop. Some states require this approach, particularly when soil fertility test levels for P are high. With this approach, farmers would need to supplement sludge N additions with N fertilizer to achieve the expected crop yield.

7.4.1 Part 503 Agronomic Rate for N and Pollutant Limits for Metals

The Part 503 rule requires that sewage sludge be land applied at a rate that is equal to or less than the agronomic rate for N at the application site (i.e., the rate that will provide the amount of N needed by the crop or vegetation while minimizing the amount of N that passes through the root zone and enters the ground water). Additional Part 503 requirements include:

- Sewage sludge cannot be land applied unless the trace element (metal) concentrations in the sludge are below the Part 503 ceiling concentrations.
- The sewage sludge must meet either (1) the pollutant concentration limits specified in Table 3 of Part 503 or (2) the Part 503 cumulative pollutant loading rate (CPLR) limits for bulk sewage sludge or the annual pollutant loading rate (APLR) limits for bagged sewage

sludge (see Chapter 3). If the sewage sludge meets the pollutant concentration limits or APLR limits, Part 503 does not require metal loadings to be tracked.

- The sewage sludge must also meet required Part 503 pathogen reduction alternatives and vector attraction reduction options (see Chapter 3).

Generally, the agronomic rate is the limiting factor regarding application rates for sewage sludge rather than Part 503 pollutant limits. Only when a CPLR limit is being met and the cumulative loading rate at a site is approaching the CPLR limit will the Part 503 pollutant limits become the limiting factor for the sewage sludge application rate. Section 7.4.4.3 discusses how to calculate sewage sludge application rates based on the CPLRs. Because the Part 503 rule requires that the maximum annual application rates for bagged sewage sludge, based on APLRs, be clearly marked on each bag, calculation of the APLR is not covered here.

The general approach for calculating sewage sludge application rates in this manual requires developing as accurate a mass balance for N in the sewage sludge and soil-crop system as possible. Equations required for calculating a N mass balance are relatively simple; choosing reasonable input values for calculations, however, is more challenging. For initial calculations, "typical" and "suggested" values for all necessary parameters are provided in tables throughout the manual. Site-specific data or the best judgement of individuals familiar with the N dynamics of the soil-crop system at the site should always be used in preference to "typical" values. Particularly for large-scale projects, laboratory mineralization studies should be considered (see Chapter 13), using samples of the actual sewage sludge to be applied and soil materials from the site, because application rate calculations are quite sensitive to the assumed annual N mineralization percentage used.

7.4.2 Crop Selection and Nutrient Requirements

The crops grown in an area will influence the scheduling and methods of sewage sludge application. Utilizing the cropping systems already present will usually be advantageous, since these crops have evolved because of local soil, climatic, and economic conditions. Since sewage sludge applications typically are limited by the N requirements of the crop, high N-use crops, such as forages, corn, and soybeans, will minimize the amount of land needed and the costs associated with sludge transportation and application. However, applying sludge to meet N needs of crops will add excess P, and eventually rates may need to be reduced to manage sludge P additions. Therefore, not only is it good practice to use fields with a mixture of crops, but the prudent manager of a land application program will continue to identify additional land areas that can be held in reserve.

Fertilizer recommendations for crops are based on the nutrients needed to achieve the desired yield of the crop to be grown and the capacity of the soil to provide the recommended plant-available nutrients. The amounts of fertilizer N, P, and K required to attain a given crop yield have been determined experimentally for numerous soils in each region of the United States. Crop response to fertilizer nutrients added has been related to soil test levels for P, K, Mg, and several of the essential trace elements (Zn, Cu, Fe, Mn). Accurate measurement of plant-available N in soil is difficult and also dependent on climate. As a result, fertilizer N recommendations for a particular locality are usually developed using a combination of (1) guidelines developed by State Agricultural Experiment Stations and the Cooperative Extension Service, based on historical experience with crop yields on different soil types using different management practices; (2) soil test data; and (3) estimates of residual N carryover from previous applications of sewage sludge, animal manures, or nitrogen-fixing crops, such as alfalfa and soybeans.

As an illustration of the general approach used to determine nutrient needs, typical relationships between yield level, nitrogen required, soil test levels for plant-available P and K, and fertilizer requirements for P and K are shown in Tables 7-3 through 7-6 for various crops in the Midwest. The amounts of supplemental P and K needed by crops increase as the yield level increases for a fixed range of existing plant-available P and K in the soil. Conversely, fertilizer needs decrease at a specific yield level as soil test levels for P and K increase.

Data such as that presented in Table 7-7 can be used to estimate the amount of plant-available N that will be mineralized from sludge organic N applied initially and from organic N estimated to be remaining from previous sewage sludge applications. These estimates can then be used to adjust the fertilizer N recommendations for the crops to be grown. As has been discussed, however, the amounts of residual organic N from previous sludge applications that may be mineralized depend on many factors. Thus, guidance as to how to best estimate these quantities of mineralizable N, as well as information on fertilizer recommendations, should be obtained from the Agricultural Experiment Stations and Extension Service of land-grant universities.

7.4.3 Calculating Residual N, P, and K

When sewage sludge is applied to soil each year, the N, P, and K added in previous years that are not taken up by crops can be partially available during the current cropping season. Sewage sludge applied at a rate to meet the N needs of a crop typically will result in increased soil P levels. Application of sewage sludge containing high K levels could increase soil K, although

Table 7-3. Representative Fertilizer Recommendations for Corn and Grain Sorghum in the Midwest

Yield (Metric tons/ha)	Nitrogen To Be Applied (kg/ha)	Fertilizer	Fertilizer P (P_2O_5) and K (K_2O) Recommended for Soil Fertility* †				
			Very Low	Low	Medium	High	Very High
			(kg/ha)				
6.7-7.4	134	P (P_2O_5):	49 (113)	35 (80)	25 (56)	15 (33)	0
		K (K_2O):	93 (112)	65 (78)	47 (57)	28 (34)	0
7.4-8.4	157	P (P_2O_5):	54 (123)	39 (90)	29 (67)	15 (33)	0
		K (K_2O):	112 (135)	84 (101)	56 (67)	28 (34)	0
8.4-10.1	190	P (P_2O_5):	59 (136)	45 (103)	29 (67)	20 (46)	4 (10)
		K (K_2O):	140 (169)	112 (135)	65 (78)	37 (45)	0
10.1-11.8	224	P (P_2O_5):	64 (146)	49 (113)	35 (80)	25 (56)	4 (10)
		K (K_2O):	167 (201)	130 (157)	84 (101)	56 (67)	0
11.8-13.4	258	P (P_2O_5):	74 (169)	59 (136)	39 (90)	25 (56)	4 (10)
		K (K_2O):	186 (224)	149 (179)	112 (135)	74 (89)	0

* Soil fertility test levels are as follows:

Soil Test	kg/P/ha	kg/K/ha
Very low	0 to 11	0 to 88
Low	12 to 22	89 to 165
Medium	23 to 33	166 to 230
High	34 to 77	231 to 330
Very high	78+	331+

† Amounts of P_2O_5 and K_2O are shown in parentheses.

1 kg/ha of fertilizer = 0.89 lb/ac
1 metric ton/ha of crop yield = 15.3 bu/ac

Table 7-4. Representative Fertilizer Recommendations for Soybeans in the Midwest

Yield (Metric tons/ha)	Nitrogen To Be Applied (kg/ha)	Fertilizer	Fertilizer P (P_2O_5) and K (K_2O) Recommended for Soil Fertility* †				
			Very Low	Low	Medium	High	Very High
			(kg/ha)				
2.0-2.7	157	P (P_2O_5):	29 (67)	25 (56)	20 (46)	15 (33)	0
		K (K_2O):	99 (119)	74 (84)	47 (57)	37 (45)	0
2.7-3.4	196	P (P_2O_5):	39 (90)	35 (80)	25 (56)	15 (33)	0
		K (K_2O):	112 (135)	84 (101)	56 (67)	56 (67)	0
3.4-4.0	235	P (P_2O_5):	49 (113)	84 (101)	35 (80)	20 (46)	0
		K (K_2O):	140 (169)	112 (135)	84 (101)	56 (67)	0
4.0-4.7	274	P (P_2O_5):	59 (136)	49 (113)	39 (90)	25 (56)	10 (23)
		K (K_2O):	167 (201)	140 (169)	112 (135)	74 (89)	0
>4.7	336	P (P_2O_5):	59 (136)	49 (113)	39 (90)	25 (56)	10 (23)
		K (K_2O):	186 (224)	158 (190)	121 (146)	74 (89)	19 (23)

* See Table 7-3 for definition of soil fertility test levels.
† Amounts of P_2O_5 and K_2O shown in parentheses.

1 kg/ha of fertilizer = 0.89 lb/ac
1 metric ton/ha of crop yield = 15.3 bu/ac.

Table 7-5. Representative Fertilizer Recommendations for Small Grains in the Midwest

Yield (Metric tons/ha)	Nitrogen To Be Applied (kg/ha)	Fertilizer	Fertilizer P (P_2O_5) and K (K_2O) Recommended for Soil Fertility* †				
			Very Low	Low	Medium	High	Very High
			(kg/ha)				
WR:1.9-2.8#	62	P (P_2O_5):	45 (103)	29 (67)	15 (33)	10 (23)	10 (23)
WR:2.8-3.4	73	P (P_2O_5):	59 (136)	45 (103)	29 (67)	15 (33)	10 (23)
WR:3.4-4.0	84	P (P_2O_5):	59 (136)	45 (103)	29 (67)	15 (33)	10 (23)
WR:4.0-4.6	95	P (P_2O_5):	69 (159)	54 (123)	45 (103)	29 (67)	10 (23)
WR:>4.6	106	P (P_2O_5):	69 (159)	54 (123)	45 (103)	29 (67)	10 (23)

***** See Table 7-3 for definition of soil fertility test levels.
† Amounts of P_2O_5 and K_2O are shown in parentheses.
# WR = Wheat and Rye.

1 kg/ha of fertilizer = 0.89 lb/ac.
1 metric ton/ha of crop yield = 14.3 bu/ac for wheat and rye.

Table 7-6. Representative Fertilizer Recommendations for Forages in the Midwest

Yield (Metric tons/ha)	Nitrogen To Be Applied (kg/ha)	Fertilizer	Fertilizer P (P_2O_5) and K (K_2O) Recommended for Soil Fertility* †				
			Very Low	Low	Medium	High	Very High
			(kg/ha)				
< 1.8	112	P (P_2O_5):	49 (113)	39 (90)	25 (56)	15 (33)	10 (23)
		K (K_2O):	224 (270)	186 (224)	140 (169)	74 (89)	0
2.2-2.7	224	P (P_2O_5):	59 (136)	49 (113)	35 (80)	25 (56)	20 (46)
		K (K_2O):	336 (405)	280 (337)	224 (270)	168 (202)	112 (135)
> 2.7	390	P (P_2O_5):	69 (159)	59 (136)	45 (103)	35 (80)	25 (56)
		K (K_2O):	448 (540)	392 (472)	336 (405)	280 (337)	224 (270)

* See Table 7-3 for definition of soil fertility test levels.
† Amounts of P_2O_5 and K_2O are shown in parentheses.

1 kg/ha - 0.89 lb/ac
1 mt/ha - 0.45 T/ac

Table 7-7. Estimated Mineralization Rates (K_{min}) for Different Sewage Sludges (Adapted From Sommers et al, 1981)

Time After Sewage Sludge Application (Years)	Fraction (K_{min})* of Organic N Mineralized From the Following Sludges: Unstabilized Primary and Waste	Aerobically Digested	Anaerobically Digested	Composted
0-1	0.40	0.30	0.20	0.10
1-2	0.20	0.15	0.10	0.05
2-3	0.10	0.08	0.05	-[†]
3-4	0.05	0.04	-	-

* Fraction of the sludge organic N (Org-N) initially applied, or remaining in the soil, that will be mineralized during the time interval shown. K_{min} values are provided as examples only and may be quite different for different sewage sludges, soils, and climates. Therefore, site-specific data, or the best judgement of individuals familiar with N dynamics in the soil-plant system, should always be used in preference to these suggested K_{min} values.

† Once the mineralization rate becomes less than 3% (i.e., 0.03), no net gain of PAN above that normally obtained from the mineralization of soil organic matter is expected. Therefore, additional credits for residual sludge N do not need to be calculated.

agronomic rates (for N) of sewage sludge usually will add K at levels less than crop needs.

The contribution of residual N carryover to plant-available N can be significant when sewage sludge is applied each year. Although the largest percentage of mineralizable organic N is converted to inorganic N during the year that the sludge is applied, the continued decomposition of organic N in succeeding years can provide some additional plant-available N for crop growth. The amount of N mineralized in sludge-treated soils is dependent on the type of sludge treatment processes used, the ratio of inorganic to organic N in the sludge, and the amount of organic N applied in previous years.

The approach proposed for evaluating residual N, P, and K from previous sewage sludge applications is as follows:

- P and K—Assume that 50 percent of the P and 100 percent of the K applied are available for plant uptake in the year of application. These quantities of P and K can be credited against fertilizer recommendations. Any P and K in excess of plant needs will contribute to soil fertility levels that can be regularly monitored and taken into account when determining fertilizer recommendations in succeeding years.
- N—Plant-available N (PAN) that may be mineralized from residual sludge organic N can sometimes be estimated by using soil tests (see Chapter 6). However, estimating PAN by using mineralization factors recommended by land-grant universities or state regulatory agencies is more common. The largest portion of organic N in sewage sludge is converted to inorganic N during the first year after application to the soil. After the first year, the amount of N mineralization decreases each year until it stabilizes at about 3 percent, a rate often observed for stable organic N fractions in soils. Once the 3 percent level has been reached, any additional quantities of PAN will not be significant enough to credit against the fertilizer N recommendation.

  Table 7-7 suggests a decay sequence where the amount of N mineralized decreases by about 50 percent each year until the 3 percent rate is reached. Using anaerobically digested sewage sludge as an example, if 20 percent of the organic N was mineralized during the first year, the amounts released in years 2 and 3 would be 10 and 5 percent, respectively, of the organic N remaining (see Table 7-7). After year 3, the mineralization rate decreases to the background rate for soil organic matter, so no additional credit for residual sludge organic N is calculated. This decay sequence may or may not be the most appropriate one to use for your state or location, but it will be used to illustrate how mineralizable N can be calculated to estimate PAN credits.

7.4.4 Calculation of Annual Application Rates

Recommended annual rates of sewage sludge application on cropland are based on the N or P requirements of the crop grown, the N and P levels in the sludge, and the metal concentrations in the sludge for which pollutant limits have been set in the Part 503 rule. As discussed in the previous section, the fertilizer N recommendation for the crop and yield level expected should be corrected for plant-available N mineralized from prior sludge additions. The basic approach for determining annual application rates of sewage sludge involves using data on sewage sludge composition to calculate maximum potential application rates based on (1) crop N requirements, (2) crop P requirements, and (3) Part 503 pollutant limits. In most cases, the actual application rate will be selected from the following two possibilities:

- The annual agronomic rate can be utilized to provide recommended N needs until the Part 503 CPLR limits for metals are reached, unless the sewage sludge meets the pollutant concentration limits in Table 3 of Part 503, in which case cumulative metal loadings do not need to be tracked. (In some cases, this approach may result in the accumulation of excess P in the soil, which can increase the potential for P entering streams and lakes through surface erosion).

- In some states, the annual rate may be limited to a rate where sludge P is equal to fertilizer P recommendations or the P removed by the crop. Nitrogen may be applied at less than the crop N need. This P rate could be followed as long as it did not exceed the agronomic N rate or any Section 503 pollutant loading limits for metals.

Another possibility is that the metals loadings at the site are approaching a Part 503 CPLR limit, which may result in an application rate that is less than the crop's N or P needs (i.e., sewage sludges that do not meet the Part 503 pollutant concentration limits for metals). Reaching a CPLR limit terminates CPLR sewage sludge application to land, in which case other options, such as incineration or surface disposal, are likely to be more feasible. Currently, however, a majority of sewage sludge in the United States can meet Part 503's pollutant concentration limits. Thus, the nutrient requirements of a crop will likely be the limiting factor rather than Part 503 pollutant limits.

The following section summarizes the basic calculations used to determine sewage sludge application rates based on N (Section 7.4.4.1) and P (Section 7.4.4.2), and the estimated project life based on CPLR limits (Section 7.4.4.3). The design example (Section 7.5) provides additional illustrations of these calculations.

7.4.4.1 Calculation Based on Nitrogen

As discussed previously, not all the N in sewage sludge is immediately available to plants, since some is present as organic N (Org-N), i.e., in microbial cell tissue and other organic compounds. Organic N must be decomposed into mineral, or inorganic forms, such as NH_4-N and NO_3-N, before it can be used by plants. Therefore, the availability of Org-N for plants depends on the microbial breakdown of organic materials (e.g., sewage sludge, animal manure, crop residues, soil organic matter, etc.) in soils.

The proportion of sludge Org-N that is mineralized in a soil depends on various factors which influence immobilization and mineralization of organic forms of N (Bartholomew, 1965; Harmsen and van Schreven, 1955; Smith and Peterson, 1982; Sommers and Giordano, 1984). Schemes for estimating the amount of mineralizable N from organic fertilizers, like animal manure and sewage sludge, have been suggested (Pratt et al., 1973; Powers, 1975; Smith and Peterson, 1982; USDA, 1979; USEPA, 1975, 1983).

Estimates of mineralizable N using decay (decomposition) series are not precise, however, since the actual N availability will depend on organic N composition, degree of treatment or stabilization of the sewage sludge before land application, climate, soil conditions, and other factors. Another approach to predicting N availability is to model (mathematically) the transformations of N in the soil. However, modeling has not yet been found to be accurate enough to give more than a general estimate of N availability (Schepers and Fox, 1989). Nevertheless, management strategies must attempt to balance the addition of plant-available N, provided by land application of organic materials like sewage sludge, with the needs of the crop. Otherwise, excess NO_3-N can be leached into groundwater by precipitation or poor management of irrigation water (Keeney, 1989).

The plant-available N, or PAN, provided by sewage sludge is influenced by several factors. Initially, the quantity of total N in the sludge and the concentrations of NO_3-N, NH_4-N and Org-N (which together make up the total N) must be determined. Commonly, the concentration of Org-N is estimated by subtracting the concentration of NO_3-N and NH_4-N from the total N, i.e., Org-N = total N - (NO_3-N + NH_4-N). The NH_4-N and NO_3-N added by sludge is considered to be as available for plants to utilize as NH_4-N and NO_3-N added by fertilizer salts or other sources of these mineral forms of N.

The availability of sewage sludge Org-N will depend on the type of treatment or stabilization the sludge received. Anaerobically digested sludge normally will have high levels of NH_4-N and very little NO_3-N, while aerobically digested sludge will have higher levels of NO_3-N by comparison. Composting and anaerobic digestion accomplishes greater stabilization of organic carbon compounds than aerobic digestion or waste activation. The greater the stabilization, the slower the rate of mineralization of carbon compounds (containing Org-N from the sewage sludge) and the lower the amounts of Org-N released for plant uptake.

Differences between these various types of sewage sludges can be seen in Table 7-7 which shows average mineralization rates for the first through fourth year following a sludge application (Sommers et al., 1981). These values, however, are averages only and can vary significantly due to differences in the characteristics of the sewage sludge, soil, and climate (i.e., temperature and rainfall). For example, assuming adequate moisture is available for microbial decomposition, increases in temperature will increase the activity of microorganisms. Therefore, mineralization rates are typically higher in the summer months than in the winter months and higher in the southern U.S. than in the northern states. Because of these differences, calculating the agronomic rate should be done on a site-specific basis. Using mineralization factors recommended by state regulatory agencies and land-grant universities that are based on decomposition or N mineralization studies, computer simulations that estimate decomposition, or documented field experience is advised.

The amount of PAN also will be affected by the amount of NH_4-N lost by volatilization of ammonia (NH_3). Ammonia volatilization losses, when animal manure or sewage sludge is applied to land, have long been recognized (Adriano et al., 1974; Beauchamp et al., 1978, 1982; Brunke et al., 1988; Christensen, 1986; Döhler and Wiechmann, 1988; Hall and Ryden, 1986; Hoff et al., 1981; Lauer et al., 1976; Rank et al., 1988; Reddy et al., 1979; Terman, 1979; Vallis et al., 1982). Accurately estimating the extent of this loss is difficult, however, given the variability in weather conditions that largely dictate how fast volatilization will occur.

In addition to weather conditions, the method of sewage sludge application, the length of time sewage sludge remains on the soil surface prior to incorporation, and the pH (e.g., lime content) of the sewage sludge also will influence the potential for volatilization losses. High pH in sewage sludge or soil will encourage the conversion of NH_4-N to NH_3, resulting in a N loss to the atmosphere. The longer the sludge remains on the soil surface and is subjected to drying conditions, the greater the risk of NH_3 volatilization losses.

With injection of liquid sewage sludge, little NH_3 should be lost to volatilization, except possibly on coarsely textured (sandy) soils. Volatilization losses, however, should be considered for surface-applied liquid sewage sludge that is later incorporated and for surface-applied dewatered sewage sludge that is later incorporated or remains on the surface. This N loss needs to be considered, or the amount of PAN reported to the farmer as being applied will be overestimated.

Volatilization losses of NH_4-N from animal manure also are of interest in many states, and guidance often is provided by state land-grant universities; thus, applicators of sewage sludge may want to seek similar guidance to estimate loss of NH_4-N as NH_3 during sewage sludge application. In addition, several states (e.g., Virginia, Washington) have developed specific guidance on NH_3 volatilization from sewage sludge that takes into account such factors as lime content of the sewage sludge and the length of time sewage sludge remains on the soil surface before it is incorporated.

For these reasons, Table 7-8 can serve as guidance for estimating NH_4-N losses as NH_3. As indicated earlier, these volatilization factors may not be the most appropriate for a specific site, so values should be obtained from state regulatory agencies or state land-grant universities that are more site-specific for a particular location.

The inability to accurately estimate volatilization losses, combined with the difficulty of estimating the amount of mineralizable N, means that regulators need to remain flexible regarding the methods used to estimate the amount of PAN per dry ton of sewage sludge.

Table 7-8. Volatilization Losses of NH_4-N as NH_3

Sewage Sludge Type and Application Method	NH_3 Volatilization Factor, K_{vol}
Liquid and surface applied	0.50
Liquid and injected into the soil	1.0
Dewatered and surface applied	0.50

With these factors in mind, a number of steps can be used to determine the agronomic rate (i.e., based on PAN). These steps are summarized below and also are shown on Worksheets 1 and 2 (see Figures 7-1 and 7-2):

1. Determine the fertilizer N recommendation for the crop and yield level anticipated on the soil that is to receive the sewage sludge application. (Since legume crops can fix their own N, they usually will not have a N fertilizer recommendation. Legume crops, however, will utilize N that is applied as fertilizer, manure, or sewage sludge, so N crop removal values can be used to estimate the N requirement for these crops.)

2. Subtract anticipated N credits from the recommended fertilizer N rate, i.e., for other sources of N such as the following:

   a. Residual N left by a previous legume crop (legumes have the ability to fix N from the air, and varying levels of N will be left in the soil when legumes are replaced by another crop; land-grant universities can provide appropriate credits that should be used for a particular site).

   b. Any N that has already been applied or will be applied during the growth of the crop by fertilizer, manure, or other sources that will be readily available for plants to use.

   c. Any N that is anticipated to be added by irrigation water that will be applied during the growth of the crop.

   d. Any residual Org-N remaining from previous sewage sludge applications. As previously discussed, Table 7-7 lists average mineralization rates, but more sewage sludge-specific and site-specific information should be used when available. Experience over time has shown that when agronomic rates of sewage sludge are used, no additional PAN above that normally obtained from soil organic matter turnover is expected after 3-4 years. Therefore, calculating PAN credits for a sludge application beyond the third year is not recommended, since these quantities are negligible. The chart in Worksheet 1 and the mineralization factors in Table 7-7 can be used to estimate the PAN for years 2 and 3. An example calculation is included in Worksheet 1.

Worksheet 1
Calculations for Determining PAN Mineralized From Residual Organic N Applied as Sewage Sludge in Previous Years

Residual N from previously-applied sewage sludge that will be mineralized and released as plant-available N (PAN) must be accounted for as part of the overall budget for PAN, when determining the agronomic N rate for sewage sludge (i.e., Worksheet 2). This residual N credit can be estimated for some sites using soil nitrate tests, but more commonly the PAN credit is estimated by multiplying a mineralization factor (K_{min}) times the amount of sludge organic N (Org-N) still remaining in the soil one and two years after sludge has been applied.

Instructions: Complete a separate chart for each year that sewage sludge was previously-applied. Studies and experience have shown that any residual sludge Org-N remaining 2-3 years after application will not contribute significantly to PAN normally mineralized from soil organic matter decomposition. Therefore, calculating PAN credits beyond the third year is usually not necessary. To determine total mineralized Org-N released as PAN, sum the values under Mineralized Org-N (Column D) for the "Growing Season Year" for which you are planning a new sludge application to estimate the residual N credit for sludge applications the previous two years.

A. Year of Growing Season[1]	B. Starting Org-N[2] (lb/acre)	C. Mineralization Rate[3] (K_{min})	D. Mineralized Org-N[4] or PAN (lb/acre)	E. Org-N Remaining[5] (lb/acre)
0-1 (sludge applied)				
1-2 (one year later)				
2-3 (two years later)				

[1] Begin with the growing season (i.e., year the crop will be grown) for which sewage sludge was applied and continue two more years (i.e., two more growing seasons).
[2] For the first year, this equals the percent Org-N in the sludge times the rate of application. For years 1-2 and 2-3, this quantity equals the amount of Org-N remaining from the previous year (i.e., column E).
[3] The mineralization rate is the fraction of sludge Org-N expected to be released as PAN for the year being calculated. Example mineralization rates can be found in Table 7-7.
[4] Multiply column C times column B and round to the nearest whole pound.
[5] Subtract column D from column B and round to the nearest whole pound.

Figure 7-1. Determining mineralized PAN from previous sludge applications.

Worksheet 1 (continued)

Example

Assume that anaerobically digested sewage sludge with 2.5% Org-N (dry weight basis) was applied at a rate of 3 ton/acre for the 1996 growing season. For the 1997 growing season, 2 ton/acre of a sludge containing 3.0% Org-N was applied to the same site. For the 1998 growing season, calculate the amount of PAN that will be mineralized from the sludge Org-N applied in the previous 2 years.

$$\text{In 1996, the sludge Org-N applied} = \frac{2.5 \text{ lb Org-N}}{100 \text{ lb sludge}} \times \frac{3 \text{ ton sludge}}{\text{acre}} \times \frac{2000 \text{ lb sludge}}{\text{ton sludge}} = 150 \text{ lb Org-N/acre}$$

$$\text{In 1997, the sludge Org-N applied} = \frac{3.0 \text{ lb Org-N}}{100 \text{ lb sludge}} \times \frac{2 \text{ ton sludge}}{\text{acre}} \times \frac{2000 \text{ lb sludge}}{\text{ton sludge}} = 120 \text{ lb Org-N/acre}$$

Use Worksheet 1 to calculate the PAN released during the 1998 growing season from the sludge applied in 1996 and 1997.

A. Year of Growing Season	B. Starting Org-N (lb/acre)	C. Mineralization Rate (K_{min})	D. Mineralized Org-N (lb/acre)	E. Org-N Remaining (lb/acre)
1996 Sludge Application				
0-1 (1996 Application)	150	0.20	30	120
1-2 (1997)	120	0.10	12	108
2-3 (1998)	108	0.05	5	103
1997 Sludge Application				
0-1 (1997 Application)	120	0.20	24	96
1-2 (1998)	96	0.10	10	86
2-3 (1999)	86	0.05	4	82

To determine the total amount of PAN mineralized in 1998 from sludge applied in 1996 and 1997, add the Mineralized Org-N (or PAN) value in the 1998 row under column D for each year's chart (i.e., 5 + 10 = 15 lb PAN/acre). **Therefore, the total PAN, or mineralized Org-N, from previous sludge applications equals 15 lb/acre.**

Figure 7-1. Determining mineralized PAN from previous sludge applications (continued).

Worksheet 2
Nitrogen Budget Sheet for Determining the Agronomic N Rate for Sewage Sludge Applications

Symbols and Abbreviations Used

Org-N = Organic N content of the sewage sludge obtained from analytical testing and determined by subtracting (NO_3-N + NH_4-N) from total N, usually given in percent (%); the resulting concentration should be converted to lb/ton (dry weight basis).

NH_4-N = Ammonium N content of the sewage sludge obtained from analytical testing and usually given in percent (%); convert to lb/ton (d.w. basis).

NO_3-N = Nitrate N content of the sewage sludge obtained from analytical testing and often given in mg/kg; convert to lb/ton (d.w. basis).

K_{min} = Mineralization rate for the sewage sludge expressed as a fraction of the sludge Org-N expected to be released as PAN for the year being calculated; example mineralization rates for different sewage sludges can be found in Table 7-7.

K_{vol} = Volatilization factor for estimating the amount of NH_4-N remaining after loss to the atmosphere as ammonia and expressed as a fraction (e.g., if K_{vol} = 1.0, 100% of the NH_4-N is retained and contributes to PAN; if K_{vol} = 0.5, then 0.5 x NH_4-N estimates the amount of NH_4-N contributing to PAN).

PAN = Plant-available N, determined by calculating: NO_3-N + K_{vol}(NH_4-N) + K_{min}(Org-N)

Helpful Conversions

mg/kg x 0.002 = lb/ton	lb/acre x 1.12 = kg/ha	lb/ton ÷ 2 = kg/mt
% x 20 = lb/ton	ton/acre x 2.24 = mt/ha	(mt = metric ton = 1000 kg)

1. Total N requirement of crop to be grown (*obtain information from Cooperative Extension Service agricultural agents, USDA-Natural Resource Conservation Service, or other agronomy professionals*). ________ lb/acre

2. Nitrogen provided from other N sources added or mineralized in the soil
   a. N from a previous legume crop (legume credit) or green manure crop ________ lb/acre
   b. N from supplemental fertilizers already, or expected to be, added ________ lb/acre
   c. N that will be added by irrigation water ________ lb/acre
   d. Estimate of available N from previous sludge applications (*from Worksheet 1*) ________ lb/acre
   e. Estimate of available N from a previous manure application (*obtain mineralization factors from land-grant university to calculate similarly as for previous sewage sludge applications*). ________ lb/acre
   f. Soil nitrate test of available N present in soil [*this quantity can be substituted in place of (a + d + e) if test is conducted properly; do not use this test value if estimates for a, d and e are used*] ________ lb/acre

   Total N available from existing, expected, and planned sources of N (*add a+b+c+d+e* <u>or</u> *b+c+f*) ________ lb/acre

3. Loss of available N by denitrification, immobilization, or NH_4^+ fixation (*check with state regulatory agency for approval before using this site-specific factor*). ________ lb/acre

4. Calculate the adjusted fertilizer N requirement for the crop to be grown (*subtract **Total** N for (2) from (1); amount for (3) can be added to this difference, only if (3) is approved for this additional adjustment*). ________ lb/acre

Figure 7-2. Determining agronomic N rate.

Worksheet 2 (continued)

5. Determine the PAN/dry ton for the sludge that will be applied [i.e., NO_3-N + K_{vol} (NH_4-N) + K_{min} (Org-N) = PAN] ________ lb/ton

6. Calculate the agronomic N rate of sewage sludge (*Divide (4) by (5)*) ________ ton/acre

7. Convert the rate of sewage sludge in dry tons/acre into gallons/acre, cubic yards/acre, or wet tons/acre, since the sludge will be applied to land as a liquid or as a wet cake material.

Figure 7-2. Determining agronomic N rate (continued).

e. Residual organic N remaining from any previous animal manure application should be estimated. Various decay schemes are used for manure applications by land-grant universities, so residual N released from a previous manure application can be estimated in a similar manner as for sewage sludge applications (i.e., step 2.d).

f. The combined residual N already present in the soil or expected to be available for crops to use can sometimes be estimated by the soil nitrate test (e.g., inorganic N left from previous fertilizer, manure, sludge, etc. applications; or credits given for the mineralization of soil organic matter and legume crop residues). The soil nitrate test can be used in some states to estimate quantities of NO_3-N that may be present from previous fertilizer N, manure, and/or sewage sludge applied and/or from mineralization of N from legume crops and soil organic matter. But because NO_3-N can be lost by leaching, the soil nitrate test must be used with care in semi-humid and humid climates. Therefore, guidance should be obtained from a land-grant university for the proper credits to use.

Note that if a soil nitrate test is used to estimate residual N contributions, then estimates for steps 2.a, 2.d, and 2.e should not be included in the summation done in step 2 on Worksheet 2.

3. Add any anticipated N losses due to denitrification, immobilization, or chemical fixation of NH_4^+ by micaceous (i.e., mica-containing) clay minerals **(use only if approved by regulatory agency)**. Denitrification [i.e., the loss of NO_3-N as nitrogen (N_2) or nitrous oxide (N_2O) gases] and immobilization (i.e., the loss of NO_3-N or NH_4-N by incorporation into organic compounds by the soil biology) can occur in soils. For soils containing hydrous mica clay minerals, some NH_4^+ may become fixed within the crystal lattices of these minerals in spaces normally occupied by K^+. If this occurs, NH_4^+ is unavailable for plant uptake unless mineral weathering occurs to again release the NH_4^+.

   The source of the NO_3-N and NH_4-N can be from fertilizer, manure, etc. as well as sewage sludge applications. Note that if fertilizer recommendations are used which account for average losses due to biological denitrification and immobilization or chemical fixation of NH_4^+, a separate credit for these processes should not be used for this step. Therefore, adding these anticipated N losses should not be done unless justification is provided to the permitting authority and approval is received.

4. Use Worksheet 2 to determine the adjusted fertilizer N rate by subtracting "total N available from existing, anticipated, and planned sources" (Worksheet step 2) from "total N requirement of crop" (Worksheet step 1). If a loss of available N by denitrification, immobilization or NH_4^+ fixation is allowed (i.e., approved by the state regulatory agency), this anticipated loss can be added to the difference obtained when subtracting the step 2 total from the step 1 amount to obtain a final adjusted fertilizer N rate.

5. Determine the PAN/dry ton of sewage sludge for the first year of application using the following equation:

   $$PAN = NO_3\text{-}N + K_{vol}\,(NH_4\text{-}N) + K_{min}\,(Org\text{-}N)$$

   where:

PAN	=	plant-available N in lb/dry ton sewage sludge
NO_3-N	=	content of nitrate N in sewage sludge in lb/dry ton
K_{vol}	=	volatilization factor, or fraction of NH_4-N not lost as NH_3 gas to the atmosphere
NH_4-N	=	content of ammonium N in sewage sludge in lb/dry ton
K_{min}	=	mineralization factor, or fraction of Org-N converted to PAN
Org-N	=	content of organic N in sewage sludge in lb/dry ton, estimated by Org. N = total N - (NO_3-N + NH_4-N)

   Example: Assume liquid, aerobically digested sewage sludge is to be incorporated into the soil by direct injection (i.e., $K_{vol} = 1.0$). The suggested mineralization rate in Table 7-7 is $K_{min} = 0.30$ for the first year. The chemical analysis of the sludge shows NO_3-N = 1,100 mg/kg, NH_4-N = 1.1% and total N = 3.4%, all on a dry weight basis, and percent dry solids is 4.6%.

   a. First convert concentrations to lb/dry ton:

   for NO_3-N — 1,100 mg/kg x 0.002 = 2.2, or 2 lb/ton (rounded to nearest whole lb)

   for NH_4-N — 1.1% x 20 = 22 lb/ton

   for total N — 3.4% x 20 = 68 lb/ton

   for Org-N — 68 - (2 + 22) = 44 lb/ton

   b. Calculate PAN:

   PAN = 2 + 1.0 (22 lb/ton) + 0.3 (44 lb/ton) = 2 + 22 + 13 = 37 lb/ton

6. Divide the adjusted fertilizer N rate (lb N/acre from step 4) by the PAN/dry ton sewage sludge (lb N/ton from step 5) to obtain the agronomic N rate in dry tons/acre.

   Example: Assume the adjusted fertilizer N rate from step 4 is 130 lb N/acre and the aerobically digested sewage sludge from the example in step

5 above is used to provide crop N needs. What is the agronomic N rate?

Agronomic N rate = 130 lb N/acre ÷ 37 lb N/ton = 3.5 dry tons/acre

7. This dry ton/acre rate can be converted to wet gallons/acre, since this is the form in which the sewage sludge will be applied:

wet tons/acre = 3.5 dry ton/acre ÷ 4.6 dry ton/100 wet ton (i.e., 4.6% solids) = 76 wet ton/acre

This wet tonnage can then be converted to gallons/acre by the following conversion:

76 wet ton/acre x 2,000 lb/wet ton x
1 gallon/8.34 lb = 18,200 gallons/acre

This rate would be equivalent to about 2/3 acre-inch of liquid (1 acre-inch = 27,150 gal), too much to apply in one application. Probably 13,000-15,000 gal/acre is a maximum amount that can normally be applied at one time using injection.

7.4.4.2 Calculation Based on Phosphorus

The majority of P in sewage sludge is present as inorganic compounds. While mineralization of organic forms of P occurs during decomposition of sludge organic matter, inorganic reactions of P are of greater importance when considering sludge P additions. Because of the predominance of inorganic P, therefore, the P contained in sewage sludge is considered to be about 50 percent as available for plant uptake as the P normally applied to soils in commercial fertilizers (e.g., triple superphosphate, diammonium phosphate, etc.). As previously discussed, the P fertilizer needs of the crop to be grown are determined from the soil fertility test for available P and the yield of the crop. The agronomic P rate of sewage sludge for land application can be determined by the following equations:

Agronomic P Rate = P_{req} ÷ Avail. P_2O_5/dry ton

where:

P_{req} = the P fertilizer recommendation for the harvested crop, or the quantity of P removed by the crop,
Avail. P_2O_5 = 0.5 (total P_2O_5/dry ton)
Total P_2O_5/dry ton = %P in sludge x 20 x 2.3*

*2.3 is the factor to convert lb P to lb P_2O_5 (the ratio of the atomic weights of P_2O_5:P, i.e.,142:62).

For nearly all sewage sludge, supplemental N fertilization will be needed to optimize crop yields (except for N-fixing legumes) if application rates are based on a crop's P needs.

7.4.4.3 Calculation Based on Pollutant Limitations

The literature pertaining to trace element (metal) additions to the soil-plant system from sewage sludge applications is extensive, and several key references can be a source of more in-depth discussions (Allaway, 1977; Berglund et al., 1984; CAST, 1976, 1980; Chaney, 1973, 1983a, 1983b, 1984; Chaney and Giordano, 1977; Davis et al., 1983; L'Hermite and Dehandtschutter, 1981; Lindsay, 1973; Logan and Chaney, 1983; Melsted, 1973; Page et al., 1987; Ryan and Chaney, 1993; Sommers and Barbarick, 1986; U.S. EPA, 1974; Walsh et al., 1976). Potential hazards associated with trace element additions have mostly pertained to their accumulation in soils which may (1) lead to a plant toxicity condition or (2) result in increased uptake of trace elements into the food chain.

As discussed in Chapter 3, the pollutant limits established in the Part 503 regulation protect human health and the environment from reasonably anticipated adverse effects of pollutants that may be present in sewage sludge.

Because most sewage sludges will likely contain pollutant concentrations that do not exceed the Part 503 "pollutant concentration limits" (see Chapter 3), pollutant loading limits will not be a factor in determining annual sewage sludge application rates for these sewage sludges. For other sewage sludges that have pollutant concentrations that exceed one or more of the Part 503 "pollutant concentration limits," the Part 503 "cumulative pollutant loading rates" (CPLRs) discussed in Chapter 3 and shown in Table 7-9 must be met; CPLRs could eventually be the limiting factor for annual

Table 7-9. Part 503 Cumulative Pollutant Loading Rate (CLPR) Limits

	Loading Limits	
Pollutant	**kg/ha**	**lb/acre**
Arsenic	41	37
Cadmium	39	35
Chromium	3,000[a]	2,700
Copper	1,500	1,300
Lead	300	270
Mercury	17	15
Molybdenum	—[a]	—
Nickel	420	380
Selenium	100	90
Zinc	2,800	2,500

[a] Chromium limits will most likely be deleted from Part 503. The CPLR for Mo was deleted from Part 503 effective February 25, 1994. EPA will reconsider this limit at a later date.

sewage sludge applications (rather than the agronomic rate of application).

For sewage sludge meeting Part 503 CPLRs, two equations are helpful for managing pollutant loadings to soils. The first equation can be used to estimate the maximum total quantity of sewage sludge permitted to be applied to a soil, based on the CPLR and the pollutant concentration in the sewage sludge being considered:

Maximum sewage sludge allowed (dry tons/acre) = lb/acre (CPLR) ÷ 0.002 (ppm pollutant)

where:

ppm pollutant = mg of pollutant per kg of dry sewage sludge.

After making this calculation for each of the 10 pollutants regulated by Part 503, the lowest "total sewage sludge" value should be used as the maximum quantity of sewage sludge allowed to be applied for that particular site. The design example in Section 7.5 shows how this equation is used.

A second equation, also illustrated in Section 7.5, can be used to determine the individual pollutant loading added by each sewage sludge application rate:

lb of pollutant/acre = sludge rate (dry tons/acre) x 0.002 (ppm pollutant)

A cumulative record of individual applications is then kept for each field receiving sewage sludge that is meeting the CPLRs. When the cumulative amount of any one regulated pollutant reaches its CPLR, no additional CPLR sewage sludge can be applied.

7.4.5 Calculation of Supplemental N, P, and K Fertilizer

Once the application rate of sewage sludge has been determined, the amounts of plant-available N, P, and K added by the sludge should be calculated and compared to the fertilizer recommendation for the crop (and yield level) to be grown. If the amount of one or more of these three nutrients provided by the sewage sludge are less than the amount recommended, then supplemental fertilizers will be needed to achieve crop yields. Refer to the design example in Section 7.5 for an illustration of how this is determined.

7.4.6 Use of Computer Models To Assist in Determining Agronomic Rates

Computer modeling often can be useful for site-specific evaluation of sewage-sludge-climate-soil-plant N dynamics at a particular location, generally with minimal additional data collection.

Computer models that specifically model N budgets in sewage sludge and soil-plant systems can provide site-specific information on soil physical and hydrologic conditions and climatic influences on N transformations. The Nitrate Leaching and Economic Analysis Package (NLEAP) developed by Shaffer et al. (1991) allows monthly and event-by-event approaches throughout the year to compute water and N budgets. The NLEAP software is included in the purchase of *Managing Nitrogen for Groundwater Quality and Farm Profitability* (Follet et al., 1991), which also serves as an excellent reference for information on parameters required for N budget calculations. Four regional soil and climatic databases (Upper Midwest, Southern, Northeastern, and Western) also are available on disk for use with NLEAP. These materials can be obtained from:

Soil Science Society of America
Attn: Book Order Department
677 S. Segoe Road
Madison, WI 53711
608/273-2021; Book $36.00;
Regional Databases $10.00 each.

Current updates of the NLEAP program can be obtained by sending original diskettes to:

Mary Brodahl
USDA-ARS-GPSR
Box E
Fort Collins, CO 80522

The computer model DECOMPOSITION (Gilmour and Clark, 1988) is specifically designed to help predict sewage sludge N transformations based on sludge characteristics as well as soil properties and climate (organic matter content, mean soil temperature, and water potential). Additional information on this model can be obtained from:

Mark D. Clark
Predictive Modeling
P.O. Box 610
Fayetteville, AR 72702

Finally, the CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) and GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) models, developed by the U.S. Department of Agriculture (Beasley et al., 1991; Davis et al., 1990; Knisel, 1980), are other potentially useful models to assist with site-specific management of sewage sludge application programs.

7.5 Design Example of Sewage Sludge Application Rate Calculations

The following detailed design example is for a midwestern city with 20 dry ton/day (18 mt/day) of sewage sludge requiring land application. The sewage sludge has undergone anaerobic digestion and has the following characteristics:

- Solids - 4.8 percent
- Total N - 3.9 percent
- NH_4-N - 1.2 percent
- NO_3-N - 200 mg/kg
- Total P - 1.9 percent
- Total K - 0.5 percent
- As - 8 mg/kg
- Cd - 10 mg/kg
- Cr - 130 mg/kg
- Cu - 1,700 mg/kg
- Pb - 150 mg/kg
- Hg - 2 mg/kg
- Mo - 14 mg/kg
- Ni - 49 mg/kg
- Se - 15 mg/kg
- Zn - 1,200 mg/kg

Climatological data were collected for the application area as described in Chapter 5. Sewage sludge application will be limited during periods of high rainfall and high soil moisture conditions because of the potential for surface runoff and the inability to use sludge application equipment. In addition, sludge application will not occur during periods of extended subfreezing temperatures due to frozen soils, as indicated by Part 503.

For this site, assume that:

- Annual sewage sludge applications cannot exceed the N requirement for the crop grown, as required by Part 503.
- Soil pH will be maintained at levels recommended by land-grant universities for the crop to be grown (or as required by state regulatory agencies).
- If nutrient additions by the sewage sludge application are not sufficient, supplemental fertilizer nutrients will be used to optimize crop production.
- Routine soil fertility testing will be done to establish fertilizer recommendations and lime requirements for optimum crop growth.
- The sewage treatment plant regularly monitors chemical composition of the sludge as required by Part 503 and state regulatory agencies.
- Records are maintained as required by Part 503 and state regulatory agencies.

Soils in the site area are generally sandy loams. Soil fertility tests have been completed and soil pH is being maintained as recommended. Crops grown in the area include corn, soybeans, oats, wheat, and forages for hay and pasture. For the 1995 growing season, one half of the fields receiving sludge will be cropped with wheat requiring 90 lb/ac (100 kg/ha) of available N per year, and one half of the fields will be cropped with corn requiring 190 lb/ac (210 kg/ha) of available N per year. Crop fertilizer requirements were obtained from local Cooperative Extension Service agents for anticipated yield levels of 80 bu/ac for wheat and 160 bu/ac for corn grain.

The soil fertility tests indicated that available P levels in the soil are medium, and that available K levels are low.

Crop	Yield (bu/ac)	N (lb/ac/year)	P_2O_5 (lb/ac/year)	K_2O (lb/ac/year)
Corn	160	190	60	140
Wheat	80	90	80	125

Assume that this anaerobically-digested sewage sludge was previously applied to the fields in 1993 and 1994, as shown in the following chart:

1995 Growing Season	Sewage Sludge Rate (% Org-N in sludge) 1994	1993
Corn	4.8 ton/acre (2.8% Org-N)	2.6 ton/acre (2.5% Org-N)
Wheat	None	4.6 ton/acre (2.5% Org-N)

For the wheat field, sewage sludge will be applied in the fall after soybeans are harvested and before the winter wheat is planted in the fall of 1994. For the corn fields, sewage sludge will be applied in the spring of 1995 before corn is planted. No other source of N, except for residual N from the 1994 and 1993 sludge applications, are planned for the corn field. The wheat field will have a 30 lb/acre N credit from the preceding soybean crop and a residual N credit for the 1993 sludge application. No irrigation water will be used, and no manure applications have been made to either field.

The liquid sewage sludge will be surface applied after soybean harvest before the soil is tilled, prior to the wheat being planted. Incorporation of the sludge will be within 0-1 day, and experience with animal manure suggests that 30% of the NH_4-N is typically lost by ammonia volatilization. Therefore, 70% will be conserved and available for plants to use, so K_{vol} = 0.7. For the corn field, the liquid sludge will be injected into the soil, so K_{vol} = 1.0.

7.5.1 Calculation of Agronomic N Rate for Each Field

Mineralization of PAN from the Org-N in this anaerobically digested sewage sludge is assumed to be the same as the K_{min} values in Table 7-7 suggest, i.e., 20% the 1st year, 10% the 2nd, and 5% the 3rd. Since the NO_3-N content is negligible (< 1lb/ton), it is not included for calculating the PAN for this sewage sludge.

Total N = 3.9% x 20 = 78 lb/ton
NO_3-N = 200/kg x 0.002 = 0.4 lb/ton
NH_4-N = 1.2% x 20 = 24 lb/ton
Org-N = 78 - 24 = 54 lb/ton

For the wheat field where sewage sludge is to be surface applied:

PAN = K_{vol} (NH_4-N) + K_{min} (Org-N) =
0.7 (24 lb/ton) + 0.20 (54 lb/ton) =
17 + 11 =
28 lb/ton

For the corn field where sludge is to be injected:

PAN = K_{vol} (NH_4-N) + K_{min} (Org-N) =
1.0 (24 lb/ton) + 0.20 (54 lb/ton) =
24 + 11 =
35 lb/ton

To calculate the residual N mineralized from previous sewage sludge applications, the Worksheet 1 chart is completed for each field, as shown in Figure 7-3. As indicated in Section 7.5 above, the wheat field had sewage sludge applied in 1993, and the corn field received sludge applications in 1993 and 1994.

For the wheat field, Org-N originally applied in 1993 was:

Org-N = 4.6 ton/acre x 20 (2.5% Org-N) =
4.6 ton/acre x 50 lb/ton = 230 lb Org-N/acre

For the corn field, Org-N originally applied in 1993 and 1994 was:

1993: Org-N = 2.6 ton/acre x 20 (2.5% Org-N) =
2.6 ton/acre x 50 lb/ton =
130 lb Org-N/acre

1994: Org-N = 4.8 ton/acre x 20 (2.8% Org-N) =
4.8 ton/acre x 56 lb/ton =
270 lb Org-N/acre

Therefore, as the Worksheet 1 charts show (Figure 7-3), the PAN credit to use in Worksheet 2 for the wheat field due to previous sewage sludge application is 8 lb N/acre. The PAN credit to use in Worksheet 2 for the corn field due to previous sewage sludge applications is 27 lb N/acre.

The agronomic N rate can now be calculated for the wheat field using Worksheet 2, as shown in Figure 7-4. The legume credit of 30 lb N/acre for the previous soybean crop is shown on line 2.a, and the residual sludge N credit is written on line 2.d. The total N credits of 38 lb/acre are subtracted from the fertilizer N recommendation to get the adjusted N requirement. This remaining N requirement is then divided by the PAN calculated earlier in this section for the wheat field, i.e., 28 lb N/ton, to get an agronomic N sludge rate of 1.9 dry ton/acre. This rate will be equivalent to:

$$\frac{1.9 \text{ dry ton}}{\text{acre}} \times \frac{100 \text{ wet ton (i.e., 4.8\% solids)}}{4.8 \text{ dry ton}} \times$$

$$\frac{2{,}000 \text{ lb}}{\text{wet ton}} \times \frac{\text{gallon}}{8.34 \text{ lb}} = 9{,}500 \text{ gallons/acre}$$

A separate Worksheet 2 can be used to calculate the agronomic rate for the corn field, as shown in Figure 7-5. The only N credit for this field is the residual sludge N credit shown on line 2.d., which is subtracted from the fertilizer N recommendation to get the adjusted N requirement (i.e., 163 lb N/acre). Dividing this requirement by the PAN/ton calculated earlier for the corn field, i.e., 35 lb N/ton, will obtain the agronomic N sludge rate of 4.7 dry ton/acre. This rate can be converted to a wet weight basis, as was done for the wheat field, which is equivalent to 23,500 gallons/acre. This amount of liquid cannot be injected in a single application, so two applications of ~12,000 gal/acre each will be needed.

7.5.2 Calculation of Long-Term Pollutant Loadings and Maximum Sewage Sludge Quantities

By comparing the pollutant concentrations in this design example to the Part 503 limits (see Chapter 3), the reader will find that all trace element levels in the sewage sludge meet the "pollutant concentration limits" except copper. Therefore, CPLR limits must be met for this sewage sludge. Utilizing the "maximum sewage sludge allowed" equation from Section 7.4.4.3 and the CPLRs from Table 7-9, the total quantity of sludge that could be applied before exceeding the CPLR limit for each pollutant can be estimated:

Arsenic	Max. sludge = 37 lb/acre ÷ 0.002 (8 mg/kg) = ~2,300 dry ton/acre
Cadmium	Max. sludge = 35 lb/acre ÷ 0.002 (10 mg/kg) = 1,750 dry ton/acre
Chromium	Pollutant limits will most likely be deleted from Part 503 rule
Copper	Max. sludge = 1,300 lb/acre ÷ 0.002 (1,700 mg/kg) = 382 dry ton/acre
Lead	Max. sludge = 270 lb/acre ÷ 0.002 (150 mg/kg) = 900 dry ton/acre

Mercury	Max. sludge = 15 lb/acre ÷ 0.002 (2 mg/kg) = 3,750 dry ton/acre
Molybdenum	Currently, no CPLR is required for Mo.
Nickel	Max. sludge = 380 lb/acre ÷ 0.002 (49 mg/kg) = ~3,900 dry ton/acre
Selenium	Max. sludge = 90 lb/acre ÷ 0.002 (15 mg/kg) = 3,000 dry ton/acre
Zinc	Max. sludge = 2,500 lb/acre ÷ 0.002 (1,200 mg/kg) = ~1,040 dry ton/acre

Assuming this particular sewage sludge continued to have the same concentrations over time, Cu would continue to be the limiting pollutant. The pollutant loadings for each individual sewage sludge application must be determined and recorded to keep a cumulative summation of the total quantity of each pollutant that has been added to each field receiving this sewage sludge. To calculate the quantity of each pollutant applied, the following equation from Section 7.4.4.3 can be used:

Sludge rate (dry ton/acre) x 0.002 (mg/kg pollutant) = lb pollutant/acre

For the two agronomic N rates calculated in Section 7.5.1, the amounts of each pollutant added by the sewage sludge are shown in Table 7-10.

Table 7-10. Amounts of Pollutants Added by Sewage Sludge in Design Example

Pollutant	Conc. in Sludge	Wheat Field (1.9 ton/acre)	Corn Field (4.7 ton/acre)
	mg/kg	lb/acre	
Arsenic	8	0.030	0.075
Cadmium	10	0.038	0.094
Chromium[a]	-	-	-
Copper	1,700	6.5	16
Lead	150	0.57	1.4
Mercury	2	0.0076	0.019
Molybdenuma	-	-	-
Nickel	49	0.19	0.46
Selenium	15	0.057	0.14
Zinc	1,200	4.6	11

[a] Limits for chromium will most likely be deleted from Part 503. Currently, no calculation or recordkeeping for a CPLR is required for Mo.

These quantities would be added to the cumulative total kept for each field receiving any sewage sludge that is meeting CPLRs.

The approximate number of years that sewage sludge (of the quality assumed in this design example) could be applied before reaching the CPLR can be estimated. If the pollutant concentrations remain the same and an average, annual application rate is assumed, the maximum sludge quantity calculated above for the most limiting pollutant (i.e., Cu) can be used to estimate the number of years a site could be continuously utilized. For this calculation, we will assume an average rate of 3.3 ton/acre/year, obtained by averaging the agronomic N rates for the wheat field and the corn field [i.e., (1.9 + 4.7) ÷ 2]. Using the following equation, the number of years can then be estimated:

Max. sludge allowed ÷ average annual rate = number of years:

382 dry ton/acre ÷ 3.3 dry ton/acre/year = ~116 years

Thus, these preliminary calculations indicate that Part 503 CPLR limits will likely not constrain the application of sewage sludge if its quality was similar to that used in this design example.

If the concentration of Cu was reduced until it met the Part 503 pollutant concentration limits and all other pollutant concentrations remained constant, the CPLRs would no longer have to be recorded to comply with the 503 regulation (see Chapter 3).

7.5.3 Calculation of Agronomic P Rate for Each Field

The equation from Section 7.4.4.2 can be used to calculate the agronomic P rate for the wheat field and corn field used in this design example. For the anaerobic sewage sludge containing 1.9% total P, plant available P_2O_5 can be estimated:

Total P_2O_5/dry ton = 1.9% x 20 x 2.3 = 87 lb P_2O_5/dry ton

Avail. P_2O_5/dry ton = 0.5 (87 lb total P_2O_5/dry ton) = ~44 lb P_2O_5/dry ton

For the wheat field, the agronomic P rate is calculated as follows:

Wheat Field - 1995 Growing Season

A. Year of Growing Season	B. Starting Org-N (lb/acre)	C. Mineralization Rate (K_{min})	D. Mineralized Org-N (lb/acre)	E. Org-N Remaining (lb/acre)
1993 Sludge Application				
0-1 (1993 Application)	230	0.20	46	184
1-2 (1994)	184	0.10	18	166
2-3 (1995)	166	0.05	8	158

PAN credit for the 1993 sludge application during 1995 is 8 lb N/acre.

Corn Field - 1995 Growing Season

A. Year of Growing Season	B. Starting Org-N (lb/acre)	C. Mineralization Rate (K_{min})	D. Mineralized Org-N (lb/acre)	E. Org-N Remaining (lb/acre)
1993 Sludge Application				
0-1 (1993 Application)	130	0.20	26	104
1-2 (1994)	104	0.10	10	94
2-3 (1995)	94	0.05	5	89
1994 Sludge Application				
0-1 (1994 Application)	270	0.20	54	216
1-2 (1995)	216	0.10	22	194
2-3 (1996)	194	0.05	10	184

PAN credit for the 1995 growing season on this field due to sewage sludge applications in 1993 and 1994 is: 5 + 22 = 27 lb N/acre.

Figure 7-3. Worksheet 1 calculations to determine residual N credits for previous sewage sludge applications.

Worksheet 2
Nitrogen Budget Sheet for Determining the Agronomic N Rate for Sewage Sludge Applications

Symbols and Abbreviations Used

Org-N = Organic N content of the sewage sludge obtained from analytical testing and determined by subtracting (NO_3-N + NH_4-N) from total N, usually given in percent (%); the resulting concentration should be converted to lb/ton (dry weight basis).

NH_4-N = Ammonium N content of the sewage sludge obtained from analytical testing and usually given in percent (%); then convert to lb/ton (d.w. basis).

NO_3-N = Nitrate N content of the sewage sludge obtained from analytical testing and often given in mg/kg; then convert to lb/ton (d.w. basis).

K_{min} = Mineralization rate for the sewage sludge expressed as a fraction of the sludge Org-N expected to be released as PAN for the year being calculated; example mineralization rates for different sewage sludges can be found in Table 7-7.

K_{vol} = Volatilization factor for estimating the amount of NH_4-N remaining after loss to the atmosphere as ammonia and expressed as a fraction (e.g., if K_{vol} = 1.0, 100% of the NH_4-N is retained and contributes to PAN; if K_{vol} = 0.5, then (0.5 x NH_4-N content) estimates the amount of NH_4-N contributing to PAN).

PAN = Plant-available N which is determined by calculating: $NO_3\text{-N} + K_{vol}(NH_4\text{-N}) + K_{min}(\text{Org-N})$

Helpful Conversions

mg/kg x 0.002 = lb/ton	lb/acre x 1.12 = kg/ha	lb/ton ÷ 2 = kg/mt
% x 20 = lb/ton	ton/acre x 2.24 = mt/ha	(mt = metric ton = 1000 kg)

1. Total N requirement of crop to be grown (*obtain information from Cooperative Extension Service agricultural agents, USDA-Natural Resource Conservation Service or other agronomy professionals*). — 90 lb/acre

2. Nitrogen provided from other N sources added or mineralized in the soil
   a. N from a previous legume crop (legume credit) or green manure crop — 30 lb/acre
   b. N from supplemental fertilizers already, or expected to be, added — -- lb/acre
   c. N that will be added by irrigation water — -- lb/acre
   d. Estimate of available N from previous sludge applications (*from Worksheet 1*) — 8 lb/acre
   e. Estimate of available N from a previous manure application (*obtain mineralization factors from land-grant university to calculate similarly as for previous sewage sludge applications*). — -- lb/acre
   f. Soil nitrate test of available N present in soil [*this quantity can be substituted in place of (a + d + e), if test is conducted properly; do not use this test value if estimates for a, d and e are used*] — -- lb/acre

   Total N available from existing, expected, and planned sources of N (*add a+b+c+d+e* or *b+c+f*) — 38 lb/acre

3. Loss of available N by denitrification, immobilization, or NH_4^+ fixation (*check with state regulatory agency for approval, before using this site-specific factor*). — -- lb/acre

4. Calculate the adjusted fertilizer N requirement for the crop to be grown (*subtract Total N for (2) from (1); amount for (3) can be added to this difference, only if (3) is approved for this additional adjustment*). — 52 lb/acre

Figure 7-4. Calculation of the agronomic N rate for the wheat field.

Worksheet 2 (continued)

5. Determine the PAN/dry ton for the sludge that will be applied [i.e., NO_3-N + K_{vol} (NH_4-N) + K_{min} (Org-N) = PAN] — 28 lb/ton

6. Calculate the agronomic N rate of sewage sludge *(Divide (4) by (5))* — 1.9 ton/acre

7. Convert the rate of sewage sludge in dry tons/acre into gallons/acre, cubic yards/acre, or wet tons/acre, since the sludge will be applied to land as a liquid or as a wet cake material.

Figure 7-4. Calculation of the agronomic N rate for the wheat field (continued).

Worksheet 2
Nitrogen Budget Sheet for Determining the Agronomic N Rate for Sewage Sludge Applications

Symbols and Abbreviations Used

Org-N = Organic N content of the sewage sludge obtained from analytical testing and determined by subtracting (NO_3-N + NH_4-N) from total N, usually given in percent (%); the resulting concentration should be converted to lb/ton (dry weight basis).

NH_4-N = Ammonium N content of the sewage sludge obtained from analytical testing and usually given in percent (%); then convert to lb/ton (d.w. basis).

NO_3-N = Nitrate N content of the sewage sludge obtained from analytical testing and often given in mg/kg; then convert to lb/ton (d.w. basis).

K_{min} = Mineralization rate for the sewage sludge expressed as a fraction of the sludge Org-N expected to be released as PAN for the year being calculated; example mineralization rates for different sewage sludges can be found in Table 7-7.

K_{vol} = Volatilization factor for estimating the amount of NH_4-N remaining after loss to the atmosphere as ammonia and expressed as a fraction (e.g., if K_{vol} = 1.0, 100% of the NH_4-N is retained and contributes to PAN; if K_{vol} = 0.5, then (0.5 x NH_4-N content) estimates the amount of NH_4-N contributing to PAN).

PAN = Plant-available N which is determined by calculating: NO_3-N + K_{vol}(NH_4-N) + K_{min}(Org-N)

Helpful Conversions

mg/kg x 0.002 = lb/ton	lb/acre x 1.12 = kg/ha	lb/ton ÷ 2 = kg/mt
% x 20 = lb/ton	ton/acre x 2.24 = mt/ha	(mt = metric ton = 1000 kg)

1. Total N requirement of crop to be grown (*obtain information from Cooperative Extension Service agricultural agents, USDA-Natural Resource Conservation Service or other agronomy professionals*). — 190 lb/acre

2. Nitrogen provided from other N sources added or mineralized in the soil
   a. N from a previous legume crop (legume credit) or green manure crop — -- lb/acre
   b. N from supplemental fertilizers already, or expected to be, added — -- lb/acre
   c. N that will be added by irrigation water — -- lb/acre
   d. Estimate of available N from previous sludge applications (*from Worksheet 1*) — 27 lb/acre
   e. Estimate of available N from a previous manure application (*obtain mineralization factors from land-grant university to calculate similarly as for previous sewage sludge applications*). — -- lb/acre
   f. Soil nitrate test of available N present in soil [*this quantity can be substituted in place of (a + d + e), if test is conducted properly; do not use this test value if estimates for a, d and e are used*] — -- lb/acre

   Total N available from existing, expected, and planned sources of N (*add a+b+c+d+e* or *b+c+f*) — 27 lb/acre

3. Loss of available N by denitrification, immobilization, or NH_4^+ fixation (*check with state regulatory agency for approval, before using this site-specific factor*). — -- lb/acre

4. Calculate the adjusted fertilizer N requirement for the crop to be grown (*subtract Total N for (2) from (1); amount for (3) can be added to this difference, only if (3) is approved for this additional adjustment*). — 163 lb/acre

Figure 7-5. Calculation of the agronomic N rate for the corn field.

Worksheet 2 (continued)

5. Determine the PAN/dry ton for the sludge that will be applied [i.e., NO_3-N + K_{vol} (NH_4-N) + K_{min} (Org-N) = PAN] — 35 lb/ton

6. Calculate the agronomic N rate of sewage sludge (*Divide (4) by (5)*) — 4.7 ton/acre

7. Convert the rate of sewage sludge in dry tons/acre into gallons/acre, cubic yards/acre, or wet tons/acre, since the sludge will be applied to land as a liquid or as a wet cake material.

Figure 7-5. Calculation of the agronomic N rate for the corn field (continued).

P_{req} = Fertilizer P_2O_5 Recommendation =
80 lb P_2O_5/acre, so

Agronomic P rate = P_{req} ÷ Avail. P_2O_5/dry ton =
80 lb P_2O_5/acre ÷ 44 lb P_2O_5/dry ton =
~1.8 dry ton/acre

For the corn field, the agronomic P rate would be:

P_{req} = 60 lb P_2O_5/acre, so

Agronomic P rate = 60 lb P_2O_5/acre ÷
44 lb P_2O_5/dry ton = ~1.4 dry ton/acre

Since the agronomic P rate for each field is less than the agronomic N rate, these rates could be selected to use. The consequence of utilizing P rates rather than N rates is that less sewage sludge per acre will normally be applied, so more land area will be needed to apply the total sludge produced by the treatment works. For example, the design example treatment works generates 7,300 dry ton/year (i.e., 20 dry ton/day x 365 days/year). If sludge was applied at a rate equal to the agronomic P rate for the corn field, about 5,220 acres/year would be needed to apply all the sludge produced (i.e., 7,300 dry ton/year ÷ 1.4 dry ton/acre). But if sludge was applied at the agronomic N rate for the corn field, only about 1,560 acres would be needed to apply all the sludge produced (i.e., 7,300 dry ton/year ÷ 4.7 dry ton/acre).

Alternatively, continuously using the agronomic N rate would result in excess P (beyond what the crop needs) being applied. As was discussed in Section 7.4.4.2, soil P fertility levels will likely be increased over time. Unusually high soil P levels can potentially increase the risk of nonpoint source pollution losses of P to surface waters and contribute to undesirable water quality. A second consequence is that supplemental N fertilizers must be added to fulfill the remaining N needs of the crop not supplied by the sewage sludge. The quantity of additional N can be calculated by returning to Worksheet 2 and multiplying the PAN/dry ton times the rate of sewage sludge applied, and then subtracting this PAN/acre value from the adjusted fertilizer N requirement.

For example, using Figure 7-5 for the corn field and assuming the agronomic P rate was used (i.e., 1.4 dry ton/acre), the supplemental N fertilizer needed is:

35 lb PAN/dry ton x 1.4 dry ton/acre =
49 lb PAN/acre

163 lb N/acre - 49 lb N/acre = 114 lb N/acre

7.5.4 Calculation of Supplemental K Fertilizer To Meet Crop Nutrient Requirements

Because K is a soluble nutrient, most of the K received by a treatment works is discharged with effluents. Consequently, sewage sludges will contain low concentrations of this major plant nutrient. Therefore, fertilizer potash (K_2O) or other sources of K will be needed to supplement the quantities of K_2O added by sewage sludge applications, particularly over the long-term.

The amount of sewage sludge K_2O applied can be calculated from sludge analysis information in a similar manner as is done for P_2O_5 (Section 7.4.4.2). Since K is readily soluble, however, all the K in sewage sludge is assumed to be available for crop growth compared to P, which is assumed to be about 50% available to plants. As with P, soil fertility testing can be used to monitor these K_2O additions and determine additional K_2O that is needed for crops.

The quantity of K_2O that can be credited against the K_2O fertilizer recommendation is calculated using the following equation:

Sludge K_2O applied = Sludge rate (dry ton/acre) x
Avail. K_2O/dry ton

where:

Avail. K_2O = %K in sludge × 20 × 1.2*

*1.2 is the factor to convert lb K to lb K_2O (the ratio of the atomic weights of K_2O:K, i.e., 94:78).

For the wheat field, which had a K fertilizer recommendation of 125 lb K_2O/acre, determining additional K_2O needs, assuming the agronomic N rate (i.e., 1.9 dry ton/acre) is used, is as follows:

Since the sewage sludge for our design example
contains 0.5% K, the available K_2O = 0.5% x
20 x 1.2 = 12 lb K_2O/dry ton.

Sludge K_2O applied = 1.9 dry ton/acre x
12 lb K_2O/dry ton = 23 lb K_2O/acre

Additional K_2O needed = 125 lb K_2O/acre -
23 lb K_2O/acre = 102 lb K_2O/acre

For the corn field, which had a fertilizer recommendation of 140 lb K_2O/acre, and again assuming the agronomic N rate (i.e., 4.7 dry ton/acre) is used, additional K_2O needs will be:

Sludge K_2O applied = 4.7 dry ton/acre x
12 lb K_2O/dry ton = 56 lb K_2O/acre

Additional K_2O needed = 140 - 56 =
84 lb K_2O/acre

7.5.5 *Additional Considerations for Land Application Program Planning*

To simplify the design example, only two fields with different crops were considered. For most land application programs, however, sewage sludge will be applied to more than two crops and to many individual fields. Application rate calculations should be made for each field receiving sewage sludge as a detailed plan is developed. For this design example, additional crops could be oats, soybeans, and forages for hay and pasture. Crop rotations and relative acreages of each crop will vary from one crop producer to another. Also keep in mind that farms with livestock will be producing animal manure nutrients in addition to the sewage sludge nutrients used for supplying plant nutrient requirements on the acreage available for growing crops.

7.6 References

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Chapter 8
Process Design for Forest Land Application Sites

8.1 General

Sewage sludge application to forests can greatly increase forest productivity. Research at the University of Washington showed that for some tree species, the use of sewage sludge as a fertilizer resulted in excellent and prolonged increases in height and diameter growth compared to controls (Henry et al., 1993). Sewage sludge amends the soil by providing nutrients, especially nitrogen (N) and phosphorus (P), that are frequently limited in forest soils, and by improving soil textural characteristics. Sewage sludge addition can improve short-term soil productivity because it provides an immediate supply of virtually every nutrient needed for plant growth in an available form. In addition, the fine particles and organics in sewage sludge can immediately and permanently enhance soil moisture and nutrient-holding characteristics. In the long-term, sewage sludge provides a continual slow release input of nutrients as the organics decompose.

Forest soils are in many ways well suited to sewage sludge application. They have high rates of infiltration (which reduce runoff and ponding), large amounts of organic material (which immobilize metals from the sewage sludge), and perennial root systems (which allow year-round application in mild climates). Although forest soils are frequently quite acidic, research has found no problems with metal leaching following sewage sludge application (U.S. EPA, 1984).

One major advantage of forest application over agricultural application is that forest products (e.g., wild edible berries, mushrooms, game, and nuts) are an insignificant part of the human food chain. In addition, in many regions, forest land is extensive and provides a reasonable sewage sludge land application alternative to agricultural cropland. The primary environmental and public health concern associated with forest application is pollution of water supplies. In many areas, particularly in the western states, forest lands form crucial watersheds and ground-water recharge areas. Contamination of water supplies by nitrates can be prevented by limiting sewage sludge application rates according to the nitrogen needs of the crop (as required by the Part 503 regulation), in this case trees (approximately 10 to 100 metric tons dry weight per hectare [t DW/ha] in a single application every 3 to 5 years).

Application of sewage sludge to forest land is feasible on commercial timber and fiber production lands, federal and state forests, and privately owned woodlots. Sewage sludge use in nurseries, green belt management, and Christmas tree production also is possible.

This chapter discusses sewage sludge applications to forest land for three common situations: (1) recently cleared forest land that has not been planted, (2) young plantations (planted or coppice), and (3) established forest stands. Each of these cases presents different design issues and opportunities. Public participation considerations are a critical aspect of forest land application systems, as discussed in Chapter 12.

8.2 Regulatory Requirements and Other Considerations

The federal Part 503 regulatory requirements associated with land application of sewage sludge to forest lands regarding metals, pathogens, and nitrogen are discussed in Chapter 3. Issues particularly relevant to land application at forest sites are discussed below.

8.2.1 Pathogens

Organisms present in forest soils are responsible for the relatively quick die off of pathogens following sewage sludge application to a forest site. Microorganisms present in the sewage sludge are initially filtered out by the soil and forest floor and then replaced by the native organisms of the soil. The survival time for most microorganisms following land application of sewage sludge to forests typically is very short but depends on a variety of soil and climatic conditions including temperature, moisture content, and pH.[1] For a further discussion of pathogen die off, see Chapter 4.

Pathogen-related concerns involving windborne contamination may arise when spray application of liquid

[1] Henry, Charles. Biosolids Utilization in Forest Lands. Draft report. University of Washington, Eatonville, WA.

sewage sludge on forest lands is used. Precautions can be taken to minimize exposure during and after spray application, such as restricting public access from the area downwind during the spray application and for several hours after spraying is completed, and considering wind velocity so that applications can be controlled. Generally, aerosols will not travel far in an established, non-dormant forest because of interception by the leaves and breakup of wind currents.

8.2.2 Nitrogen Dynamics

As with other types of land application sites, nitrogen needs at forest sites (i.e., N needed by trees and understory) are an essential component of the land application system. Sewage sludge at a forest site must be applied at a rate that is equal to or less than the agronomic rate for N, as required by the Part 503 regulation. Key factors regarding nitrogen levels at forest sites include nitrogen uptake by plants; mineralization of nitrogen; ammonia volatilization; denitrification; soil immobilization rates; nitrogen leaching; and temperature-related effects. These factors are discussed in Section 8.9 below, particularly as they affect determination of sewage sludge application rates at forest sites.

8.3 Effect of Sewage Sludge Applications on Tree Growth and Wood Properties

8.3.1 Seedling Survival

Seedlings of deciduous species and many conifers, including Douglas fir and Sitka spruce, have shown excellent tolerance to sewage sludge in demonstration projects. At relatively light application rates (i.e. agronomic loadings), seedling mortality is not a problem, and planting should be possible soon after sludge application.

8.3.2 Growth Response

Growth response has been documented on a number of stands of Douglas-fir in Washington (Henry et al., 1993). Growth responses can range from 2% to 100% for existing stands, and over 1,000% for trees planted in soils amended with heavy applications of sewage sludge. The magnitude of this response depends on site characteristics and tree stand ages. Some of the main site differences affecting growth response include:

- *Site class*. In both young Douglas-fir plantations and older stands, greater growth responses have been found where the trees are doing poorly due to lack of nutrients.

- *Thinned versus unthinned stands treated with sewage sludge*. There appears to be little difference in total wood produced in unthinned versus thinned stands that have received sewage sludge applications. In thinned stands, however, growth is concentrated in trees with larger diameters.

- *Response by species*. Most tree species grow faster in soil treated with sewage sludge; however, some species respond dramatically while others show only a slight response. Excellent response has been shown by black locust, European alder, hybrid poplar, Japanese larch, and catalpa (Sopper, 1993).

Greater growth responses have been seen when trees have been planted directly in soil already amended with large amounts of sewage sludge, such as a soil reclamation site. In this case, special management practices are required. An excellent example of this type of application is Christmas tree plantations.

Because sewage sludge application to forest sites is relatively new and limited data have been collected, it is difficult to estimate the value added to a forest site when sewage sludge is land applied. A conservative estimate of the value of sewage sludge could be based on the value of the nitrogen fertilizer potential alone, which would be approximately $30/dry ton of sewage sludge. Preliminary studies, however, have shown a greater growth response to sewage sludge than to chemical nitrogen fertilizer. Additionally, the effect appears to be much longer lasting, with some studies showing continued growth response 8 years after application.

8.3.3 Wood Quality

Accelerated tree growth (200 to 300 percent) resulting from sewage sludge addition has the potential for changing basic wood characteristics, including specific gravity, shrinkage, fibril angle, and certain mechanical properties. Research indicates that both positive and negative effects on wood quality occur in trees grown on sewage sludge-amended soil. In some studies, static bending tests, which show combined effects, have indicated no significant change when the strength properties of specimens cut from trees grown on sewage sludge-amended soils were compared with specimens of wood produced without sewage sludge. Other studies have shown a 10 to 15 percent reduction in density and in modulus of rupture and elasticity.[2]

8.4 Effect of Sewage Sludge Application on Forest Ecosystems

Although immediately after land application of sewage sludge a site is greatly altered in appearance, within six months understory growth often is much more vigorous than before sewage sludge application. Increased understory also is typically higher in nutrients and can provide better habitat for wildlife. A number of wildlife studies have found increased populations of animals on

[2] See footnote 1.

sites receiving sewage sludge compared to nearby sites that were not amended with sewage sludge (Henry and Harrison, 1991).

8.5 Forest Application Opportunities

8.5.1 Forest Stand Types

The land application designer may have the option of selecting among the following types of forest sites for sewage sludge addition:

- Sites recently cleared prior to replanting.
- Young plantations of an age conducive to sewage sludge application over the tops of trees.
- Established forests.

The advantages and disadvantages associated with each type of forest site are summarized in Tables 8-1 to 8-3.

8.5.1.1 Applications Prior to Planting

Clearcuts offer the easiest, most economical sites for sewage sludge application. Because application takes place prior to tree planting, many agricultural sewage sludge application methods can be used. Vehicles delivering sewage sludge from the treatment plant can discharge semi-solid sewage sludge (15% or more solids) directly on the land, followed by spreading by a dozer and disking. Ease of delivery depends on the amount of site preparation (stump removal, residual debris burning, etc.), slopes, soil conditions, and weather. Site preparation and sewage sludge characteristics are also major factors in application technique (e.g., temporary spray irrigation systems; injectors and splash plates for liquid material; manure spreaders for solid material).

While sewage sludge application is easier to perform on clearcuts, these sites also may require additional management practices to control grasses and rodents such as voles. If application to a clearcut is planned, a program of periodic disking and herbicides should be conducted to control grasses and rodents. Tree trunk protection devices also are available to provide a barrier against rodent girdling. Additionally, fencing or bud capping may be required to prevent excessive deer browsing. Sewage sludge injection into the soil may minimize plantation establishment problems.

8.5.1.2 Applications to Young Stands

Application of sewage sludge to existing stands typically is made by a tanker/sprayer system, which can apply sewage sludge with an 18% solids content over the tops of the trees (canopy) 125 feet (40 m) into a plantation. This method requires application trails at a maximum of 250 feet (80 m) intervals. King County Metro, Washington (including Seattle), has developed a throw spreader that is capable of applying a dewatered sewage sludge up to 70 m over a plantation. This method has greatly reduced application costs and allows trail spacing of greater distances (120 m with overlap for evenness of applications). A good tree age or size for this type of application are trees over 5 years or over 4 to 5 feet high because they minimize maintenance otherwise needed in clearcut areas. Timing of applications may be important with over-the-canopy applications because sewage sludge sticking on new foliage could retard the current year's growth during the active growth season.

Table 8-1. Sewage Sludge Application to Recently Cleared Forest Sites

Advantages

1. Better access for sludge application equipment. Also, optimal access can be established for additional sludge application in the future.
2. Possible option of incorporating the sludge into the soil (versus a surface application) if the site is sufficiently cleared.
3. Possible option of establishing a flooding or ridge and furrow sludge application system (versus spray application) if the site topography is favorable.
4. Option to select tree species that show good growth and survival characteristics on sludge-amended sites.
5. Often easier to control public access to the site because cleared areas are less attractive than wooded areas for typical forest recreational activities.

Disadvantages

1. Seedlings have low nitrogen uptake rates. If nitrate contamination of an underlying potable aquifer is a potential problem, initial sludge applications must be small relative to the volume of sludge application to established forests.
2. An intensive program of weed control is necessary since the weeds grow faster than the seedlings and compete for nutrients, space, light, etc. Use of herbicides and cultivation between tree rows usually is required for the first 3 to 4 years.
3. Intensive browsing by deer and damage to young trees by voles and other pest species may require special control measures, since these animals may selectively feed upon trees grown on sludge-amended sites due to their higher food value.

Table 8-2. Sewage Sludge Application to Young Forest Plantations (Over 2 Years Old)

Advantages

1. Seedlings are established and more tolerant of fresh sludge applications.
2. Weed control is less of a problem than with cleared sites because of established trees and vegetation.
3. Nitrogen uptake by the trees is rapidly increasing, and acceptable sludge application rates can be higher on these sites over aquifers than on recently cleared sites.
4. Access for sludge application equipment usually is still good.
5. Rapid growth response from most deciduous and many coniferous tree seedlings can be expected.

Disadvantages

1. Sludge application by spraying over the canopy may be restricted to those periods when the trees are dormant, to avoid the problem of sludge clinging to foliage. Application during periods of the year when heavy rainfalls are common may potentially alleviate this problem. In addition, sewage sludge applied to broad leaf species quickly dries and flakes off the leaves.
2. Some weed control will probably be necessary.

Table 8-3. Sewage Sludge Application to Closed Established Forest (Over 10 Years Old)

Advantages

1. Established forests are less susceptible to sludge-induced changes in vegetation (e.g., weed growth).
2. Excellent growth response can be expected to result from the increased nutrients.
3. Sludge application by spraying can be done under the tree foliage, so it is not necessary for the trees to be dormant.
4. During precipitation, rapid runoff of storm water containing sludge constituents is unlikely because the forest canopy breaks up the rain and accumulated organic debris on the forest floor absorbs runoff.
5. Forest soils under established forests usually have high C-to-N ratios resulting in excellent capability to immobilize (store) nitrogen for slow release in future years. Consequently, it often is feasible to make an initial heavy application of sludge, e.g., 74 t/ha (33 T/ac), and achieve tree growth response for up to 5 years without subsequent sludge applications.

Disadvantages

1. Access by sludge application vehicles into a mature forest often is difficult. The maximum range of sludge spray cannons is about 40 m (120 ft). To obtain fairly uniform coverage, the spray application vehicle requires access into the site on a road grid, spaced at approximately 75-m (250-ft) intervals. Most established forest sites do not have such grid-like roads. As a result, access roads must be cut through the forest, or the selected sludge application area(s) are largely restricted to narrow 36-m (120-ft) strips on both sides of existing roads. Access into commercial forests is usually easier than into publicly owned forest lands.
2. In an established publicly owned forest, it may not be advantageous to accelerate vegetation with sludge applications. In contrast, commercial forest operations desire faster growth of trees.

Notes:
t = metric tonnes
T = English tons (short)

Liquid sewage sludge also has been successfully applied using a sprinkler irrigation system. Clogging of nozzles has been the major drawback to this method. Manure spreaders are capable of applying dewatered sewage sludge which cannot be sprayed. Depending on the range of sewage sludge trajectory, application trails may need to be at closer intervals than with other methods.

It is recommended that sewage sludge applications take place during the time that tree growth is reduced, but uptake of nutrients also is reduced during this time. When sewage sludge is first applied to the soil, the available N is in the NH_4^+ form, which does not leach. In addition, in some cases such as in northern cool climates, during the non-growing season soil temperatures are low and neither N mineralization (transformation of organic N to NH_4^+) or nitrification (transformation of NH_4^+ to NO_3^-) occurs significantly. Thus nutrients are effectively "stored" until the next growing season.

8.5.1.3 Applications to Mature Stands

Applications to older stands have the advantage that sewage sludge can be applied year-round. Because spraying takes place under the tree foliage, no foliage will be affected. Application methods are similar to those described for young plantations. In many cases, however, stands are not in rows, which may eliminate some of the alternatives available for plantations.

8.5.2 Christmas Tree Plantations

One clearcut application scenario that has worked well in the state of Washington is the use of sewage sludge application in Christmas tree stands. Typically, a high level of maintenance is common, and weed establishment and rodent populations are minimized as standard practice.

8.6 Equipment for Sewage Sludge Application at Forest Sites

8.6.1 Transfer Equipment

Sewage sludge usually comes from the wastewater treatment plant (WWTP) in an over-the-road vehicle. Once at the site it is often stored, at least temporarily, before being transferred to an application vehicle. Exceptions to storage are when a multi-purpose highway/application vehicle is used (generally by smaller facilities) and when applications are close to the WWTP. The two basic mechanisms for transferring sewage sludge from vehicles to storage facilities are (1) direct dumping, and (2) pumping. The transfer method suitable for a particular site depends on how liquid the sewage sludge is (i.e., how easy it is to pump), or the position and configuration of the storage vessel (i.e., whether gravity is sufficient to transfer the sewage sludge).

Direct dumping of sewage sludge is the easiest method for unloading a trailer from a treatment plant. Gravity dumping requires either using an in-ground storage facility or driving the truck onto a ramp above the storage facility. Additionally, sewage sludge must be dilute enough to flow from the trailer (<8% solids) or pressurized tank (<15% solids), or the trailer bed must be tilted.

Pumping the sewage sludge can work if the sewage sludge is liquid enough. Below 10% to 15% solids, most sewage sludge flows as a semi-solid and can be fed through a pump. Higher solids concentrations restrict or eliminate the flow of sewage sludge to the pump. Centrifugal pumps can be used for dilute sewage sludge (<10% to 13% solids), or chopper-type centrifugal pumps may be able to pump sewage sludge of up to 15% solids. If dewatered sewage sludge (>15%) is brought to the site and a pump is to be used to transfer the sludge, water must be added and mixed with the sewage sludge before pumping is possible.

8.6.2 Application Equipment

There are four general types of methods for applying sewage sludge to forests: (1) direct spreading; (2) spray irrigation with either a set system or a traveling gun; (3) spray application by an application vehicle with a spray cannon; and (4) application by a manure-type spreader. The main criteria used in choosing a system is the liquid content of the sewage sludge. Methods 1, 2, and 3 are effective for liquid sewage sludge (2% to 8% solids); Methods 1 and 2 can be used for semi-solid sewage sludge (8% to 18% solids); and only Method 4 is acceptable for solid sewage sludge (20% to 40% solids). Table 8-4 lists these methods, their range of application, relative costs, and advantages and disadvantages. The method used by most municipalities for forest applications is spray application by an application vehicle with a mounted cannon, although King County Metro in Washington state now applies a dewatered sewage sludge with a throw spreader.

Many application vehicles have been developed for use in agricultural applications. Most of these can be readily modified for forest use by mounting a spray nozzle and pump on the tank. Application vehicles can also be custom made. Depending on the site needs, a specially designed all-terrain vehicle can be used. In some cases, a used heavy-duty truck chassis with a rear-mounted tank has been modified for forest use. The application vehicle can either be filled by a traveling tanker, directly from on-site storage, or can itself be an over-the-road multi-purpose (transport/application) vehicle. Once full, the application vehicle moves into the forest over the roads or trails and

Table 8-4. Comparison of Different Application Systems for Forest Sites (Henry, 1991)

System and Range	Relative Costs	Advantages	Disadvantages
Sludge spreading and incorporation range = 10’ (3 m)	Low capital and O&M	Simple to operate; any % solids	Need cleared site; difficult plantation establishment with some species
Spray irrigation: Set irrigation systems range = 30’ - 200’	High capital, low O&M	Simple to operate	Frequent clogging; use only low % solids; brush interferes
Traveling big gun range = 200’	Moderate capital, low O&M	Simple to operate on appropriate sites	Frequent clogging; use only low % solids; brush interferes
Application vehicle with mounted cannon range = 125’	Low-moderate capital, high O&M	Any terrain; sludge up to 18% solids	May need special trails
Manure-type spreader range = 50’-200’	Low capital and O&M	Only effective way to apply high % solids sludge	Limited to high % solids; trails may need to be close together

O&M = operation and maintenance costs.

unloads the sewage sludge in uniform thin layers while the vehicle is either moving or stationary.

Considerations for on-site storage are discussed in Chapter 14.

8.7 Scheduling

Sewage sludge applications to forest sites can be made either annually or once every several years. Annual applications are designed to provide N only for the annual uptake requirements of the trees, considering volatilization and denitrification losses and mineralization from current and prior years. An application one year followed by a number of years when no applications are made utilizes soil storage (immobilization) of nitrogen to temporarily tie up excess nitrogen that will become available in later years.

In a multiple-year (e.g., every 3 to 5 years) application system, the forest floor, vegetation, and soil have a prolonged period to return to normal conditions, and the public can use the site for recreation in the non-applied years. Application rates, however, are not simply an annual rate multiplied by the number of years before reapplication, but rather need to be calculated so that no NO_3^- leaching occurs. If the sewage sludge is quite liquid (<5% solids), annual applications may be preferred, since the water included with heavier applications at low percent solids may exceed the soil's infiltration rate. In this case surface sealing may occur, increasing the potential for runoff as well as anaerobic conditions, which can cause odor problems or stress the plants.

For liquid and semi-liquid sewage sludge, if the total depth of an application is to be greater than approximately one-quarter of an inch, it is recommended that a series of three or more partial applications (with the number depending on the percent solids of the sludge) be made rather than one heavy application. This practice allows more even applications to be made, provides time for stabilization or drying of the sewage sludge to occur, and is important for maintaining infiltration and controlling runoff. The "rest" between applications will range from 2 to 14 days depending on weather conditions.

Scheduling sewage sludge application also requires a consideration of climatic conditions and the age of the forest. High rainfall periods and/or freezing conditions can limit sewage sludge applications in almost all situations. The Part 503 regulation prohibits bulk sewage sludge from being applied to forest land that is flooded, frozen, or snow-covered so that the sewage sludge enters a wetlands or other surface waters. In addition, vehicle access to steeper soils could potentially be too difficult during the wet parts of the year. As discussed in Section 8.5.1.2, all applications to young plantations should be done when the trees are dormant (e.g., during the late fall, winter, and early spring).

An application schedule for a 1-year period is shown in Table 8-5 for a design in the Pacific Northwest. Using such a schedule, it would be feasible to avoid the need for storage, especially when alternative management schemes are available. On-site storage, however, may also be desirable.

Table 8-5. Monthly Application Schedule for a Design in the Pacific Northwest

	Glacial Soil		Residual Soil	
Month	Young Plantation	Established Forest	Young Plantation	Established Forest
January	A[a]	A	LA	LA
February	A	A	LA	LA
March	A	A	LA	LA
April	NA	A	NA	A
May	NA	A	NA	A
June	NA	A	NA	A
July	NA	A	NA	A
August	NA	A	NA	A
September	NA	A	NA	A
October	A	A	LA	LA
November	A	A	LA	LA
December	A	A	LA	LA

[a] Abbreviations:
A = Site available, no limitations.
NA = Not available, damage will be caused by sludge on growing foliage.
LA = Limited availablity, periods of extended rain are to be avoided due to vehicle access problems

8.8 Determining Sewage Sludge Application Rates for Forest Sites

8.8.1 General

As with agricultural lands, sewage sludge application rates at forest sites usually are based on tree N requirements. As discussed below, nitrogen dynamics of forest systems are somewhat more complex than agricultural systems because of recycling of nutrients in decaying litterfall, twigs and branches, and the immobilization of the NH_4^+ contained in sludge as a result of decomposition of these materials. As with agricultural applications, concentrations of trace elements (metals) in some sewage sludges may limit the cumulative amount of sewage sludge that can be placed on a particular area (see Chapter 7, Section 7.4.4.3).

8.8.2 Nitrogen Uptake and Dynamics in Forests

In general, uptake and storage of nutrients by forests can be as large as that of agricultural crops if the system is correctly managed and species are selected that respond to sewage sludge. The trees and understory utilize the available N from sewage sludge, resulting in an increase in growth. There is a significant difference between tree species in their uptake of available N. In addition, there is a large difference between the N uptake by seedlings, vigorously growing trees, and mature trees. (One study found that in young Douglas-fir, uptake can be up to 100 lb-N/ac/yr when the trees fully occupy the site, but as low as 25 lb-N/ac/yr in old Douglas-fir stands [Dyck et al., 1984]). Finally, the amount of vegetative understory on the forest floor will affect the uptake of N; dense understory vegetation markedly increases N uptake.

Table 8-6 provides estimates of annual N uptake by the overstory and understory vegetation of fully established and vigorously growing forest ecosystems in selected regions of the United States. The reported average annual N uptakes vary from 106 to 300 kg/ha/year (89 to 267 lb/ac/year), depending on species, age, etc. Note that all of the trees listed in the table are at least 5 years old, and that during initial stages of growth, tree seedlings will have relatively lower N uptake rates than shown.

Table 8-6. Estimated Annual Nitrogen Removal by Forest Types

Forest Type	Tree Age (years)	Average N Uptake (lb/ac/yr)	Average N Uptake (kg/ha/yr)
Eastern Forests (Irrigated Wastewater)			
Mixed Hardwoods	40-60		200
Red Pine	25		100
Old Field with White Spruce Plantation	15		200
Pioneer Succession	5-15		200
Aspen Sprouts	-		100
Southern Forests (Irrigated Wastewater)			
Mixed Hardwoods	40-60		280
Southern Pine with No Understory (mainly Loblolly)	20		200
Southern Pine with Understory (mainly Loblolly)	20		260
Lake States Forests (Irrigated Wastewater)			
Mixed Hardwoods	50		100
Hybrid Poplar[a]	20		150
Western Forests			
Irrigated Wastewater			
Hybrid Poplar	4-5		300
Douglas Fir Plantation	15-25		200
Sludge Application			
Hybrid cottonwood	5	250	
Young Douglas-fir, 100% site occupied	7-15	100	
Older Douglas-fir	>40	45	
Understory, first application[b]	-	100	
Understory, reapplications	-	0	

Sources: Stone (1968) for irrigated wastewater sites; Henry (see footnote 1) for western sludge application.
[a] Short-term rotation with harvesting at 4 to 5 years; represents first growth cycle from planted seedlings.
[b] Adjust by % site covered.

Calculation of sewage sludge application rates to supply plant N requirements is somewhat more complicated than for agricultural crops because the following nitrogen transformations need to be considered in addition to N mineralization and ammonia volatilization from the sewage sludge: (1) denitrification, (2) uptake by understory, and (3) soil immobilization for enhancement of forest soil organic-N (ON) pools. Table 8-7 presents ranges of values and suggested design values for nitrogen transformations and losses from sewage sludge applied to forest environments. The discussion below focuses on major aspects of nitrogen dynamics in forest ecosystems.

8.8.2.1 Nitrogen Mineralization

Mineralization (transformation of organic N to NH_4^+) occurs when the organics in sewage sludge decompose, releasing NH_4^+. Typical values for N mineralization for the first year can be quite variable, ranging from 10% to 50% or more. A recent study conducted on a number of sewage sludges from Oregon found that N mineralization

Table 8-7. Ranges of Values and Suggested Design Values for Nitrogen Transformations and Losses From Sewage Sludge Applied to Forest Environments (Henry, 1993)

Transformation/Loss Design Value	Range	Suggested
Nitrogen Mineralization		
Anaerobically digested	20% - 65%	
short detention		40%
long detention		20%
Lagooned	10% - 20%	
short detention		20%
long detention		10%
Composted	5% - 50%	
mixed or with short detention		40%
long detention, fully cured		10%
Ammonia Volatilization	0% - 25%	
Open stand		10%
Closed stand		0%
Denitrification		
Moist soils much of year		10%
Dry soils		0%
Soil Immobilization	0 - 1,000 lb/ac	
First application		
young stand		100 lb/ac
old stand		0 lb/ac
Reapplications		0 lb/ac
Plant Uptake (see Table 8-6)		

ranged from 20% to 65% for anaerobically digested sewage sludge, 15% to 19% for lagooned sewage sludge, and 36% to 50% for short-detention composted sewage sludge for the first year.[3] Table 8-7 gives ranges and typical values for mineralization of sewage sludge applied to forest sites. Because mineralization of different sewage sludge varies so much, it is recommended that mineralization studies be conducted on specific sewage sludge.

8.8.2.2 Ammonia Volatilization

Volatilization losses (when NH_4^+ escapes to the atmosphere) from sewage sludge surface-applied to agricultural soils have been measured from 10% to 60% of the initial NH_4^+, and a typical design number is 50%. Forest environments, however, probably lose considerably less than this due to the low pH of the forest floor, the low wind speed in forest stands, and less radiation reaching the forest floor. Measurements taken both in western and eastern Washington forests which were fairly open range from 10% of the initial NH_4^+ being lost with a light liquid application (dry site) (Henry and Zabowski, 1990), 25% in a western Washington forest with a closed canopy, and 35% lost in an open older forest stand in western Washington.[4] Current work in British Columbia with surface applications to hybrid poplar plantations suggests losses ranging from 25% to 100% of the initial NH_4^+.[5] Suggested conservative values in Table 8-7 are 10% in open stands and no ammonia volatilization in closed stands.

8.8.2.3 Denitrification

Excess NH_4^+ not taken up by the vegetation or immobilized by the soil will in most cases microbially transform into nitrate. When there is little oxygen in the soil, some of the NO_3^- can be lost to the atmosphere as N_2 or N_2O, a process called denitrification. Depending on soil conditions, denitrification losses up to 25 percent of the total can occur (U.S. EPA, 1983). Measurements taken in a dry eastern Washington forest showed no denitrification (Henry and Zabowski, 1990), while in a well drained western forest about 10% denitrification was predicted (Coles et al., 1992). Table 8-7 contains suggested values for denitrification.

8.8.2.4 Soil Immobilization Rates

Immobilization is the transformation of NH_4^+ into organic-N by soil microbes. Because forest soils include an organic layer containing decaying litterfall, twigs, and branches, the soil may have a lot of excess organic carbon both in the forest floor and the surface soil horizons. When this carbon decomposes, it uses some of the available N. This immobilization represents long-term soil storage of nitrogen that will be re-released (mineralized) at a very slow rate. Depending on the amount of carbon and whether the site has been fertilized before, immobilization can be up to 1,100 kg/ha (Henry, 1991). A young stand with a good forest floor, however, probably will immobilize in the neighborhood of 220 kg/ha.

When sewage sludge is re-applied, little additional N will be immobilized unless the previous application was made many years before. Table 8-7 contains suggested values for immobilization. Overestimation of N immobilization at forest sites can result in sewage sludge application rates that significantly exceed tree N requirements. Consequently, estimates of immobilization should either be set very conservatively or based on sewage sludge field studies that document the increase of soil organic-N from different horizons.

The carbon to nitrogen ratios (C:N) of the forest floor and surface soil horizons can serve as indicators of the potential for soil immobilization of N from sewage sludge applied to forest sites (excluding large woody debris that decompose slowly). Generally, when the C:N ratio is greater than 20-30:1, immobilization will occur. Woody materials generally have much higher ratios (often exceeding 70:1). When sewage sludge is applied, the available N allows microbial populations to expand rapidly and decomposes the soil organic matter, temporarily locking up the N in microbial biomass or in long-term stable humic acids. The N incorporated into the cell structure of the microorganisms can eventually be released gradually as they die off.

8.8.2.5 Nitrogen Leaching

Typically, N is the limiting constituent for land applications of sewage sludge because when excess N is applied, it often results in nitrate leaching. The N available from sewage sludge addition can be microbially transformed into NO_3^- through a process known as nitrification. Because NO_3^- is negatively charged, it easily leaches to the ground water with percolating rainfall. A number of studies conducted at the University of Washington's Pack Forest Research Center confirmed that heavy applications of N resulted in substantial increases of NO_3^- in the ground water (Riekirk and Cole, 1976; Vogt et al., 1980).[6,7]

[3] Henry, C., A. Haub, and R. Harrison. Mineralization of sewage sludge nitrogen from six Oregon cities. Draft report.

[4] See footnote 1.

[5] Van Ham, M., and C. Henry. 1995. Personal communication between M. Van Ham and C. Henry, Pack Forest Research Center, University of Washington, Eatonville, WA.

[6] Henry, C., R. King, and R. Harrison. Distribution of nitrate leaching from application of municipal biosolids to Douglas-fir. Draft report.

[7] Henry, C., and D. Cole. Nitrate leaching from fertilization of three Douglas-fir stands with municipal biosolids. Draft report.

8.8.2.6 Effects of Temperature on Nitrogen Dynamics

In northern climates where winter soil temperatures are low, transformations caused by microbial action in soil slow down considerably. For instance, when the soil temperature decreases about 18°F, microbial action is about half as fast. At about 40°F microbial action essentially stops. Through much of the winter the average temperature of the soil may be at or below 40°F under forest stands in northern parts of the United States. This means that mineralization, nitrification, and denitrification essentially stop. Thus, the nutrients from land application of sewage sludge made during the winter will essentially be stored in the forest floor and soil layers until temperatures increase. Thus, NO_3^- leaching will not significantly occur from winter applications because NO_3^- will not be formed.

8.8.3 Calculation Based on Nitrogen for a Given Year

The calculation for the application rate at forest sites based on N for a given year involves determining site N requirements and available N in the sewage sludge. A site's net N needs are the sum of the N uptake by trees and understory and soil immobilization of N:

$$N_{req} = U_{tr} + U_{us} + SI \qquad (8\text{-}1)$$

where:

N_{req} = N requirements to be supplied by a given application of sewage sludge, kg/ha
U_{tr} = N uptake, by trees, kg/ha (Table 8-6)
U_{us} = N uptake by understory, kg/ha (Table 8-6)
SI = N immobilization in soil from initial sewage sludge application, kg/ha (Table 8-7)

The requirements for N are met by: 1) the N mineralized from previous applications, and 2) the N supplied by the current application of sewage sludge (NH_4^+, NO_3^- and mineralized ON). Organic-N is converted to NH_4^+ relatively rapidly during the first year. In future years, the remaining organic matter becomes more and more recalcitrant (does not decompose as easily) and ON mineralization is much reduced. Without local data on mineralization rates, it is recommended that ON mineralization be ignored beyond three years after application. The N supplied from previous applications is calculated as shown in equation 8-2.

$$\begin{aligned} N_{prev} = \{ & (S_1)(ON_1)(1-K_0)(K_1) \\ & + (S_2)(ON_2)(1-K_0)(1-K_1)(K_2) \\ & + (S_3)(ON_3)(1-K_0)(1-K_1)(1-K_2)(K_3)\}1{,}000 \qquad (8\text{-}2) \end{aligned}$$

where:

N_{prev} = Total mineralized N from sewage sludge applications in previous years, kg/ha
$S_{1,2,etc.}$ = Sewage sludge application rate 1, 2, etc. years ago, t/ha
$ON_{1,2,etc.}$ = Percent N in sewage sludge 1, 2, etc. years ago, expressed as a fraction
$K_{1,2,etc.}$ = Mineralization rate of ON 1, 2, etc. years after the year of application, expressed as a fraction

The amount of N available the year of application from a ton of the sewage sludge (PAN) is calculated from equation 8-3.

$$PAN = \{(AN)(1-V) + NN + (ON_0)(K_0)\}(1-D)(10) \qquad (8\text{-}3)$$

where:

PAN = Total plant available nitrogen, kg/ton
AN = Percent NH_4^+-N in sewage sludge as applied, %
NN = Percent NO_3^--N in sewage sludge as applied, %
ON_0 = Percent ON in sewage sludge as applied, %
K_0 = Mineralization rate of ON during the year of application, expressed as a fraction
V = Loss of ammonia by volatilization, expressed as a fraction
D = Loss of N by denitrification, expressed as a fraction

The sewage sludge application rate to supply a given year's N requirement is then calculated from the previous two equations:

$$S_0 = (N_{req} - N_{prev})/PAN \qquad (8\text{-}4)$$

Table 8-8 provides some example calculations for a young plantation and older stand of Douglas-fir. In comparing

Table 8-8. Example First-year Application Rate for Sewage Sludge Based on Available Nitrogen for Two Different Types of Douglas-fir Stands

Assumptions	Young Stand	Older Stand
Uptake by trees, U_{tr} (kg/ha)	112	50
Uptake by understory, U_{us} (kg/ha)	101	28
Soil immobilization, SI (kg/ha)	224	56
N required, N_{req} (kg/ha) (Eq. 8-1)	437	134
N mineralization, previous sewage sludge app., N_{prev} (kg/ha) (Eq. 8-2; no previous application)	0	0
Initial ammonia-N, AN (%)	1.0	1.0
Initial nitrate-N, NN (%)	0.0	0.0
Initial organic-N, ON (%)	4.0	4.0
Fraction of ON mineralized, K_0 (g/g)	.25	.25
Fraction of ammonia volatilized, V (g/g)	.25	.10
Fraction of N lost to denitrification, D (g/g)	.25	.10
Plant available N, PAN (kg/t) (Eq. 8-3)	17.5	19.0
Sewage sludge application rate, S_0 (t/ha) (Eq. 8-4)	33.3	7.8

these cases, note that total N requirements are higher for the young stand than the older stand (390 lb/ac vs 120 lb/ac), and available N in the sewage sludge is lower in the younger stand due to higher losses from volatilization and denitrification (26.3 lb/ac vs 34.2 lb/ac for the older stand). Consequently there is a large difference in sewage sludge application rates to meet N requirements in the two stands: 14.8 T/ac for the younger stand and 3.5 T/ac for the older stand.

8.8.4 Calculation of Sewage Sludge Application Rates for First and Subsequent Years

The sewage sludge application rate in any given year involves N budget calculations using procedures described in Section 8.8.3 so as not to exceed site N uptake requirements. Although the basic approach is the same for any year's application, special considerations in performing the N budget analysis will vary somewhat depending on whether it is an initial application, and whether subsequent applications are done annually or periodically (i.e., intervals exceeding one year).

A key consideration in the N budget for an initial application is determination of the amount of N in the sewage sludge that will be immobilized by the soil (SI in Equation 8-1). Sewage sludge additions will build up the soil N pools to the point that an equilibrium will eventually exist between soil N mineralization and immobilization. Thus, for subsequent *annual* applications, it should be assumed that there will be no additional soil immobilization. In fact, unless site-specific data documenting its existence is available, it is prudent to assume no additional soil immobilization unless the last application was made a considerable time in the past (>5-10 years).

The main difference between *periodic* applications compared to *annual* applications is that cumulative applications over the same time period will be lower because the N available from mineralization of previous sewage sludge applications will generally be less than the potential N uptake by trees in the years when sewage sludge is not applied. This means that more total forest acreage will generally be required for utilization of a given amount of sewage sludge compared to annual applications.

8.8.5 Calculation Based on Part 503 Pollutant Limits for Metals

The same Part 503 pollutant limits for metals that pertain to sewage sludge application at agricultural sites, as discussed in Chapter 7, also apply to forest sites (see Chapter 3 for a discussion of pollutant limits).

8.9 Design Example of Sewage Sludge Application at Forest Sites

This design example was developed in part to demonstrate the procedures needed to ensure protection of drinking water aquifers during an annual sewage sludge land application program. The criteria used for an annual sewage sludge land application project at a forest site are:

1. Nitrogen applications cannot exceed the ability of the forest plants to utilize the N applied, with appropriate adjustments for losses.

2. Cumulative metal loading limits cannot exceed the cumulative pollutant loading rates (CPLRs), if applicable (see Chapter 3), in the Part 503 rule.

8.9.1 Sewage Sludge Quantity and Quality Assumptions

The sewage sludge generated by the hypothetical community in this design example is assumed to have the following average characteristics:

- Anaerobically digested sewage sludge is generated on the average of 18.2 t/day (20 T/day), dry weight, by an activated sludge sewage treatment plant.
- Liquid sewage sludge averages 4 percent solids by weight; its volume is 445,600 L/day (117,600 gal/day).
- Average sewage sludge analysis on a dry weight basis is the same as the design example for agricultural applications (see Chapter 7 for metals concentrations):
  - Organic-N (ON) = 2.5 percent by weight.
  - Ammonia-N (AN) = 1 percent by weight.
  - Nitrate-N (NN) = none.

8.9.2 Site Selection

The hypothetical community for this design example is located in the Pacific Northwest. A large commercial forest is located 24 km (15 mi) from the sewage treatment plant. The site owner believes that he can expect a significant increase in tree growth rate resulting from the nutrients in sewage sludge. Preliminary investigations of the owner's property show that a total of 3,000 ha (7,400 ac) are available, of which 1,200 ha (3,000 ac) have the following desirable characteristics:

- Convenient vehicle access to public and private roads, plus an in-place network of logging roads within the area.
- No surface waters used for drinking or recreational purposes are located within the area. Intermittent stream locations are mapped, and 90-m (290-ft) (or greater) buffer zones can be readily established around the stream beds.

- Ground water under one portion of the site has the potential to serve as a drinking water aquifer.
- Public access is limited by signs and fences adjacent to public roads.
- Topography is satisfactory, in that the area consists largely of slopes less than 6 percent, and slopes steeper than 30 percent can be readily excluded from the sewage sludge application program.
- There are no residential dwelling units within the area.
- The area is roughly equally divided between young hybrid poplar that is harvested on a 5-year rotation and an established stand of Douglas-fir. However, the 1,200 ha (3,000 ac) area contains 200 ha (500 ac) that either contain tree species that are incompatible with sewage sludge applications (e.g., they fix nitrogen) or have slopes exceeding 30%. These areas are excluded.

8.9.2.1 Soil and Hydrological Properties of the Site

The soils are of two types: glacial outwash, and residual soil developed from andesitic bedrock. The glacial outwash is located largely on terraces with slopes less than 10 percent. Infiltration is rapid. The soil pH ranges between 5.5 and 6.0, and CEC is 14 meq/100 g. A 2.5-cm to 5.0-cm (1-in to 2-in) litter layer exists in the established forest. The ground water table is approximately 9 m (30 ft) below the soil surface. Residual soil is found on slopes ranging up to 40 percent. Slopes steeper than 30 percent were eliminated from further consideration.

8.9.3 Determining the Sewage Sludge Application Rate Based on Nitrogen

For this design example, assume that the sewage sludge is to be land applied on an annual basis, and that the quantity of sewage sludge applied is limited by N. The purpose of the calculation is to have the plant-available N in the applied sewage sludge equal the N uptake of the trees and understory, accounting for assumed atmospheric losses discussed in Section 8.8.3. This is a conservative approach intended to prevent leaching of nitrate to the ground water aquifer.

Step 1. Calculate Net N Requirements for First 5 Years

N requirements for the hybrid poplar and the Douglas-fir stands are calculated separately for the first 5 years using Equation 8-1. Table 8-9 summarizes the assumptions used to calculate net N requirements. For the hybrid poplar tree, N uptake is assumed to gradually increase, from 50 kg N/ha in the first year to 250 kg N/ha in the fifth year. Uptake of the understory is 100 kg N/ha in the first year and 50 kg N/ha in the second year, and is assumed to be negligible in subsequent years. The amount of N immobilized as a result of decomposition of soil organic carbon is assumed to be 100 kg/ha in the first year and 0 in subsequent years. Table 8-9 shows a high N need for the poplar of 250 kg/ha in the first year, which drops to 100 kg/ha in the second year, and gradually increases back to 250 kg/ha by the fifth year.

Table 8-9. N Requirements for Sewage Sludge Application to Hybrid Poplar and Established Douglas-fir Plantations

Year	N_{tr}	N_{us}	SI	N_{req}
kg/ha				
Hybrid poplar				
1995	50	100	100	250
1996	100	50	0	150
1997	150	0	0	150
1998	200	0	0	200
1999	250	0	0	250
Douglas-fir				
1995	100	100	150	350
1996	100	0	0	100
1997	100	0	0	100
1998	100	0	0	100
1999	100	0	0	100

Initial N required for the Douglas-fir stand is higher than for the hybrid poplar (350 kg/ha) because of higher initial N uptake by trees (100 kg/ha) and higher N immobilization (150 kg/ha) because of higher initial litter/soil organic carbon content. Understory uptake in the first year was assumed to be the same as for the hybrid poplar (100 kg/ha). In subsequent years, N uptake by trees is assumed to remain steady at 100 kg/ha, whereas N uptake by the understory and immobilization is assumed to be negligible. The net effect of these assumptions is that the N needs for the Douglas-fir stand in the second through fifth years remain steady at 100 kg/ha, as shown in Table 8-9.

Step 2. Calculate Initial Available N in Sewage Sludge for Each Year

Available N in the sewage sludge needs to be calculated for each forest stand type, and recalculated for any year in which changing site conditions may affect N availability. In the first two years surface application is made to a very open stand where both heat and wind reach the soil surface, thus volatilization can be high (assumed to be 0.5), but since the soils are well drained, denitrification is low (assumed to be 0.1). Mineralization rate for this first year is taken from Table 7-7 in Chapter 7 in the column for anaerobically treated sewage sludge. N availability from sewage sludge applied to the hybrid poplar plantation for the first year is calculated using Equation 8-3 as follows:

$$\begin{aligned}PAN_{1,2} &= \{(AN)(1\text{-}V) + NN + (ON_0)(K_0)\}(1\text{-}D)(10)\\ &= \{(1.0)(1\text{-}0.5) + 0 + (2.5)(0.20)\}(1\text{-}0.1)(10)\\ &= 9.0 \text{ kg/t}\end{aligned}$$

During the following years, the trees reduce both radiation and wind reaching the soil surface, so ammonia volatilization is assumed to be reduced to 0.25, while denitrification remains relatively constant at 0.1.

$$\begin{aligned}PAN_{3\text{-}5} &= \{(AN)(1\text{-}V) + NN + (ON_0)(K_0)\}(1\text{-}D)(10)\\ &= \{(1.0)(1\text{-}0.25) + 0 + (2.5)(0.20)\}(1\text{-}0.1)(10)\\ &= 11.3 \text{ kg/t}\end{aligned}$$

Available N from sewage sludge applied to the Douglas-fir stand will be 11.3 kg/t for all 5 years because the wind and heat reaching the forest floor are presumed to be very similar to the third year conditions in the poplar stand.

Step 3. Calculate First-Year Sewage Sludge Application Rate

First-year sewage sludge application rates to forest sites can be substantially higher than in subsequent years because of the initial response of understory growth, which increases N uptake, and immobilization of N, as discussed in Section 8.8.2; no mineralization of ON from previous applications occurs. The initial sewage sludge application rate is calculated using Equation 8-4:

$$\begin{aligned}S_0 &= (N_{req} - N_{prev})/PAN\\ &= (250 - 0)/9.0\\ &= 28 \text{ t/ha(for the hybrid poplar)}\\ \\ &= (350 - 0)/11.3\\ &= 31 \text{ t/ha(for the Douglas-fir)}\end{aligned}$$

Step 4. Calculate Sewage Sludge Application Rates for Subsequent Years

Sewage sludge application rates for subsequent years must take into account mineralization of organic N from previous sewage sludge applications. Table 8-10 shows the results of mineralization calculations for the second through fifth years. In this example, the second-year sewage sludge application rate to supply N requirements of the hybrid poplars drops from 27.8 t/ha to 12 t/ha and then gradually increases to 19.2 t/ha in the fifth year. The Douglas-fir stand shows an even more dramatic drop from 31 t/ha in the first year to 4.7 t/ha in the second year. The third year application rate for Douglas-fir increases to 6.8 t/ha, with slight additional increases to 6.4 and 7.5 t/ha for the fourth and fifth years, respectively.

Table 8-10. Sewage Sludge Application Rates to Meet N Requirements at Forest Sites

Year	N_{req}	N_{prev}	PAN	S_0	S (cumulative)
t/ha					
Hybrid poplar					
1995	250	0	9	27.8	28
1996	150	42	9	12.0	40
1997	150	32	11.3	10.4	50
1998	200	35	11.3	14.6	65
1999	250	33	11.3	19.2	84
Douglas-fir					
1995	350	0	11.3	31.0	31
1996	100	46	11.3	4.7	36
1997	100	23	11.3	6.8	43
1998	100	27	11.3	6.4	49
1999	100	15	11.3	7.5	56

Notes:
N_{req} = N requirements to be supplied by a given application of sewage sludge, kg/ha
N_{prev} = Total mineralized N from sewage sludge applications in previous years, kg/ha
PAN = Total plant nitrogen, kg/ton
S_0 = Sewage sludge application rate for a given year
S = Sewage sludge application (cumulative)

8.9.4 Site Capacity Based on Nitrogen

The design example site has 1,000 ha (2,471 ac) suitable for sewage sludge application, which is roughly equally divided between established Douglas-fir forest and the hybrid poplar plantation (assume 500 ha [1,235 ac] of each). The quantity of sewage sludge that can be applied during the first 5 years is summarized in Table 8-11. Total application in the first year could be as high as 29,400 t. In the second year this drops to 8,400 t, and gradually increases to 13,300 t by the fifth year.

Table 8-11. Maximum Annual Sewage Sludge Application Based on N Requirements

	Area	Hybrid Poplar		Douglas Fir		Total
Year	(ha)	(t/ha)	(t)	(t/ha)	(t)	(t)
1995	500	27.8	13,900	31.0	15,500	29,400
1996	500	12.0	6,000	4.7	2,400	8,400
1997	500	10.4	5,200	6.8	3,400	8,600
1998	500	14.6	7,300	6.4	3,200	10,200
1999	500	19.2	9,600	7.5	3,700	13,300

t = metric tonnes.

Since the community generates 18.2 t/day (20 T/day), dry weight of sewage sludge, or 6,643 t/year (7,307 T/year), this would supply sewage sludge applied at the first year design rate of only one-fourth of the site. This scenario also requires less than the entire site for reapplication (at the lesser rates of years 2-5). Therefore, the hypothetical site appears to be of quite sufficient area. However, careful planning and record keeping will be required to schedule the amount and location of sewage sludge applications to maintain a good program.

8.10 References

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Chapter 9
Process Design for Land Application at Reclamation Sites

9.1 General

This chapter presents design information for application of sewage sludge to reclamation sites.[1] It is assumed that the preliminary planning discussed in earlier chapters has been done, that a sewage sludge transportation system has been selected, and that reclamation sites are potentially available within a reasonable distance from the treatment works. Primary emphasis is on the revegetation of the reclamation site with grasses and/or trees. If future land use for agricultural production is planned, the reader should also refer to Chapter 7, "Process Design for Agricultural Land Application Sites."

Extensive areas of disturbed land that can benefit from reclamation exist throughout the United States as a result of mining for clay, gravel, sand, stone, phosphate, coal, and other minerals. Also fairly widespread are construction areas (e.g., roadway cuts, borrow pits) and areas where dredge spoils or fly ash have been deposited (Sopper and Kerr, 1982). Other areas needing reclamation include clear-cut and burned forests, shifting sand dunes, landfills, and sites devastated by toxic fumes. Some disturbed mining sites may be designated as "Superfund" sites, and applicable regulations may pertain.

Disturbed land can result from both surface and underground mining operations, as well as the deposition of ore processing wastes. The Soil Conservation Service reported that as of July 1, 1977, the minerals industry had disturbed a total of 2.3 mil ha (5.7 mil ac), of which about 50 percent was associated with surface mining (U.S. Soil Conservation Service, 1977). Only about one-third of the disturbed areas was reported to have been reclaimed. Table 9-1 presents the amount of hectares under permit for surface, underground, and other mining operations during the period 1977 to 1986. Table 9-2 presents the number of hectares that have been reclaimed with bonds released during 1977 to 1986—about 40 percent of the land under permit (Sopper, 1993).

Most disturbed lands are difficult to revegetate. These sites generally provide a harsh environment for seed

[1] 40 CFR Part 503 defines a reclamation site as drastically disturbed land that is reclaimed using sewage sludge (see Chapter 3).

Table 9-1. Hectares Under Permit for Surface, Underground, and Other Mining Operations From 1977 to 1986[a] (Sopper, 1993)

Year	Total Hectares
1978	68,635
1979	146,002
1980	141,842
1981	153,880
1982	136,568
1983	182,896
1984	265,768
1985	175,057
1986	107,429
Total	1,378,077

[a] States and Indian tribe lands included in above tabulations were Alabama, Alaska, Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Missouri, Montana, New Mexico, North Dakota, Ohio, Pennsylvania, Tennessee, Texas, Utah, Virginia, Washington, West Virginia, Wyoming, Crow Tribe, Hopi Tribe, Navajo Tribe.

Table 9-2. Number of Hectares Reclaimed With Bonds Released During 1977 to 1986[a] (Sopper, 1993)

Year	Total Hectares
1978	19,078
1979	42,580
1980	51,401
1981	52,547
1982	80,351
1983	69,874
1984	96,910
1985	81,696
1986	68,280
Total	562,717

[a] States and Indian tribe lands included in above tabulations were Alabama, Alaska, Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Missouri, Montana, New Mexico, North Dakota, Ohio, Pennsylvania, Tennessee, Texas, Utah, Virginia, Washington, West Virginia, Wyoming, Crow Tribe, Hopi Tribe, Navajo Tribe.

germination and subsequent plant growth. Major soil problems may include a lack of nutrients and organic matter, low pH, low water-holding capacity, low rates of water infiltration and permeability, poor physical properties, and the presence of toxic levels of trace metals. To correct these conditions, large applications of lime and fertilizer may be required, and organic soil amendments and/or mulches also may be necessary.

Pilot- and full-scale demonstration projects have shown that properly managed sewage sludge application is a feasible method of reclaiming disturbed land and can provide a cost-effective option for sewage sludge use. According to the 1990 NSSS, 65,800 dry metric tons per year (1.2 percent of the sewage sludge used or disposed of annually) are used for land reclamation (58 FR 9257). Table 9-3 lists some of the more significant land reclamation projects using sewage sludge during the past 20 years. Research has shown that good plant cover can be established on many types of disturbed lands using sewage sludge, which is superior to inorganic fertilizer for such uses (Sopper, 1993). Sewage sludge has been found to have a beneficial effect on the establishment and growth of grass and legume species on mine land (Sopper, 1993). In addition, the pH buffering capacity of sewage sludge makes it beneficial in the reclamation of acidic sites (Gschwind and Pietz, 1992).

At reclamation sites, sewage sludge application usually is performed once. The sewage sludge is not applied again to the same land area at periodic intervals in the future, as is the case at agricultural and forest sites. Thus, most reclamation projects must have a continuous supply of new disturbed land on which to apply sewage sludge in future years. This additional disturbed land may be created by ongoing mining or mineral processing operations or may consist of presently existing large areas of disturbed land which are gradually reclaimed. In either case, an arrangement is necessary with the land owner to allow for future sewage sludge land application throughout the life of the sewage sludge land application project.

9.2 Consideration of Post-Sewage Sludge Application Land Use

If land application of sewage sludge is used in the reclamation process, it is important to consider federal and state mining regulations concerning revegetation (e.g., 30 CFR Parts 816 and 817) and the federal Surface Mining Control and Reclamation Act (Public Law 95-87, Section 515) (U.S. Department of Interior, 1979; Federal Register, 1982) and its amendments (54 FR 23). Regulations established under this Act require that a diverse, effective, and permanent vegetative cover of the seasonal variety native to the affected land must be established and must be capable of self-regeneration and plant succession equal in coverage to the natural vegetation of the area (Federal Register, 1982). Before beginning a land application project using sewage sludge at a reclamation site, the final use of the site after it has been reclaimed must be considered regarding compliance with these regulations. If the post-mining land use is to be agricultural production or animal grazing, agricultural land application requirements for sewage sludge must be followed, such as the federal Part 503 regulation and any applicable state regulations. If the site is to be vegetated primarily for erosion control, a single large application of sewage sludge is desirable for rapid establishment of the vegetative cover. Generally, Part 503 requirements for agricultural, forest, and reclamation sites are the same (see Chapter 3). As discussed in Section 9.3.1.1, the Part 503 regulation specifies that for land reclamation, the permitting authority can authorize a variance from the agronomic rate requirement for sewage sludge application.

In humid regions, a majority of the reclaimed mine areas have been planted to forests. Some of these areas are managed for lumber or pulp production, while others are allowed to follow natural succession patterns. If the reclaimed area is to be turned into forest land, larger sewage sludge application rates can be considered than those used for agricultural crops, since the products from the forest are generally not a factor in the human food chain. In all cases, post-mining land use must be considered prior to the use of sewage sludge in land reclamation.

9.2.1 Mining Regulations

Prior to mining, a plan must be submitted to the appropriate agency stating the method of reclamation and post-mining land use. Amended regulations under the Surface Mining Control and Reclamation Act issued in 1982 and 1988 set forth the following requirements:

- The permanent vegetative cover of the area must be at least equal in extent of cover to the natural vegetation of the area and must achieve productivity levels comparable to unmined lands for the approved post-mining land use. Both native and introduced species may be used.
- The period of responsibility begins after the last year of augmented seeding, fertilization, irrigation, or other work that ensures revegetation success.
- In areas of more than 26 inches of average annual precipitation, the period of extended responsibility will continue for not less than 5 years. In areas with 26 inches of precipitation or less, the period of responsibility will continue for not less than 10 years.
- Normal husbandry practices essential for plant establishment would be permitted during the period of responsibility so long as they can reasonably be expected to continue after bond release.

Table 9-3. Recent Land Reclamation Projects With Municipal Sludge (Adapted From Sopper, 1993)

Type of Disturbed Land	State	Sludge: Type[a]	Sludge: Application Rates (mg/ha)	Plant/Animal Studied	Parameters Tested[b]
Acid strip mine spoil	PA	Dig.-D + effluent	5-20 cm	Ryegrass Hybrid poplar	WA
Deep mine anthracite refuse	PA	Dig.-D	0, 40-150	10 tree spp. 5 Grass spp. 5 Legume spp.	GR PA SA WA
Acid strip mine spoil Top-soil strip mine spoil (49 sites)	PA	Dig.-D,C	134	Tall fescue Orchardgrass Birdsfoot trefoil Ryegrass	GR PA SA WA
Zinc smelter site	PA	Dig.-D	47	5 Grass species 5 Legume species 11 Tree species	GR PA SA
Acid strip mine spoil	PA	Dig.-D,C/C	120-134	Microorganisms	SO,SA
Abandoned Pyrite mine	VA	Dig.-D	82-260	Tall fescue Lespedeza Weeping lovegrass Wheat, rye, oats	GR PA SA WA
Sandstone and siltstone mine soil	VA	Dig.-D	22, 56, 112, 224	Tall fescue	GR SA,PA
Non acid-forming overburden	VA	Dig.-D,C	112	Hay/pasture seed mix	SA
Borrow pit	SC	Dig-D	0, 17, 34, 68	Tall fescue Sweetgum	GR PA
Acid strip mine spoil	WV	Dig.-D,C	Various (NI)	Blueberries	GR PA
Overburden minesoil	WV	Dig.-D	0, 22.4, 44.8, 78.4	Red clover Tall fescue Orchardgrass Birdsfoot trefoil	SA,PA GR
Iron ore tailings	WI	Dig.-D	42-85	5 Native prairie grasses 4 Prairie forbes Foxtail	GR
Taconite tailings	WI	Dig.-D	28-115	4 Grass-legume mixtures	GR
Copper mine spoil	CO	Dig.-D	0, 30, 60	Fourwing saltbush Mountain big sagebrush	GR,PA,SA
Copper mine Borrow pit Kaolin spoil Marginal land	TN GA	Dig.-D	0, 34, 69, 275	Pine species Sweetgum	GR,SA
Acid stripmine spoil	IL	Dig.-L	0, 31-121	Tall fescue Weeping lovegrass	GR WA
Acid stripmine spoil	KY	(NI)	28-96	European alder Blacklocust Cottonwood Loblolly pine Northern red oak	GR PA SA
Reconstructed prime farmland	KY	Dig.-D	0, 22.4, 448	Grain sorgham Corn	GR PA,SA
C and D canal dredge material	MD	Dig.-D	112	KY bluegrass Tall fescue Red fescue Weeping lovegrass	PA SA WA
C and D canal dredge material	DE	Dig.-D	100	Tall fescue Red fescue KY bluegrass	PA SA

Table 9-3. (continued)

Type of Disturbed Land	State	Sludge Type[a]	Sludge Application Rates (mg/ha)	Plant/Animal Studied	Parameters Tested[b]
Acid stripmine spoil	OH	Dig.-D	11-716	Tall fescue	GR,PA SA,WA
Degraded, Semiarid Grassland	NM	Dig.-D	0, 22.5, 45, 90	Blue gamma Galleta Bottlebrush squirreltail	GR,PA,SA
Zn smelter surroundings	OK	Dig.-L + effluent	2.5-34 cm	10 grass spp. 1 legume	GR PA SA
Lignite overburden	TX	Dig.-D	56	NA	SA,WA

[a] Dig. = digested, L = liquid, D = dewatered, C = composted, C/C = dewatered cake and compost mix, NI = no information.
[b] GR = growth responses, PA = plant tissue analysis, SA = soil analysis, WA = water analysis, SO = soil organisms, PO = pathogenic organisms, AH = animal health, NA = not applicable.

- In areas of more than 26 inches of precipitation, the vegetative cover and production of pasture, grazing land, and cropland shall be equal to or exceed the success standard only during any 2 years except the first year. Areas approved for other uses shall equal or exceed success standards during the growing season of the last year of the responsibility period. In areas with less than 26 inches of precipitation, the vegetative cover must be equal to the success standard for at least the last 2 years of the responsibility period.
- The ground cover, productivity, or tree stocking of the revegetated area shall be considered equal to the success standards approved by the regulatory authority when they are not less than 90 percent of the success standard with 90 percent statistical confidence.

Under the federal mining regulations, the potential post-mining land use must be of a level equal to or higher than the pre-mining land use. Typical land uses include:

- Wilderness or unimproved use.
- Limited agriculture or recreation with little development, such as forest land, grazing, hunting, and fishing.
- Developed agriculture or recreation, such as crop land, water sports, and vacation resorts.
- Suburban dwellings or light commercial and industry.
- Urban dwelling or heavy commercial and industry.

Many of these land uses are compatible with sewage sludge application.

9.3 Nutrients, Soil pH, and Climate Considerations

9.3.1 Nutrients

During mining and regrading operations, the original surface layers are usually buried so deeply that the soil nutrients present are not available to plants in the disturbed soil. Nitrogen and phosphorus are often deficient on disturbed lands, with phosphorus often being the most limiting fertility factor in plant establishment. Sewage sludge is generally an excellent source of these nutrients. The amount of sewage sludge applied at one time during land reclamation can be relatively large (7 to 450 dry t/ha or 3 to 200 T/ac) to ensure that sufficient nutrients, as well as organic matter, are introduced into the soil to support vegetation until a self-sustaining ecosystem is established. The local agricultural experiment station or Cooperative Extension Service can provide recommendations for the additional quantities of N, P, and K required to support vegetation for the site.

9.3.1.1 Nitrogen

An advantage of using sewage sludge for land reclamation is that it is a slow-release source of organic nitrogen fertilizer that will supply some nitrogen for 3 to 5 years. Depending on the treatment process, much of the original wastewater nitrogen is in the organic form and therefore not immediately available for plant use until it is converted to inorganic nitrogen by mineralization, making it available to plants. This process is discussed in Chapters 4 and 7.

Under the federal Part 503 regulation, the permitting authority may authorize for reclamation sites a sewage sludge application rate greater than the agronomic rate for N. The person who applies the sewage sludge must be able to show that N application in excess of crop and vegetative requirements would not contaminate ground water or surface water. The permitting authority may allow a temporary impact on the reclamation site (e.g., may allow one application only, at a higher application rate).

The amount of nitrogen needed to establish vegetation on a reclamation site depends on the type of vegetation to be grown and the amount of nitrogen available in the soil. The designer should have information on:

- The amount and type of nitrogen in the sewage sludge (organic N, ammonium, and nitrate).
- The plant-available nitrogen content of the existing soil, if available.
- The fertilizer nitrogen requirements of the vegetation planned for the site.

This information is used to determine the sewage sludge application rate so that sufficient nitrogen is applied for the vegetation but is not in excessive amounts that could cause unacceptable levels of nitrate leaching into surrounding ground water, as shown in Section 9-7.

The designer should also consider the postreclamation land use when determining the amount of nitrogen needed to supply the vegetative needs. If the vegetation grown is to be harvested and removed from the site, supplemental nitrogen applications may be needed periodically to maintain adequate productivity. If the reclaimed area is reforested or the vegetation grown is not harvested, most of the nitrogen will remain on the site and be recycled through leaf fall and vegetation decomposition.

Sewage sludge applications on mine land usually increase the total nitrogen concentration in the foliage of vegetation (Sopper, 1993). It has been speculated that while excessively high nitrogen concentrations in plants do not harm the plants themselves, they could cause metabolic disruptions in foraging animals. No published documentation of this phenomenon exists, however (Sopper, 1993).

Drastically disturbed lands can be divided into two categories—those requiring topsoil enhancement and those without topsoil. On sites with topsoil, an agricultural application rate might be used, with relatively small quantities of sewage sludge being applied annually (as discussed in Chapter 7). On abandoned sites or sites without topsoil replacement, however, a much larger application of sewage sludge may be necessary to establish vegetation and improve the physical status of the soil. Soil fertility is also increased by the nitrogen and phosphorus in sewage sludge as well as the many micronutrients in sewage sludge necessary for plant growth.

9.3.2 Soil pH and pH Adjustment

Most grasses and legumes, as well as many shrubs and deciduous trees, grow best in the soil pH range from 5.5 to 7.5, and pH adjustments may be necessary at reclamation sites.

Several states have adopted regulations stating that where sewage sludge is applied to land, the soil pH must be adjusted to 6.0 or greater during the first year of initial sewage sludge application and 6.5 during the second year (Pennsylvania Department of Environmental Resources, 1988). In addition, the soil pH of 6.5 may need to be maintained for 2 years after the final sewage sludge application. This is recommended because trace metals are more soluble under acidic conditions than neutral or alkaline conditions. If the soil pH is not maintained above 6.0 and is allowed to revert to more acidic levels, some trace metals in the sludge may become soluble; once in solution, the metals would be available for plant uptake.

Lime often is used for pH adjustment, but other agents also are feasible. Recommendations for pH adjustment can usually be obtained by sending soil samples to a qualified laboratory or the agricultural experiment station soil testing lab at the nearest land grant college or university. Common soil tests for lime requirements often seriously underestimate the lime requirement for sulfide-containing disturbed lands. In addition, the application of sewage sludge on disturbed lands may cause further acidification. This must be taken into consideration in calculating lime requirements.

9.3.3 Factors Affecting Crop Yields at Reclamation Sites

Where sewage sludge is applied at reclamation sites for agricultural production, crop yields can be variable. Limiting factors can include climatic conditions and shallow rooting depths (Gschwind and Pietz, 1992). Peterson et al. (1982) found that adequate moisture and essential elements for crop needs were critical for corn yields grown immediately after land leveling on sewage sludge-amended soil at a strip mine reclamation site. Pietz et al. (1982) found that important parameters were shallow rooting depth, soluble salts, moisture stress, and element interactions in plant tissue, sewage sludge, and soil.

9.3.4 Special Considerations for Arid Lands

When sewage sludge is land applied to reclamation sites in arid climates, the concentration of soluble salts in the sludge should be considered. Accumulation of salts can hinder revegetation of native grasses because of competition from salt-tolerant, early successional plants (Jacobs et al., 1993). Other considerations for sewage sludge application to arid lands are discussed in Chapter 7.

9.4 Vegetation Selection

9.4.1 General

Many plant species have been successfully established at reclamation sites. Each site should be considered unique, however, and plant species or seed mixtures to be used should be carefully selected. Local authorities should be consulted for recommendations of appropriate species and varieties of plants as well as plant establishment techniques. Revegetation suggestions for various regions of the United States are presented in Tables 9-4 through 9-14. Table 9-15 presents some successful plant species and species mixtures used in

Table 9-4. Humid Eastern Region Vegetation

Various grasses, legumes, trees, and shrubs have been evaluated for use on disturbed lands in the humid regions of the United States. Grass species that have shown promise for use on low pH soils in the eastern United States include weeping lovegrass, bermudagrass varieties, tall fescue, chewings fescue, switchgrass, red top, colonial bentgrass, creeping bentgrass, velvet bentgrass, deertongue, big bluestem, little bluestem, and brown sedge bluestem (Bennett et al., 1978).

Some of the more agriculturally important grass species adapted to better soil conditions on disturbed sites include bromegrass, timothy, orchardgrass, perinnial rye grass, Italian ryegrass, Kentucky bluegrass, Canadian bluegrass, Reed canarygrass, Dallisgrass, bahiagrass, and in special situations, lawn grasses including *Zoysia japonica* Steud and *Zoysia matrella*. In addition to the common grasses, several of the cereal grains, such as rye, oats, wheat, and barley have been used, but mainly as companion crops (Bennett et al., 1978).

Legume species tested on disturbed sites in eastern United States include alfalfa, white clovers, crimson clover, birdsfoot trefoil, lespedezas, red clover, crownvetch, and hairy vetch. Other species that have been successfully tested include flat pea, kura clover, zigzag clover, sweet clover, and yellow sweet clover (Bennett et al., 1978).

Several grass and legume mixtures have been used successfully in Pennsylvania to revegetate drastically disturbed lands amended with municipal sludges. The primary mixture and seeding rate used for spring and summer seeding is:

Species	Amount kg/ha
Kentucky-31 tall fescue	22
Orchardgrass	22
Birdsfoot trefoil	11
Total	55

Metric conversion factor:
1 kg/ha = 0.89 lb/ac.

For late summer and early fall seeding the following mixture has been used successfully:

Species	Amount kg/ha
Kentucky-31 tall fescue	11
Orchardgrass	5
Winter rye (1 bu/ac)	63
Total	79

Metric conversion factor:
1 kg/ha = 0.89 lb/ac.

This mixture has usually been sufficient to establish a vegetative cover to protect the site over the winter season. The following spring, an additional seed mixture, consisting of orchardgrass (11 kg/ha; 9.8 lb/ac) and birdsfoot trefoil (11 kg/ha; 9.8 lb/ac), is applied. Other seeding mixtures for spring, summer, and fall seeding are found in Rafaill and Vogel, 1978.

Several tree and shrub species have been utilized on disturbed land areas in the eastern United States. However, in general, trees and shrubs have been planted either after the soil has been stabilized with herbaceous species, like grasses and legumes, or has been planted with them. On certain drastically disturbed areas, trees may be the only logical choice of vegetation where a future monetary return is expected. They do provide long-term cover and protection with little or no additional care and maintenance. The same precautions should be exercised in selecting tree species for use on disturbed land sites as in selecting grasses and legumes. The soil acidity, plant nutrient requirements, chemical and physical properties of the soil, site topographical influences, and other environmental factors should be considered.

Common tree and shrub species grown successfully on disturbed land sites in the eastern United States include black locust, European black alder, autumn olive, white pine, scotch pine, Virginia pine, short leaf pine, red pine, Norway spruce, European and

sewage sludge reclamation projects. Food crop selection is discussed in Chapter 7.

Plant species to be used should be selected for their ability to grow under drought conditions and their tolerance for either acid or alkaline soil material. Salt tolerance is also desirable.

If the goal of the reclamation effort is to establish a vegetative cover sufficient to prevent erosion, a perennial grass and legume mixture is a good crop selection. It is important to select species that are not only compatible, but also grow well when sewage sludge is used as the fertilizer. A combined grass and legume seeding mixture allows the grass species to germinate quickly

Table 9-5. Drier Mid-West and Western Region Vegetation

A large number of plant species have been tested on disturbed lands in the Intermountain Region of the United States (Berry, 1982). Fewer species have been evaluated for reclamation use in the drier regions of the United States. The objective in many reclamation plantings in the drier regions is to return the area to climax vegetation. In almost every instance, the soils are not the same as before the disturbance occurred, and it would seem in many cases that species lower in the successional stage may be better adapted and more easily established on these sites. Whether a single species or a mixture is selected depends on several factors, including the planned future use of the site, the desire to have the planting blend with the surrounding vegetation, and the adaptability and compatibility of the species selected. The factors limiting the successful establishment of vegetation on disturbed areas may be different on a site being reclaimed than on adjacent undisturbed areas, where a plant species may be growing together in what appears to be a stable community. Even after the species have been selected, the proportionate amounts of seeding are not easily determined. The successful experiences of the past 40 years from seeding range mixtures and planting critical areas appears to be the best guide to the opportunities for success of either single species or mixtures (Berg, 1978).

Table 9-6. Western Great Lakes Region

This region includes Wisconsin, eastern Minnesota, and the western upper peninsula of Michigan. The common grasses, generally used in mixtures with a legume, are tall fescue, smooth brome, and timothy. Kentucky bluegrass and orchardgrass are also well adapted. “Garrison” creeping foxtail and reed canarygrass perform well on wet sites. The most commonly used legumes are birdsfoot trefoil and crownvetch. Numerous species of woody plants can be used depending on specific site conditions. Siberian crabapple, several species of poplars, tatarian and Amur honeysuckles, silky dogwood, redosier dogwood, European black alder, black cherry, and green ash perform well. Autumn olive is adapted to the southern portion of this area.

Table 9-7. Northern and Central Prairies

This is the region known as the Corn Belt. Grasses adapted to the area are Kentucky bluegrass, tall fescue, smooth brome, timothy, and orchardgrass. Reed canarygrass is adapted to wet areas. Switchgrass, big bluestem, and Indiangrass are well adapted warm season natives. Birdsfoot trefoil, crownvetch, and alfalfa are commonly used legumes.

Woody species that have been successful include autumnolive, European black alder, poplar species, tatarian honeysuckle, Amur honeysuckle, black cherry, eastern red cedar, pines, oaks, black walnut, green ash, black locust, black haw, and osage-orange.

Table 9-8 Northern Great Plains

This region includes most of the Dakotas and Nebraska west to the foothills of the Rocky Mountains and includes northeastern Colorado. The native wheatgrass (western, thickspike, bluebunch, streambank, and slender) are used extensively in seeding mixtures. Western wheatgrass should be included in most mixtures, although for special purposes thickspike or streambank wheatgrass are more appropriate. Green needlegrass is an important component of mixtures except in the drier areas. On favorable sites big bluestem, little bluestem, and switchgrass provide opportunities for color or for a different season of use. Prairie sandreed is adapted to sandy soils throughout the region. “Garrison” creeping foxtail and reed canarygrass are adapted to wet sites.

Crested wheatgrass has been used extensively and is long-lived in this climate. Intermediate and pubescent wheatgrasses are useful in establishing pastures. The use of smooth brome and tass fescue is limited to the eastern portions of the Northern Great Plains where the annual precipitation exceeds 50 cm (19.7 in). Alfalfa and white sweetclover are the only legumes used in most of the area for reclamation plantings.

Many native and introduced woody plants are adapted for conservation plantings. Fallowing to provide additional moisture is required for establishment of most woody plants and cultivation must generally be continued for satisfactory performance of all but a few native shrubs. These practices may not be compatible with certain reclamation objectives, thereby limiting the use of woody species to areas with favorable moisture situations. Some woody plants useful in this area, if moisture and management are provided, are Russian-olive, green ash, skunkbush sumac, Siberian crabapple, Manchurian crabapple, silver buffaloberry, tatarian honeysuckle, chokecherry, Siberian peashrub, Rocky Mountain juniper, and willow species.

Table 9-9. Southern Great Plains

The Southern Great Plains are considered to be the area from southcentral Nebraska and southeastern Colorado to central Texas. The most common native grasses of value in reclaiming drastically disturbed lands include big bluestem, little bluestem, Indiangrass, switchgrass, buffalograss, blue grama, sideoats grama, and sand lovegrass. Introduced bluestems such as yellow bluestem, Caucasian bluestem, and introduced kleingrass, blue panicgrass, and buffelgrass are important in the southern and central portions of this plant growth region. Alfalfa and white sweetclover are the most commonly used legumes. Russian-olive is a satisfactory woody species in the northern portions and along the foothills of the Rocky Mountains. Junipers, hackberry, and skunkbush sumac are important native species. Osage-orange is well adapted to the eastern part of this area. Desirable woody plants require special management for use on most drastically disturbed lands.

Table 9-10. Southern Plains

This area is the Rio Grande Plains of south and southwest Texas. The characteristic grasses on sandy soils are seacoast bluestem, two-flow trichloris, silver bluestem, big sandbur, and tanglehead. The dominant grasses on clay and clay loams are silver bluestem, Arizona cottontop, buffalograss, curlymesquite, and grama grasses. Indiangrass, switchgrass, seacoast bluestem, and crinkleawn are common in the oak savannahs.

Old World bluestems, such as yellow and Caucasian bluestems, are satisfactory only where additional moisture is made available. Natalgrass and two-flower trichloris have shown promise in reclamation plantings.

Table 9-11. Southern Plateaus

The area is made up of the 750- to 2,400-m (2,450- to 7,875-ft) altitude plateaus of western Texas, New Mexico, and Arizona. The area includes a large variety of ecological conditions resulting in many plant associations. Creosote-tarbush desert shrub, grama grassland, yucca and juniper savannahs, pinyon pine, oak, and some ponderosa pine associations occur. Little bluestem, sideoats grama, green sprangletop, Arizona cottontop, bush muhly, plains bristlegrass, vine-mesquite, blue grama, black grama, and many other species are common and are useful in reclamation plantings, depending on the site conditions and elevation.

Table 9-12. Intermountain Desertic Basins

This region occupies the extensive intermountain basins from southern Nevada and Utah, north through Washington, and includes the basin areas of Wyoming. The natural vegetation ranges from almost pure stands of short grasses to desert shrub. There are extensive area dominated by big sagebrush or other sagebrush species.

A wide variety of species of grasses is available for this area. Among the most commonly used species are the introduced Siberian wheatgrass, crested wheatgrass, intermediate wheatgrass, pubescent wheatgrass, tall wheatgrass, and hard fescue. Native grasses used include bluebunch wheatgrass, beardless wheatgrass, big bluegrass, Idaho fescue, and Indian ricegrass. Four-wing and Nuttall saltbush have performed well in planting trials. Available woody species are limited, though junipers, Russian-olive, skunkbush sumac, and other native and introduced woody plants are adapted to the climate where moisture is adequate.

Table 9-13. Desert Southwest

This is the desert of southwestern Arizona, southern Nevada, and southern California. Creosotebush may occur in almost pure stands or with tarbush. Triangle bur-sage, white bur-sage, rubber rabbitbrush, and ocotillo are prominent on some sites. Large numbers of annual and perennial forbs are present. Saltbushes, winterfat, and spiny hopsage are common. The few grasses present in the understory are largely big galleta, desert saltgrass, grama grasses, and species of threeawns.

Only minor success has been obtained in establishing vegetation on disturbed lands in the desert southwest. Irrigation for establishment may be essential in some areas, and the longevity of stands when irrigation is discontinued is not known. Big galleta and bush muhly show promise. Native shrubs such as creosotebush, fourwing saltbush, and catclaw have also been established. Reseeding annuals such as goldfields, California poppy, and Indianwheat have also shown promise.

Table 9-14. California Valleys

The climate of the central California Valleys is classified as semiarid to arid and warm and the moisture is deficient at all seasons. The largest area of grassland lies around the edge of the central valley and is dominated by annual species. The only areas remaining in grass in the valley are usually too alkaline for crop production. The grasses remaining in these sites are desert salt-grass and alkali sacaton.

Recommended for seeding in the area of more than 40 cm (15.8 in) annual precipitation is a mixture of “Luna” pubescent wheatgrass, “Palestine” orchardgrass, and rose clover. Crimson clover, California poppy, and “Blando” brome can be added.

Inland in the 30 cm (12 in) precipitation areas, a mixture of “Blando” brome, Wimmera ryegrass, and “Lana” woolypod vetch is recommended. In the 15- to 30-cm (6 to 12 in) precipitation zone “Blando” brome (soft chess) and rose clover are generally used.

Table 9-15. Some Sucessful Plant Species and Species Mixtures Used in Various Sludge Reclamation Projects (Sopper, 1993)

State	Species	Seeding Rate (kg/ha^{-1})
CO	Slender wheatgrass[a]	5.1
	Intermediate wheatgrass[a]	4.8
	Pubescent wheatgrass[a]	4.6
	Crested wheatgrass[a]	3.8
	Smooth brome[a]	4.6
	Meadow brome[a]	2.6
	Timothy[a]	1.5
	Orchardgrass[a]	1.4
IL	Tall fescue	22
	Weeping lovegrass	8
IL	K-31 tall fescue	22
	Weeping lovegrass	7.8
IL	Common bermudagrass[a]	11
	Sericea lespedeza[a]	28
	Kobe lespedeza[a]	11
	Perennial rye grass[a]	22
	Potomac orchardgrass[b]	17
	Sericea lespedeza[b]	22
	Kobe lespedeza[b]	11
	Potomac orchardgrass[c]	22
	Penngift crownvetch[c]	17
IL	Tall fescue	25
	Perennial ryegrass	25
	Western wheatgrass	25
IL	Reed canarygrass	34
	Tall fescue	46
	Redtop	17
IL	Alfalfa[a]	22.9
	Bromegrass[a]	9.5
	Tall fescue[a]	9.1
MD	Tall fescue	40
	Birdsfoot trefoil	10
OH	Fall, balbo rye	9.6 (bu/ha^{-1})
	Spr., K-31 tall fescue[a]	11
	Korean lespedeza[a]	3.4
	Sweet clover[a]	3.5
	Orchardgrass[a]	3.3
OK	Switchgrass	154
	Kleingrass	154
PA	Reed canarygrass	224
	Tall fescue	224
	Orchardgrass	224
	Birdsfoot trefoil	224
	Crownvetch	224
	Deertongue	224
	Switchgrass	224
	Alfalfa	224
	Ladino clover	224
PA	K-31 tall fescue[a]	39
	Birdsfoot trefoil[a]	8
	Rye grass[a]	6
PA	Tall fescue[a]	22
	Orchardgrass[a]	22
	Birdsfoot trefoil[a]	11
	Crownvetch[a]	11
PA	Blackwell switchgrass	17
	Niagara big bluestem	34
	Birdsfoot trefoil[a]	22
	K-31 tall fescue[a]	45
	Perennial ryegrass[b]	22
	Lathco flatpea[b]	67
	Oahe intermediate	
	Wheat grass	34
	Tall fescue[c]	22
	Orchardgrass[c]	22
	Crownvetch[c]	17

Table 9-15. (continued)

State	Species	Seeding Rate (kg/ha^{-1})	State	Species	Seeding Rate (kg/ha^{-1})
PA	K-31 tall fescue[a]	22		Ladino clover[a]	5.6
	Orchardgrass[a]	22	VA	Tall fescue	67.3
	Birdsfoot trefoil[a]	11		Weeping lovegrass	22
	Crownvetch[a]	11		Korean lespedeza	11.2
VA	Tall fescue[a]	8.4	VA	Ky-31 tall fescue	80
	Perennial ryegrass[a]	8.4	WI	Canada bluegrass[a]	11
	Annual ryegrass[a]	8.4		Red clover[a]	9.7
	Tall fescue[b]	22		Smooth brome[b]	15.2
	Perennial rye[b]	22		Alfalfa[b]	11
	Sericea lespedeza[b]	22		Western wheatgrass[c]	9.7
	Black locust[b]	0.8		Alsike clover[c]	11
VA	K-31 tall fescue[a]	67		Barley[d]	16.5
	Redtop[a]	5.6		Japanese millet[d] (added to above mixtures)[d]	8.6

[a-d] Species with the same superscript letter represent a seeding mixture.

and provides a complete protective cover during the first year, while also allowing time for the legume species to become established and develop into the final vegetative cover. The grasses will also take up a large amount of the nitrogen, preventing it from leaching into the ground water. Since legume species can fix nitrogen from the atmosphere, additional sewage sludge nitrogen additions are often unnecessary.

If a site is to be reforested, it is still generally desirable to seed it with a mixture of grasses and legumes. The initial grass and legume cover helps to protect the site from erosion and surface runoff and takes up the nutrients supplied by the sewage sludge. Planting slow-growing tree species is generally not recommended because of the extreme competition from the fast-growing herbaceous vegetation. Fast-growing hardwoods seem to survive and grow well because they can usually compete successfully. Suitable species might be black locust, hybrid poplar, European alder, Catalpa, and European larch.

9.4.2 Seeding and Mulching

Herbaceous species can be seeded by direct drill or broadcast, hydroseeding, or aerial seeding. Disturbed sites, however, often are too rocky and irregular for drill seeding. Broadcast seeding is generally more desirable because the stand of vegetation produced is more natural in appearance, with a more uniform and complete cover, and is effective in erosion prevention and site stabilization. Broadcasting also achieves a planting depth that is better suited to the variety of different sized seeds usually found in mixtures of species. Aerial broadcast seeding may also be useful for large tracts. It is generally not necessary to cover the seed, since the first rainfall will normally push the seed into the loosened surface spoil and result in adequate coverage.

On sites that have good topsoil, agricultural seeding rates can be used. On abandoned sites, however, it may be necessary to apply much larger amounts of seed (Sopper and Seaker, 1983). Mulching is generally not necessary except on specific sites. Mulching involves applying organic or inorganic materials to the soil surface to protect the seed, reduce erosion, modify extremes in surface spoil temperatures, and reduce evaporation. Mulching is generally advisable on steep slopes and on black anthracite refuse or fly ash banks to protect germinating vegetation from high surface temperatures, which may be lethal to most plants. Mulching may also be required by some state regulatory agencies for specific situations. Materials used for mulching are straw, hay, peanut hulls, corn cobs, bagasse, bark, sawdust, leaves, and wood chips.

9.5 Sewage Sludge Application Methods

9.5.1 Transportation

Chapter 14 discusses sewage sludge transport in detail. A special consideration in transport of sewage sludge to reclaimed mined land is the potential to backhaul sewage sludge (i.e., use the same trucks, railcars, etc., that transport the mined ore to the city for transporting the sewage sludge from the city back to the mining area). For example, in 1981-82, the city of Philadelphia backhauled about 54,432 t (60,000 T) of sewage sludge annually in coal trucks a distance of 450 km (280 mi) to help reclaim strip mine sites in western Pennsylvania (Sopper et al., 1981).

9.5.2 Site Preparation Prior to Sewage Sludge Application

Under federal and state mining regulations, disturbed mine sites generally must be graded after mining to the approximate original contour of the area. Abandoned areas where no regrading has been done should also be regraded to a relatively uniform slope of less than 15 percent prior to sewage sludge application.

9.5.2.1 Scarification

Prior to sewage sludge application, the soil surface should be roughened or loosened to offset compaction caused during the leveling or grading operation. This will help to improve surface water infiltration and permeability and slow the movement of any surface runoff and erosion. A heavy mining disk or chisel plow is typically necessary to roughen the surface. It is advisable that this be done parallel to the site contours.

9.5.2.2 Debris Removal

Preparing a site for land reclamation may require the removal of debris from mining, construction, or other operations previously conducted at the site. The extent to which debris must be removed depends on the post-reclamation use. For example, if agricultural activities are planned, the top 60 cm (24 in) should be free of foreign material of any significant size (Gschwind and Pietz, 1992). If the site is to be revegetated for erosion control, debris should be removed from the top 30 cm (12 in) of soil. If an irrigation hose is used, extensive rock removal will prevent excessive wear of the hose (Gschwind and Pietz, 1992).

9.5.2.3 Erosion and Surface Runoff Control Measures

Surface runoff and soil erosion from the reclamation site should be controlled. These measures may include erosion control blankets, filter fences, straw bales, and mulch. It may be necessary to construct diversion terraces and/or sedimentation ponds. The local Natural Resources Conservation Service (formerly the Soil Conservation Service) can be contacted for assistance in designing erosion and surface runoff control plans. In addition, see Chapter 13 of this manual.

9.5.3 Methods of Application

Methods for land application of sewage sludge include surface spreading, incorporation, spray irrigation, and injection. These methods are discussed in Chapter 14.

9.5.4 Storage

Sewage sludge storage will probably be needed at a reclamation site. The Part 503 regulation defines storage as the placement of sewage sludge on land on which the sewage sludge remains for two years or less. Storage may occur at the treatment works and/or at the land application site. In general, when liquid sewage sludge is used, storage is provided at the treatment plant in digesters, holding tanks, or lagoons. At land application sites where large quantities of liquid sewage sludge are used, storage lagoons may be built at the site.

If dewatered sewage sludge is used, storage may be more advantageously located at the land application site. Small storage areas may also be desirable at the treatment plant for times of inclement weather or equipment breakdown.

At currently mined sites, it may be necessary to transport and stockpile dewatered sewage sludge at the site prior to land application while the area is being backfilled and topsoiled. This would allow large quantities of sewage sludge to be applied in a relatively short period of time and also allows more efficient use of manpower and equipment. Some states have specific regulations concerning sewage sludge stockpiling onsite for short periods of time. For example, in Pennsylvania, the sewage sludge storage area must be diked to prevent surface water from running into or out of the storage area.

9.6 Scheduling

The timing of sewage sludge application depends on the climate, soil conditions, and growing season. The Part 503 regulation prohibits bulk sewage sludge application to flooded, frozen, or snow-covered reclamation sites in such a way that the sewage sludge enters a wetland or other surface waters (except as provided in a permit issued under Section 402 or 404 of the Clean Water Act). Sewage sludge should not be applied during periods of heavy rainfall because this greatly increases the chances of surface runoff. Sewage sludge also should not be applied in periods of prolonged extreme heat or dry conditions, since considerable amounts of nitrogen will be lost before the vegetation has a chance to establish itself. If sewage sludge is applied and allowed to dry on the soil surface, from 20 to 70 percent of the NH_4-N will be volatilized and lost to the atmosphere as NH_3. The exact amount of NH_4-N lost will depend on soil, sewage sludge, and climate conditions (U.S. EPA, 1978).

Sewage sludge applications should be scheduled to accommodate the growing season of the selected plant species. If soil conditions are too wet when sewage sludge is applied, the soil structure may be damaged, bulk density increased, and infiltration decreased due to heavy vehicle traffic on the wet soil. This may increase the possibility of soil erosion and surface runoff. In addition, the tractors or trucks may experience difficulty driving on the wet soil.

If the area to receive sewage sludge is covered under federal or state mining regulations, the sewage sludge application must be scheduled to comply with the revegetation regulations. For example, in Pennsylvania, mined land can be seeded in the spring as soon as the ground is workable, usually early in March, but seeding must terminate by May 15. The late summer seeding season is from August 1 until September 15. The designer should check on requirements for his or her locale.

9.7 Determining Sewage Sludge Application Rates at Reclamation Sites

9.7.1 General Information

Historically, land application of sewage sludge at reclamation sites generally has involved large applications of sludge to sufficiently establish vegetation, with rates sometimes exceeding 200 t/ha and no subsequent applications. Such high application rates almost invariably exceed agronomic rates for plant nitrogen needs, and can result in temporary leaching of nitrate into ground water.

The Part 503 rule specifies that, in general, application of sewage sludge should not exceed the agronomic rate for N, but that higher rates may be allowed at reclamation sites if approved by the permitting authority. When determining sewage sludge application rates, it is useful to draw a general distinction between "reconstructed" and "abandoned" reclamation sites:

- "Reconstructed" reclamation sites generally include coal mine reclamation sites that have been or are being reclaimed according to provisions of the 1977 federal Surface Mining Reclamation and Control Act (SMCRA), and surface-mine reclamation sites involving non-coal minerals (such as iron and copper) regulated by other federal or state programs that require a measure of soil reconstruction after the mineral has been removed. SMCRA requires grading of spoils to reestablish the approximate original contour of the land, the saving and replacement of topsoil on all areas affected by mining, and additional soil reconstruction for prime farmlands. Grading of mine spoils and replacement of topsoil is also a routine practice at active surface mine sites involving non-coal minerals.
- "Abandoned" reclamation sites are typically abandoned coal mine sites, especially those involving acid- or toxic-forming spoil or coal refuse, where disturbance occurred prior to enactment of SMCRA and natural revegetation has been sparse. Other mine sites where mining practices or unfavorable overburden chemistry have resulted in poor vegetation establishment also can be considered "abandoned" reclamation sites.

Generally, application of sewage sludge at rates exceeding plant N requirements is not justified at reconstructed reclamation sites, and procedures for determining sewage sludge application rates should be the same as those described in Chapter 7 for agricultural crops or Chapter 8 for forest sites. An exception might be where topsoil was very thin or missing before mining, such as forest lands on steep slopes with weakly developed soil horizons (Sopper, 1993).

Large, one-time sewage sludge applications that exceed the agronomic rate for N are most likely to be justified at abandoned sites, such as abandoned acid strip mine spoils, where ground-water quality is usually already severely degraded. At such sites, the long-term benefits of the large addition of organic matter in the sewage sludge to the mine spoils for establishing an improved vegetative cover exceed the short-term effects of leaching of excess nitrate from the sludge. Section 9.7.2 below describes a procedure for determining application rates at abandoned reclamation sites where the agronomic rate may not be sufficient to reestablish vegetation.

9.7.2 Approach for Determining a Single, Large Application of Sewage Sludge at a Reclamation Site

The approach for determining the maximum acceptable one-time application of sewage sludge to a reclamation site is based on evaluating the effect of N in excess of plant needs from a large application on soil-water nitrate concentrations. The main steps in this procedure involve:

1) Determine the maximum allowable application rate (S_{max}) (e.g., based on the Part 503 CPLR limits, see Chapter 3).

2) Perform N budget calculations to determine the available N in excess of plant needs (using S_{max}, as described in Section 9.7.3).

3) Estimate the soil-water nitrate concentrations that will result from the excess N from a one-time application at S_{max}.

4) If soil-water nitrate concentrations from application of S_{max} are not acceptable, a lower application rate is set that will not exceed a defined acceptable soil-water nitrate concentration.

Section 9.7.3 provides a design example that illustrates this process.

9.7.3 Design Example for a Single, Large Sewage Sludge Application at a Reclamation Site

A five-acre area of abandoned acidic mine spoils (pH 3.9) in Kentucky is to be reclaimed using a single large application of sewage sludge to provide organic matter and nutrients required to support establishment of a mixture of grass and legumes, with a first-year N requirement of 300 kg/ha. Based on appropriate soil tests, it was determined that agricultural lime application of 12.3 t/ha (5.5 T/ac) is sufficient to raise the soil pH to 6.5. The spoils are slowly permeable (0.2 cm/hr). Net precipitation infiltrating into the ground is estimated to be 80 cm (31.5 in), of which 20 percent is estimated to be lost by evapotranspiration. Depth to ground water is 5 m (16 ft).

The sewage sludge to be applied has undergone anaerobic digestion and has the following characteristics:

- Solids - 4.0 percent
- Organic N - 2.5 percent
- NH_4-N - 1.0 percent
- NO_3-N - 0 percent
- Total P - 2.0 percent
- Total K - 0.5 percent
- As - 10 mg/kg
- Cd - 10 mg/kg
- Cr - 1,000 mg/kg
- Cu - 3,750 mg/kg
- Pb - 150 mg/kg
- Hg - 2 mg/kg
- Mo - 8 mg/kg
- Ni - 100 mg/kg
- Se - 15 mg/kg
- Zn - 2,000 mg/kg

Step 1. Calculate Maximum Application Based on Metal Loading

The cumulative pollutant loading rate for a particular metal is calculated using the following equation:

$$S_{max} = L/C_m \text{ (1,000 kg/t)} \qquad \textit{(9-1)}$$

where:

S_{max} = The total amount of sewage sludge, in t/ha, that would result in the cumulative pollutant loading rate limit, L.
L = The Part 503 cumulative pollutant loading rate limit (CPLR) for sewage sludge in kg/ha (see Chapter 3).
C_m = Concentration, in mg/kg, of the metal of concern in the sewage sludge being applied.

The limiting metal in this example is copper, with S_{max} = 400 t/ha. In reality, most sewage sludges contain lower copper levels; this higher level is used here to illustrate an application rate higher than the agronomic rate. Since sludge applications at 400 t/ha could result in a high nitrogen impact on ground water during the first two years of operation, a loading rate of 200 t/ha was selected, which is sufficient for establishing vegetation. Note that if the copper concentration in the sewage sludge in this example met Part 503's "pollutant concentration limit" (as do all the other pollutants listed) rather than the CPLR limit for copper, cumulative metal loadings would not be required to be tracked (see Chapter 3), and application rates would not be limited by cumulative pollutant loadings (see Chapter 7, Section 7.4.4.3).

Step 2. Determine Excess N Available for Leaching

Available N content of the revised S_{max} (200 t/ha) is calculated using the following equation:

$$N_p = S\,[(NO_3) + K_v\,(NH_4) + F_{(year\ 0\text{-}1)}\,(N_o)]\,(10) \qquad \textit{(9-2)}$$

where:

N_p = Plant-available N (from this year's sewage sludge application only), in kg/ha.
S = Sewage sludge application rate, in dry t/ha.
NO_3 = Percent nitrate-N in the sewage sludge, as percent.
K_v = Volatilization factor, usually set at 0.5 for surface-applied liquid sewage sludge, or 1.0 for incorporated liquid sludge and dewatered sludge applied in any manner.
NH_4 = Percent ammonia-N in the sewage sludge, as percent (e.g., 1% = 1.0).
$F_{(year\ 0\text{-}1)}$ = Mineralization factor for organic N in the sewage sludge in the first year, expressed as a fraction (e.g., 0.2).
N_o = Percent organic N in the sewage sludge, as percent (e.g., 2.5% = 2.5).

Since the sludge is to be surface applied, K_v = 0.5.

$$N_{p1} = 200\,[(0.0) + (0.5)(1.0) + (0.2)(2.5)]\,(10)$$
$$= 2{,}000 \text{ kg/ha}$$

Available N in the second year after the one-time application is simply the amount mineralized from the initial application, using the following equation:

$N_m = (S)\ (K_m)\ (N_o)$ *(9-3)*

where:

N_m = Quantity of N_o mineralized in the year under consideration, in kg/ha.
S = Sewage sludge application rate, in dry t/ha.
K_m = Mineralization factor for the year under consideration, expressed as a fraction.
N_o = Percent organic N originally present in the sewage sludge, as percent (e.g., 2.5% = 2.5).

In this example, for illustrative purposes, K_{m2} = 0.80 and K_{m3} = 0.36 in the second and third years respectively for anaerobic sludge. Thus:

N_{m2} = (200) (0.80) (2.5)
= 400 kg/ha

N_{m3} = (200) (0.36) (2.5)
= 180 kg/ha

A simplified N budget for the S_{max} sludge application for the first three years after application is as follows, with N_r representing plant uptake (300 kg/ha):

Year 1: $N_{excess} = N_{p1} - N_r$ = 2,000 - 300 = 1,700 kg/ha
Year 2: $N_{excess} = N_{m2} - N_r$ = 400 - 300 = 100 kg/ha
Year 3: $N_{excess} = N_{m3} - N_r$ = 100 - 300 = 0 kg/ha

In the first year, available N is more than 6 times the plant uptake, and by the second year is slightly more than plant uptake. In the third year, mineralized N is less than potential plant uptake. Consequently, with a one-time large application of sewage sludge, leaching of nitrate can be expected during the first year, with minimal leaching in the second year and no leaching in the third year. These N budget calculations have been simplified for this illustrative example; the more detailed annual N budget calculations contained in the Worksheets in Chapter 7 can also be used.

Step 3. Calculation of Potential Nitrate Leaching into Ground Water

It is possible to make a conservative estimate of the quantity of nitrates potentially leaching into the ground water by calculating the maximum potential concentration of excess nitrates percolating from the site into the underlying aquifer. This is done by assuming that all N in excess of plant needs is converted to nitrates, and that no dilution of percolate occurs in existing ground water.

Assume annual net infiltration of precipitation, P_I = 80 cm.
Assume evapotranspiration losses, ET = 20% = 0.20.

If all of the excess nitrogen in the sludge applied is mobile (an unlikely and very conservative assumption), the concentration of nitrate in the percolate is calculated using the following equation:

Soil Water NO_3, mg/L =

$$\frac{(N_{excess}\ \text{kg/ha})\ (10^6\ \text{mg/kg})\ (1{,}000\ \text{cm}^3/\text{L})}{(10^8\ \text{cm}^2/\text{ha})\ (P_I,\ \text{cm})\ (1-ET)}$$

$$= \frac{(1{,}700\ \text{kg/ha})\ (10^6\ \text{mg/kg})\ (1{,}000\ \text{cm}^3/\text{L})}{(10^8\ \text{cm}^2/\text{ha})\ (80\ \text{cm})\ (1-0.20)}$$

$$= 266\ \text{mg/L}$$

Repeating the calculation for the excess N in the second year indicates a maximum NO_3 concentration of 16 mg/L. By the third year, the site would meet the nitrate drinking water MCL of 10 mg/L because no excess N exists.

If the potential concentration of nitrate-N in the percolate that exceeds the MCL during the first two years after sewage sludge application is unacceptable to the regulatory agency, even though by the third year leaching effects are minimal, and if there is no extraction of potable water from the aquifer, maximum sludge application rates can be calculated based on a maximum acceptable level of NO_3 in percolating soil water.

Additional information on the design of mine land reclamation projects using municipal sewage sludge can be found in the *Manual for the Revegetation of Mine Lands in Eastern United States Using Municipal Biosolids* (Sopper, 1994).

9.8 References

When an NTIS number is cited in a reference, that document is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-487-4650

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Chapter 10
Land Application at Public Contact Sites, Lawns, and Home Gardens

10.1 General

In addition to land application at agricultural, forest, and reclamation sites, sewage sludge and domestic septage can be land applied to lawns and home gardens as well as "public contact sites." The Part 503 regulation defines public contact sites as land with a high potential for contact by the public, such as parks, ball fields, cemeteries, plant nurseries, turf farms, and golf courses. In many cases, sewage sludge is applied to these types of sites from bags or other containers[1] that are sold or given away (hereafter referred to as "bagged" sewage sludge), although sewage sludge also can be land applied to these types of sites in bulk form. Often the sewage sludge used at these sites is processed and marketed by municipalities or private firms as a brand-name fertilizer and/or soil conditioning product. Designing land application programs geared toward public contact sites, lawns, and home gardens may be particularly useful for municipalities with limited land available (e.g., highly populated areas with few agricultural, forest, or reclamation sites available for sewage sludge application).

This chapter discusses how the Part 503 requirements pertain to land application of sewage sludge and domestic septage at public contact sites, lawns, and home gardens (Section 10.2). Important factors to consider in designing a marketing program for sewage sludge to be land applied at public contact sites, lawns, and home gardens are discussed in Section 10.3.

10.2 Part 503 Requirements

Many of the strictest requirements in Part 503 must be met for sewage sludge or domestic septage that is land applied to public contact sites, lawns, and home gardens (e.g., Class A pathogen reduction; for metals, annual pollutant loading rate limits for bagged sewage sludge or pollutant concentration limits for bulk sewage sludge, see Chapter 3). Domestic septage applied to public contact sites, lawns, or home gardens must meet the same requirements as bulk sewage sludge that is land applied, although less burdensome requirements pertain to domestic septage applied to other types of land (agricultural, forest, or reclamation sites), as described in Chapter 11. The stringent requirements are specified for sewage sludge that is land applied to public contact sites, lawns, and home gardens because of the high potential for human contact with sewage sludge at these types of sites and because it is not feasible to impose site restrictions when sewage sludge is sold or given away in bags or other containers for application to the land. The sewage sludge used in this manner must meet the requirements for metals, pathogens, vector attraction reduction, management practices, and other requirements specified in Part 503 for application to these types of sites, as discussed in Chapter 3.

The effects of the Part 503 regulation on current sewage sludge land application programs depends on the quality of the sewage sludge. If a sewage sludge meets certain Part 503 requirements, the sewage sludge can be considered "exceptional quality" (EQ), as discussed in Chapter 3. EQ sewage sludge can be applied as freely as any other fertilizer or soil amendment to any type of land. If EQ sewage sludge requirements are met, current land application operations, including those with already successful marketing programs for sewage sludge (see Section 10.3), may continue with a minimum of additional regulatory requirements. For sewage sludge preparers[2] who have difficulty meeting the Part 503 requirements for public contact sites, lawns, or home gardens, operational changes may need to be implemented to further reduce pathogen or metal levels for land application at these types of sites. The types of sewage sludge treatment and preparation that can achieve EQ-quality sewage sludge (e.g., heat drying) are discussed in Chapter 3.

10.3 Marketing of Sewage Sludge

After processing to achieve Part 503 requirements, sewage sludge that is to be land applied at public contact

[1] The Part 503 regulation defines "other containers" as open or closed receptacles, such as buckets, boxes, carton, or vehicles, with a load capacity of 1 metric ton or less.

[2] The Part 503 regulation defines a person who prepares sewage sludge as either the person who generates sewage sludge during the treatment of domestic sewage in a treatment works or the person who derives a material from sewage sludge.

sites, lawns, and home gardens often is marketed to distributors or end users (e.g., landscapers, home gardeners), frequently as bagged sewage sludge. Designing a marketing program for sewage sludge has some similarities to marketing any commercial product, including:

- Maintaining the "high quality" of the product
- Ensuring the product is readily available
- Developing and maintaining product demand
- Offering competitive pricing

Two marketing factors particularly relevant to sewage sludge are:

- Maintaining good public relations
- Ensuring that the operations are acceptable to the community

Having a diversified range of products may be useful. In the case of sewage sludge, this might include producing a Class B bulk sewage sludge for agricultural, forest, and reclamation sites, and a Class A bagged sewage sludge product, such as compost, for use by landscapers, public works departments, and the public.

10.3.1 Developing Product Demand

To create and maintain product demand, many municipalities or private firms use a trade name to enhance marketability, such as Milorganite, a heat-dried, bagged sewage sludge produced by the city of Milwaukee, Wisconsin, and Philorganic, a composted sewage sludge produced by the city of Philadelphia, Pennsylvania. Other cities that produce heat-dried sewage sludge include Chicago, Houston, Atlanta, Tampa Bay, and New York City. Municipalities that produce composted sewage sludge include the District of Columbia, Kittery (Maine), Denver, Missoula (Montana), and Los Angeles.

Some municipalities also conduct market surveys to determine who would be interested in purchasing their product; use agricultural professionals as sales agents; advertise in professional journals and the mass media; and contract with an intermediary for distribution.

The wastewater treatment plant or other preparer of sewage sludge may be able to increase marketability by offering the customer various important "services," such as (Warburton, 1992):

- Storing the user's purchased sewage sludge at the wastewater treatment plant (in accordance with Part 503 provisions).
- Providing the user with results of nutrient, pollutant, and any ground-water, surface water, or plant tissue sampling tests.
- Offering dependable transport to the land application site at times suitable for land application.
- Assisting in obtaining required permits.
- Performing reliable inventory management, so that the "product" is always available when needed.

In many cases, marketing of sewage sludge can include promoting the concept of reuse/recycling. For example, the City of Los Angeles now reuses 100% of its 300 dT/day of sludge through agricultural land application (at various sites), as soil cover at a landfill, and composting. Los Angeles has implemented several innovative sewage sludge marketing programs. One is the "Full Cycle Recycle" composting program, which includes public education for LA's "Topgro" soil amendment/compost product. Topgro is produced from city wastes (sewage sludge and/or yard trimmings), processed locally, and marketed as "home grown" to local nurseries, retailers, and City agencies in bulk or bag at competitive prices. Another LA sewage sludge marketing program is a cooperative composting project between the city's Department of Public Works and Department of Recreation and Parks, in which sewage sludge, zoo manure, and plant wastes are processed and used as compost at city parks; the composting facility also serves as an educational center for the public (Molyneux et al., 1992).

10.3.2 Marketing Cost Considerations

The costs of a sewage sludge marketing program may be high relative to costs of direct land application. Major cost factors include:

- Dewatering the sewage sludge.
- Composting, heat drying, or other processes to achieve adequate pathogen reduction and vector attraction reduction.
- Market development.
- Transportation.

Dewatering and other processing can involve significant capital expenditures. Some generators/preparers of sewage sludge may choose to contract out some processing technologies, which can be done through competitive bidding between vendors that produce similar products (e.g., a heat-dried product, compost, certain alkaline stabilization processes that meet Part 503 Class A pathogen reduction requirements) to reduce program costs (Warburton, 1992). The City of Los Angeles has reduced its sludge management program costs by an average of $3 per dry ton as a result of improved management, decreased transportation times, price rebates, volume discounts, and minimizing truck loading times (Molyneux et al., 1992).

A marketing program for sewage sludge always should include examination of the costs of transporting the sewage sludge. Transportation costs may include conveying the sludge from the wastewater treatment plant to the processing center, transport of bulking materials for composting, and distribution of the finished sewage sludge product. Although extending the geographical marketing area would increase shipping costs, it may be worthwhile if it is likely that potential buyers in the extended area are willing to pay a higher price for the product.

Some municipalities charge the distributor or end user for the use of a sewage sludge product, as shown in Table 10-1. The table indicates that from 38% to 60% of POTWs sell their sludge at rates ranging from $4 to $6 per cubic yard or $34 to $63 per ton. In some cases, the municipality may not make a "profit" from selling sewage sludge, but the sales can reduce operating costs for overall sewage sludge management. In other cases, the sewage sludge generator or preparer pays the landowner or person responsible for land applying sewage sludge if payment results in lower sewage sludge management costs.

In some localities, demand has exceeded supply for marketed sewage sludge. In other areas, marketed sewage sludge programs have failed because of poor or inconsistent product quality or operational practices unacceptable to the community. Demand for sewage sludge for land application tends to be seasonal, peaking in the spring and fall in areas with four-season climates. In areas with mild climates year-round, a constant market can be developed.

Table 10-1. Percent of POTWs Selling Sewage Sludge and Mean Price of Sewage Sludge Sold (Adapted From U.S. EPA, 1990)

Reported Flow Rate Group[a]	% of POTWs That Sell[b]	Price Per Ton[c]	Price Per Cubic Yd[c]
1	60.0%	$63	$5
2	71.4	34	6
3	42.1	-	4
4	37.5	-	6

[a] Flow rate group 1 = >100 MGD; 2 = >10-100 MGD; 3 = >1-10 MGD; 4 = 0-1 MGD.
[b] Percents based on a total of 46 POTWs.
[c] 50% of the POTWs who reported that they sold sewage sludge provided price data.

10.4 References

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Chapter 11
Land Application of Domestic Septage

11.1 General

Land application of domestic septage is an economical and environmentally sound practice used by many rural communities. Like land application programs for other types of sewage sludge, a properly managed land application program for domestic septage can benefit from the reuse of the organic matter and nutrients in the domestic septage without adversely affecting public health. Sometimes, however, finding suitable sites, overcoming local opposition, or meeting regulatory requirements may be difficult. The Part 503 regulation governing the use or disposal of sewage sludge, promulgated in February 1993, includes simplified requirements for the land application of domestic septage (compared to more extensive requirements for other types of sewage sludge generated by a wastewater treatment plant). While the Part 503 rule provides minimum guidelines for state programs, individual state regulations may be more stringent.

The Part 503 regulation includes minimum requirements for the application of domestic septage to land used infrequently by the general public, such as agricultural fields, forest land, and reclamation sites.

For land application of domestic septage to land where public exposure potential is high, however (i.e., public contact sites or home lawns and gardens), the same Part 503 requirements as those for bulk sewage sludge applied to the land must be met (i.e., general requirements, pollutant limits, pathogen and vector attraction reduction requirements, management practices, frequency of monitoring requirements, and recordkeeping and reporting requirements) (U.S. EPA, 1994a). See Chapter 3 for a discussion of each of these provisions of the Part 503 rule.

The remainder of this chapter focuses on the land application of domestic septage to agricultural land, forests, or reclamation sites. For additional information on applications to these types of land, see *Domestic Septage Regulatory Guidance: A Guide To Part 503* (U.S. EPA, 1993).

11.1.1 Definition of Domestic Septage

Domestic septage is defined in the Part 503 regulation as the liquid or solid material removed from a septic tank, cesspool, portable toilet, Type III marine sanitation device, or a similar system that receives only domestic sewage (water and wastewater from humans or household operations that is discharged to or otherwise enters a treatment works). Domestic sewage generally includes wastes derived from the toilet, bath and shower, sink, garbage disposal, dishwasher, and washing machine. Domestic septage may include household septage as well as septage from establishments such as schools, restaurants, and motels, as long as this septage does not contain other types of wastes than those listed above.

Domestic septage characteristics are presented in Table 11-1 (conventional wastewater parameters and nutrients) and Table 11-2 (metals and organics) (U.S. EPA, 1994a).

Table 11-1. Characteristics of Domestic Septage: Conventional Parameters (U.S. EPA, 1994b)

	Concentration (mg/L)		
Parameter	**Average**	**Minimum**	**Maximum**
Total solids	34,106	1,132	130,475
Total volatile solids	23,100	353	71,402
Total suspended solids	12,862	310	93,378
Volatile suspended solids	9,027	95	51,500
Biochemical oxygen demand	6,480	440	78,600
Chemical oxygen demand	31,900	1,500	703,000
Total Kjeldahl nitrogen	588	66	1,060
Ammonia nitrogen	97	3	116
Total phosphorus	210	20	760
Alkalinity	970	522	4,190
Grease	5,600	208	23,368
pH	—	1.5	12.6

Table 11-2. Characteristics of Domestic Septage: Metals and Organics (U.S. EPA, 1994b)

Parameter	Concentration (mg/L) Average	Minimum	Maximum
Metals			
Iron	39.3	0.2	2740
Zinc	9.97	< 0.001	444
Manganese	6.09	0.55	17.1
Barium	5.76	0.002	202
Copper	4.84	0.01	261
Lead	1.21	< 0.025	118
Nickel	0.526	0.01	37
Chromium (total)	0.49	0.01	34
Cyanide	0.469	0.001	1.53
Cobalt	0.406	< 0.003	3.45
Arsenic	0.141	0	3.5
Silver	0.099	< 0.003	5
Cadmium	0.097	0.005	8.1
Tin	0.076	< 0.015	1
Mercury	0.005	0.0001	0.742
Organics			
Methyl alcohol	15.8	1	396
Isopropyl alcohol	14.1	1	391
Acetone	10.6	0	210
Methyl ethyl ketone	3.65	1	240
Toluene	0.17	.005	1.95
Methylene chloride	0.101	0.005	2.2
Ethylbenzene	0.067	0.005	1.7
Benzene	0.062	0.005	3.1
Xylene	0.051	0.005	0.72

11.1.2 Domestic Septage Versus Industrial/Commercial Septage

The specific definition of domestic septage in the Part 503 regulation does not include many materials that are often called septage by industry. Commercial and industrial septage are not considered domestic septage. The factor that differentiates commercial and industrial septage from domestic septage is the type of waste being produced (a treatment works, e.g., a septic tank, receiving domestic sewage), rather than the type of establishment generating the waste. For example, sanitation waste and residues from food and normal dish cleaning from a restaurant are considered domestic sewage, whereas grease trap wastes from a restaurant are classified as commercial septage. If restaurant grease trap wastes are included with domestic septage in a truckload, then the whole truckload is not covered by the Part 503 regulation (U.S. EPA, 1993). Instead, commercial and industrial septage and mixtures of these septages with domestic septage are regulated under 40 CFR Part 257 if the septage is used or disposed on land. Industrial and commercial septage containing toxic compounds or heavy metals require special handling, treatment, and disposal methods; a discussion of these methods is beyond the scope of this manual.

11.2 Regulatory Requirements for Land Application of Domestic Septage

11.2.1 Determining Annual Application Rates for Domestic Septage at Agricultural Land, Forests, or Reclamation Sites

Federal requirements that have been established under Part 503 for land application of domestic septage are discussed in Chapter 3. According to the Part 503 regulation, the maximum volume of domestic septage that may be applied to agricultural land, forest land, or a reclamation site during a 365-day period depends on the amount of nitrogen required by the crop for the planned crop yield. The maximum volume for domestic septage is calculated by the following formula:

$$AAR = \frac{N}{0.0026}$$

Where:

AAR = Annual application rate in gallons per acre per 365 day period.
N = Amount of nitrogen in pounds per acre per 365 day period needed by the crop or vegetation grown on the land.

For example, if 100 pounds of nitrogen per acre is required to grow a 100 bushel per acre crop of corn, then the AAR of domestic septage is 38,500 gallons per acre (U.S. EPA, 1993):

$$AAR = \frac{100 \text{ lbs/acre/year}}{0.0026} = 38{,}500 \text{ gallons/acre/year}$$

Application rate requirements pertain to each site where domestic septage is applied and must be adjusted to the nitrogen requirement for the crop being grown (U.S. EPA, 1993). Nitrogen requirements of a crop depend on expected yield, soil conditions, and other factors such as temperature, rainfall, and length of growing seasons. Local agricultural extension agents should be contacted to determine the appropriate nitrogen requirements for use in the above equation for calculation of the application rate.

Table 11-3 outlines typical nitrogen requirements of various crops and corresponding domestic septage application rates (U.S. EPA, 1993). These values are listed as general guidance only; more specific information on the

Table 11-3. Typical Crop Nitrogen Requirements and Corresponding Domestic Septage Application Rates (U.S. EPA, 1993)

	Expected Yield (bushel/acre/ year)	Nitrogen Requirement (lb N/acre/ year)[1]	Annual Application Rate (gallons/acre/ year)
Corn	100	100	38,500
Oats	90	60	23,000
Barley	70	60	23,000
Grass & Hay	4 tons/acre	200	77,000
Sorghum	60	60	23,000
Peanuts	40	30	11,500
Wheat	70	105	40,400
Wheat	150	250	96,100
Soybeans	40	30	11,500
Cotton	1 bale/acre	50	19,200
Cotton	1.5 bales/acre	90	35,000

[1] These figures are very general and are provided for illustration purposes. They should not be used to determine your actual application rate. Crop fertilization requirements vary greatly with soil type. Expected yields and climatic conditions are also important factors in determining the appropriate volume of domestic septage to apply to a particular field. Different amounts of nutrients can be required by the same crop grown in different parts of the country. To get more specific information on crop fertilization needs specific to your location, contact local agricultural extension agents.

amount of nitrogen required for the expected crop yield under local soil and climatic conditions should be obtained from a qualified, knowledgeable person, such as a local agricultural extension agent. The crop nitrogen requirement is then used in the annual application rate formula to calculate the gallons per acre of domestic septage that can be applied.

While not required by the Part 503 rule, it is important that the septic tank pumper inform the landowner or lease holder of the land application site regarding how much of the crop's nitrogen requirement was added by the applied domestic septage. This information will allow the land owner to determine how much additional nitrogen, if any, in the form of chemical fertilizer will need to be applied (U.S. EPA, 1993). The pumper should also inform the landowner/leaser of any site restrictions.

11.2.1.1 Protection of Ground Water from Nitrogen Contamination

The primary reason for requiring the annual rate calculation is to prevent the over-application of nitrogen in excess of crop needs and the potential movement of nitrogen through soil to ground water. The annual application rate formula was derived using assumptions that facilitate land application of domestic septage. For example, fractional availability of nitrogen from land-applied domestic septage was assumed over a 3-year period to obtain the 0.0026 factor in the application formula. Also, in deriving the formula, domestic septage was assumed to contain 313 mg/l per year available nitrogen (in year three and thereafter) (U.S. EPA, 1992a).

Domestic septage from portable chemical toilet and type III marine sanitation device wastes can contain 4 to 6 times more total nitrogen than was assumed to derive the annual application rate formula, however (U.S. EPA, 1993). While not required by the Part 503 regulation, it is recommended that land appliers consider reducing the volume applied per acre of such high nitrogen-containing domestic septage (U.S. EPA, 1993). For example, if the land owner is expecting to grow a 100-bushel per acre corn crop and the domestic septage contains 6 times more total nitrogen, the gallons applied should be reduced 6-fold (from 38,500 to about 6,400 gallons).

For additional guidance on avoiding nitrogen contamination of ground water when land applying domestic septage with a high nitrogen content or dewatered domestic septage, see *Domestic Septage Regulatory Guidance: A Guide to the EPA 503 Rule* (U.S. EPA, 1993).

11.2.2 Pathogen Reduction Requirements

Domestic septage must be managed so that pathogens (disease-causing organisms) are appropriately reduced. The Part 503 regulation offers two alternatives to meet this requirement. Pathogen reduction alternative 1 (no treatment) and restrictions are presented in Figure 11-1 (U.S. EPA, 1993); the requirements of pathogen reduction alternative 2 (with treatment) are listed in Figure 11-2 (U.S. EPA, 1993). Both of the pathogen reduction alternatives impose crop harvesting restrictions. Site access controls and grazing restrictions, however, are also required when the domestic septage is not treated (alternative 1 only). Certification that the Part 503 pathogen reduction requirement has been met is also required of the domestic septage land applier, as discussed in Section 11.2.4 below. Chapter 3 discusses the pathogen reduction requirements of Part 503 in greater detail.

11.2.3 Vector Attraction Reduction Requirements

For application of domestic septage to agricultural land, forests, or reclamation sites, the Part 503 regulation requires that one of the following three options be implemented to reduce vector attraction (U.S. EPA, 1994b):

- Subsurface injection.
- Incorporation (surface application followed by plowing within 6 hrs).
- Alkali stabilization.

Domestic septage is land applied without treatment, and the following restrictions must be observed:

Crop Restrictions:

- Food crops with harvested parts that touch the domestic septage/soil mixture and are totally above ground shall not be harvested for 14 months after application of domestic septage.
- Food crops with harvested parts below the surface of the land shall not be harvested for either (1) 20 months after application if domestic septage remains on the land surface for 4 months or longer, or (2) 38 months after application if domestic septage remains on the land surface for less than 4 months, prior to incorporation into the soil.
- Feed, fiber, and food crops shall not be harvested for 30 days after application of the domestic septage.
- Turf grown on land where domestic septage is applied shall not be harvested for one year after application of the domestic septage when the harvested turf is placed on either a lawn or land with a high potential for public exposure, unless otherwise specified by the permitting authority.

Grazing Restrictions:

- Animals shall not be allowed to graze on the land for 30 days after application of domestic septage.

Site Restrictions:

- Public access to land with a low potential for public exposure shall be restricted for 30 days after application of domestic septage. Examples of restricted access include remoteness of site, posting with no trespassing signs, and/or simple fencing.

Figure 11-1. Part 503 pathogen reduction Alternative 1 for domestic septage (without additional treatment) applied to agricultural land, forests, or reclamation sites (U.S. EPA, 1993).

For detailed information on subsurface injection and incorporation practices at land application sites, see Chapter 14.

Alkali stabilization of domestic septage involves raising its pH. Vector attraction is reduced if the pH is raised to at least 12 through alkali addition and maintained at 12 or higher for 30 minutes without adding more alkali. When this option is used, every container of domestic septage must be monitored to demonstrate that it meets the requirement (U.S. EPA, 1992b). When this is done, the treatment component of alternative 1 for pathogen reduction, discussed above, also is met. This vector attraction reduction requirement is slightly less stringent than the alkali addition method required by Part 503 for other types of sewage sludge. This option addresses the practicalities of using or disposing domestic septage, which is typically treated by lime addition to the domestic septage hauling truck (see Section 11.3). The treated septage is typically applied to the land shortly after lime addition. During this very short time interval, the pH is unlikely to fall to a level at which vector attraction could occur (U.S. EPA, 1992b).

The pH of the domestic septage is raised to 12 or higher by the addition of alkali material and, without adding more alkali, the pH remains at 12 or higher for 30 minutes prior to being land applied. In addition, the following restrictions must be observed.

Crop Restrictions:

- Food crops with harvested parts that touch the domestic septage/soil mixture and are totally above ground shall not be harvested for 14 months after application of domestic septage.
- Food crops with harvested parts below the surface of the land shall not be harvested for either (1) 20 months after application if domestic septage remains on the land surface for 4 months or longer, or (2) 38 months after application if domestic septage remains on the land surface for less than 4 months, prior to incorporation into the soil.
- Feed, fiber, and food crops shall not be harvested for 30 days after application of the domestic septage.

Grazing Restrictions: None

Site Restrictions: None

Figure 11-2. Part 503 pathogen reduction Alternative 2 for domestic septage (with pH treatment) applied to agricultural land, forests, or reclamation sites (U.S. EPA 1993).

If a land applier of domestic septage chooses pathogen reduction alternative 1 (see Figure 11-1), which involves land application of domestic septage without additional treatment, the Part 503 rule also requires that one of the first two vector attraction reduction options listed in Table 11-3 be met (U.S. EPA, 1993). If a land applier chooses pathogen reduction alternative 2 (pH treatment as described in Figure 11-2), he or she must meet the requirements of the third vector attraction reduction option shown in Figure 11-3 (U.S. EPA, 1993).

11.2.4 Certification Requirements for Pathogen and Vector Attraction Reduction

The land applier of domestic septage must sign a certification that the pathogen and vector attraction reduction requirements of the Part 503 regulation have been met. The required certification is shown in Figure 11-4. The certification includes a statement by the land applier that his or her employees, if any, are qualified and capable of gathering the needed information and performing the necessary tasks so that the required pathogen and vector attraction reduction requirements are met. A person is qualified if he or she has been sufficiently trained to do their job correctly.

Vector Attraction Reduction Option 1:

Injection

Domestic septage shall be injected below the surface of the land, **AND** no significant amount of the domestic septage shall be present on the land surface within one hour after the domestic septage is injected;

or

Vector Attraction Reduction Option 2:

Incorporation

Domestic septage applied to the land surface shall be incorporated into the soil surface plow layer within six (6) hours after application;

or

Vector Attraction Reduction Option 3:

pH Adjustment

The pH of domestic septage shall be raised to 12 or higher by addition of alkali material and, without the addition of more alkali material, shall remain at 12 or higher for 30 minutes.

Figure 11-3. Part 503 vector attraction reduction options for domestic septage applied to agricultural land, forests, or reclamation sites (U.S. EPA, 1993).

11.2.5 Restrictions on Crop Harvesting, Animal Grazing, and Site Access

As discussed above, the Part 503 regulation for domestic septage application to agricultural land, forests, or reclamation sites includes various restrictions on the crops harvested and animals grazed on the site, as well as access to the site by the public. The requirements are less restrictive if the domestic septage has been alkali stabilized. Figures 11-1 and 11-2 summarize crop, grazing, and public access restrictions for untreated and alkali-stabilized domestic septage, respectively (U.S. EPA, 1993). It is recommended that land appliers of domestic septage inform the owner/operator of the land where the domestic septage has been applied about these crop harvesting and site access restriction requirements.

For more detailed information, see EPA's *Domestic Septage Regulatory Guidance* (U.S. EPA, 1993) and 40 CFR Part 503. It is important to note that state regulations may differ and be more restrictive than the requirements outlined in Figures 11-1 and 11-2.

11.2.6 Recordkeeping and Reporting

Records must be kept by a land applier of domestic septage for five years after any application of domestic septage to a site, but Part 503 does not require land appliers of domestic septage to report this information. These required records might be requested for review at any time by the permitting or enforcement authority (U.S. EPA, 1993). The retained records must include the information shown in Figure 11-5 and a written certification (see Figure 11-4). EPA's *Domestic Septage Regulatory Guidance* (U.S. EPA, 1993) contains examples of ways to organize record keeping for sites where domestic septage is land applied.

Certification[a]

I certify under penalty of law that the pathogen requirements in *[insert pathogen reduction alternative 1 or 2]* and the vector attraction reduction requirements in *[insert vector reduction alternative 1, 2, or 3]* have/have not *[circle one]* been met. This determination has been made under my direction and supervision in accordance with the system designed to ensure that qualified personnel properly gather and evaluate the information used to determine that the pathogen requirements and the vector attraction reduction requirements have been met. I am aware that there are significant penalties for false certification, including the possibility of fine and imprisonment.

Signed:

(to be signed by the person designated as responsible in the firm that applies domestic septage)

[a] EPA is proposing changes in the certification language.

Figure 11-4. Certification of pathogen reduction and vector attraction requirements (U.S. EPA, 1994b).

- The location of the site where domestic septage is applied (either the street address, or the longitude and latitude of the site, available from U.S. Geological Survey maps).
- The number of acres to which domestic septage is applied at each site.
- The date and time of each domestic septage application.
- The nitrogen requirement for the crop or vegetation grown on each site during the year. Also, while not required, indicating the expected crop yield would help establish the nitrogen requirement.
- The rate (in gallons per acre) at which domestic septage is applied to the site during the specified 365-day period.
- The certification shown in Figure 11-4.
- A description of how the pathogen requirements are met for each volume of domestic septage that is land applied.
- A description of how the vector attraction reduction requirement is met for each volume of domestic septage that is land applied.

Figure 11-5. Part 503 5-year recordkeeping requirements (U.S. EPA, 1993).

11.2.7 Part 503 Required Management Practices

Certain management practices for the land application of all types of sewage sludge, including domestic septage, are included in Part 503. These management practices require that the land application of sewage sludge and domestic septage does not adversely affect endangered or threatened species; does not take place during flooded, frozen or snow-covered conditions; and does not occur within 33 ft (10 m) of wetlands or surface waters (U.S. EPA, 1994b). For additional information on these management practices, see Chapter 3.

11.2.8 State Requirements for Domestic Septage

The Part 503 regulation sets minimum requirements for land application of domestic septage that must be met in all states. States may, however, adopt (or continue to use) regulations that are more stringent than the federal rule.

State regulations for domestic septage use or disposal vary widely. In most cases, states require a hauler to submit for approval use or disposal plans for domestic septage. Most states also provide recommendations on how domestic septage should be land applied (U.S. EPA, 1994b). In addition, states usually issue hauler licenses, although some states delegate this authority to counties or other municipal agencies (U.S. EPA, 1994b).

Since promulgation of the Part 503 federal regulation, many states have reviewed their regulations regarding land application of sewage sludge and domestic septage. Those states that have regulations less stringent than the federal regulation will likely change state regulations to meet the minimum federal requirements (U.S. EPA, 1994b). For further assistance with applicable state regulations, contact your state septage coordinator.

11.3 Adjusting the pH of Domestic Septage

The Part 503 regulation regarding land application of domestic septage is less burdensome if alkali stabilization is practiced. Stabilization is a treatment method designed to reduce levels of pathogenic organisms, lower the potential for putrefaction, and reduce odors. Stabilization methods for domestic septage are summarized in Table 11-4 (U.S. EPA, 1994a). The simplest and most economical technique for stabilization of domestic septage is pH adjustment. Usually, lime is added to liquid domestic septage in quantities sufficient to increase the pH of the septage to at least 12.0 for 30 minutes (U.S. EPA, 1994b). If the lime is added before or during pumping of the septic tank, in many cases 30 minutes will elapse before the truck reaches the land application site. Other stabilization options, such as aerobic digestion, are relatively simple but have higher capital and operating costs (U.S. EPA, 1994b), and cannot be used to meet Part 503 domestic septage treatment requirements (for application to agricultural land, forests, or reclamation sites).

To raise the pH of domestic septage to 12 for 30 minutes, sufficient alkali (e.g., at a rate of 20 lb to 25 lb of lime [as CaO or quicklime] per 1,000 gal [2.4 kg to 3.6 kg per 1,000 L]) of domestic septage typically is needed, although septage characteristics and lime requirements vary widely (U.S. EPA, 1994b). EPA recommends the following approaches for alkali stabilization prior to land application (U.S. EPA, 1994b):

- Addition of alkali slurry to the hauler's truck before the domestic septage is pumped into the truck, with additional alkali added as necessary after pumping.
- Addition of alkali slurry to the domestic septage as it is pumped from the septic tank into the hauler's truck. (Addition of dry alkali to a truck during pumping with a vacuum pump system is not recommended; dry alkali will be pulled through the liquid and into the vacuum pump, causing damage to the pump.)
- Addition of either alkali slurry or dry alkali to a holding tank containing domestic septage that has been discharged from a pumper truck.

Many states allow domestic septage to be alkali-stabilized within the truck. Some states, however, prohibit alkali stabilization in the hauler's truck and require a separate holding/mixing tank where alkali addition and pH can be easily monitored. A separate holding and mixing tank is preferred for alkali stabilization for the following reasons (U.S. EPA, 1994b):

- More rapid and uniform mixing can be achieved.
- A separate holding and mixing tank affords more control over conditions for handling and metering the proper quantity of alkali.
- Monitoring of pH is easier, and more representative samples are likely to be collected due to better mixing.
- Raw domestic septage can be visually inspected.

To prevent damage to vacuum pumps and promote better mixing of the alkali and domestic septage, alkali should be added as a slurry (U.S. EPA, 1994b). The slurry can be added to the truck before pumping the tank, although the amount of alkali necessary to reach pH 12 will vary from load to load. Provisions should be made to carry additional alkali slurry on board the truck to achieve the necessary dosage (U.S. EPA, 1994b).

Compressed air injection through a coarse-bubble diffuser system is the recommended system for mixing the contents of a domestic septage holding tank. Mechanical

Table 11-4. Summary of Domestic Septage Stabilization Options (U.S. EPA, 1994b)

Method	Description	Advantages	Disadvantages
Alkali sltabilization[a]	Lime or other alkaline material is added to liquid domestic septage to raise pH to 12.0 for minimum of 30 min.	Very simple; minimal operator attention. Low capital and O&M costs. Provides temporary reduction in sulfide odors. Meets EPA criteria for reduction in vector attraction. Reduces EPA site restriction requirements for land application.	Increases mass of solids requiring disposal. Handling of lime may cause dust problems. Lime feed and mixing equipment require regular maintenance.
Aerobic digestion	Domestic septage is aerated for 15 d to 20 d in an open tank to achieve biological reduction in organic solids and odor potential. (Time requirements increase with lower temperatures.)	Relatively simple. Can provide reduction in odors.	High power cost to operate aeration system. Large tanks or basins required. Cold temperatures require much longer digestion periods.
Anaerobic digestion	Domestic septage is retained for 15 d to 30 d in an enclosed vessel to achieve biological reduction in organic solids.	Generates methane gas, which can be used for digester heating or other purposes.	Requires skilled operator to maintain process control. High maintenance requirements for gas handling equipment. High capital costs. Generally not used except for co-treatment with sewage sludge.
Composting	Liquid domestic septage or domestic septage solids are mixed with bulking agent (e.g., wood chips, sawdust) and aerated mechanically or by turning. Biological activity generates temperatures sufficiently high to destroy pathogens.	Final product is potentially marketable and attractive to users as soil amendment.	Costly materials handling requirement. Requires skilled operator process control. High odor potential. High operating costs.

[a] Only alkali stabilization meets Part 503 domestic septage treatment requirements.

mixers are not recommended because they often become fouled with rags and other debris present in the septage (U.S. EPA, 1994b).

Figure 11-6 presents a procedure for alkali-stabilizing septage within the pumper truck. Methods recommended by domestic septage servicing professionals are presented in *Domestic Septage Regulatory Guidance* (U.S. EPA, 1993), along with associated cautions.

If pH adjustment is used for domestic septage, the Part 503 requirements apply to each truckload unless pH adjustment was done in a separate treatment device (e.g., lagoon or tank) (U.S. EPA, 1993).

11.3.1 Sampling for pH

Land appliers of domestic septage should not automatically assume that the lime or other alkali material added to domestic septage and the method of mixing chosen will adequately increase pH. The pH must be tested. A representative sample should be taken from the body of the truckload or tank of domestic septage for testing. For example, a sampling container could be attached to a rod or board and dipped into the domestic septage through the hatch on top of the truck or tank or through a sampling port (U.S. EPA, 1993). Alternatively, a sample could be taken from the rear discharge valve at the bottom of the truck's tank. If the lime has settled to the bottom of the tank, however, and has not been properly mixed with the domestic septage, the sample will not be representative.

Two separate samples should be taken 30 minutes apart, and both of the samples must test at pH 12 or greater (with the pH reading converted to an equivalent value at 25°C to account for the influence of hot and cold weather on meter readings). If the pH is not at 12 or greater for a full 30 minutes, additional alkali can be added and mixed with the domestic septage. After mixing in the additional alkali, however, the domestic septage must be at 12 or greater for a full 30 minutes to meet the pH requirement of the Part 503 regulation (U.S. EPA, 1993).

Purpose	To raise the pH of domestic septage to 12 for a minimum of 30 min.
Approach	• Add lime slurry in sufficient quantity *before* pumping the tanks and add additional slurry as needed *after* pumping. • Add lime slurry in sufficient quantity *during* pumping of the tanks by vacuuming slurry through small suction line fitted to main suction hose.
Type of lime	• Pulverized quicklime (CaO). • Hydrated lime ($Ca(OH)_2$). (Less quicklime is required than is hydrated lime to achieve the same pH, but quicklime is more corrosive and difficult to handle.)
Dosage	Typically 20 lb to 25 lb quicklime per 1,000 gal of domestic septage (or about 26 lb to 33 lb of hydrated lime per 1,000 gal).
Slurry	Approximately 80 lb of pulverized quicklime or hydrated lime in 50 gal of water. Mix mannually with paddle in a 55-gal drum or in a 200-gal polyethylene tank with electric mixer (preferred). CAUTION: Heat is liberated when quicklime is added to water. Wear rubber gloves, appropriate respirator (for dust), and goggles. Add lime slowly to partially full tank. an emergency eyewash station should be located nearby.
Application rate	Typically 12 to 15 gal quicklime slurry per 1,000 gal of domestic septage (or 15 gal to 20 gal hydrated lime slurry).
Monitoring	After lime slurry has been mixed with domestic septage, collect sample from top access hatch using a polyethylene container fastened to a pole. Measure pH with pH meter at 25°C (or convert reading to 25°C). (pH paper can also be used, but it is more cumbersome and less accurate.) If the pH is less than 12, add more slurry. If pH 12 has been reached, record pH and time. Sample again after 15 min. If the pH has dropped below 12, add more lime. *The pH must remain at 12 for at least 30 min.* Sample and record pH prior to applying septage to the land.

Figure 11-6. Procedure for lime-stabilizing domestic septage within the pumper truck (U.S. EPA, 1994b).

11.4 Methods of Application

The most common, and usually most economical, method for using or disposing domestic septage is land application (e.g., land spreading, irrigation, incorporation). Various options for land applying domestic septage are summarized in Table 11-5 (U.S. EPA, 1994b).

The simplest application method involves a hauler truck applying domestic septage by opening a valve and driving across the land application site. A splash plate or spreader plate improves domestic septage distribution onto the soil surface. The domestic septage should be discharged through a simple screen or basket located on the truck between the outlet pipe and the spreader plate. This screen prevents nondegradable materials such as plastics and other objectionable trash from being applied to the soil. A simple box screen can be fabricated from expanded metal. Collected trash should be lime-stabilized and sent to a sanitary landfill. The domestic septage must be lime-stabilized prior to surface application, injected below the surface, or plowed into the soil within 6 hours of application to meet federal Part 503 requirements for vector attraction reduction (U.S. EPA, 1994b).

While relatively easy, the application method described above also is the least flexible and is difficult to control from a management perspective. In addition, soil may become compacted, and trucks not designed for off-road use may have difficulty driving on the site. Small, rural land application operations where little environmental or human health risk is likely to occur, however, may find this approach acceptable. A transfer or storage tank must be available when sites are inaccessible due to soil, site, or crop conditions (U.S. EPA, 1994b).

Another common approach is to use a manure spreader or a special liquid-waste application vehicle that removes screened domestic septage from a holding tank and spreads it on or injects it below the soil surface. If the domestic septage is incorporated into the soil by plowing or is injected, pH adjustment may not be required to meet the Part 503 vector attraction reduction requirements (U.S. EPA, 1994b). If pH adjustment is done, this also meets some of the Part 503 requirements for pathogen reduction. Figure 11-7 illustrates a subsurface injection device that injects either a wide band or several narrow bands of domestic septage into a cavity 10-15 cm (4 to 6 in) below the soil surface (U.S. EPA, 1980).

A third approach is to pretreat the domestic septage (with a minimum of screening) during discharge into a holding/mixing tank by adding lime and stabilizing it to pH 12 for 30 min, and then to spray the domestic septage onto the land surface using commercially available application equipment. Adjustment of pH reduces odors and eliminates the need to incorporate the domestic septage into the soil (U.S. EPA, 1994b).

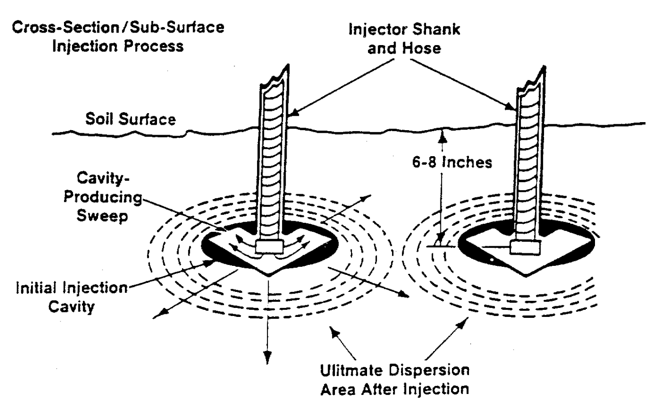

Figure 11-7. Subsurface soil injection (Cooper and Rezek, 1980).

Table 11-5. Summary of Land Application Methods for Domestic Septage (U.S. EPA, 1994b)

Method	Description	Advantages	Disadvantages
Surface Application (for all surface application methods, domestic septage must be incorporated into soil within 6 hrs if the pH is not adjusted and if the septage is applied to agricultural land, forest, or a reclamation site.)			
Spray irrigation	Pretreated (e.g., screened) domestic septage is pumped through nozzles and sprayed directly onto land.	Can be used on steep or rough land. Minimizes disturbance of soil by trucks.	Large land area required. High odor potential during application. Storage tank or lagoon required during periods of wet or frozen ground. Potential for nozzle plugging.
Ridge and furrow irrigation	Pretreated domestic septage is applied directly to furrows.	Lower power requirements and odor potential than spray irrigation.	Limited to 0.5% to 1.50% slopes. Storage lagoon required.
Hauler truck spreading	Domestic septage is applied to soil directly from hauler truck using a splash plate to improve distribution.	Same truck can be used for transport and disposal.	High odor potential during and immediately after spreading. Storage tank or lagoon required during wet or freezing conditions. Slope may limit vehicle operation. Hauler truck access limited by soil moisture; truck weight causes soil compaction.
Farm tractor and wagon spreading	Domestic septage is transferred to farm equipment for spreading.	Increases opportunities for application compared to hauler truck spreading.	High odor potential during and immediately after spreading. Storage tank or lagoon required. Requires additional equipment (tractor and wagon).
Subsurface Incorporation			
Tank truck or farm tractor with plow and furrow cover	Liquid domestic septage is discharged from tank into furrow ahead of single plow and is covered by second plow.	Minimal odor and vector attraction potential compared with surface application. Satisfies EPA criteria for reduction of vector attraction.	Slope may limit vehicle operation. Storage tank or lagoon required during periods of wet or frozen ground.
Subsurface injection	Liquid domestic septage is placed in narrow opening created by tillage tool.	Minimal odor and vector attraction potential compared with surface application. Satisfies EPA criteria for reduction of vector attraction.	Slope may limit vehicle operation. Specialized equipment and vehicle may be costly to purchase, operate, and maintain. Storage tank or lagoon required during wet or frozen conditions.

11.5 Operation and Maintenance at Land Application Sites Using Domestic Septage

Key elements of a successful operation and maintenance program for a domestic septage land application site include (U.S. EPA, 1994b):

- Provision of receiving and holding facilities for the domestic septage to provide operational flexibility (optional).
- Proper domestic septage treatment prior to application as required to meet federal and state regulations (need for treatment depends on requirements of application method).
- Control of domestic septage application rates and conditions in accordance with federal and state rules.
- Proper operation and maintenance of the application equipment.
- Monitoring of domestic septage volumes and characteristics, as well as soil, plant, surface water and ground water as required by federal and state regulations.
- Odor control.
- Good recordkeeping and retention of records for at least 5 years.

Odor problems should not arise at a site where domestic septage is land applied if the requirements of Part 503 are followed. A well-managed operation that uses pH adjustment and practices subsurface injection or surface application/incorporation at or below agronomic rates (see Section 11.2.1.1) will create minimal odor emissions. Additional guidelines for minimizing odor problems at land application sites are presented in EPA's *Guide to Septage Treatment and Disposal* (U.S. EPA, 1994b).

Operation and maintenance requirements for land application of domestic septage vary widely depending on the application technique and the type of equipment used.

11.6 References

When an NTIS number is cited in a reference, that document is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-487-4650

U.S. EPA. 1994a. A plain English guide to the Part 503 biosolids rule. EPA/832/R-93/003. Washington, DC.

U.S. EPA. 1994b. Guide to septage treatment and disposal. EPA/625/R-94/002. Cincinnati, OH.

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Chapter 12
Public Participation

12.1 Introduction

A critical factor in establishing a sewage sludge land application program in most communities is the participation of local citizens from the beginning and at various key stages of the project's development. If not given the opportunity to discuss their concerns, whether based on legitimate issues or misperceptions, resistance from members of the community can significantly complicate a project and result in additional costs. Moreover, if the public's viewpoint is ignored until late in the planning process, opposition within the community may solidify and be difficult to overcome. Thus, public participation is as important a factor as any technical consideration in establishing a sewage sludge land application system (Lue-Hing et al., 1992). Public involvement in the decision-making process will help to minimize opposition and to identify the major barriers to local acceptance (U.S. EPA, 1984).

A sewage sludge land application project has the best chance of gaining public acceptance if a public outreach effort is organized to stress the demonstrated value of sewage sludge as a resource. Once acceptance has been achieved, it is most likely to be maintained through conscientious management of the site during operations.

In general, the public's willingness to participate in—and ultimately accept—the siting of a sewage sludge land application site will depend on:

- An understanding of the need for the project regarding its costs and benefits.
- A sense of confidence that the project will adequately protect public health and safeguard the environment.
- Encouragement of active public involvement in project development so that local interests can be factored into the plan.

Planning for public participation in the siting of a sewage sludge land application site involves careful and early evaluation of what should be communicated, to whom, by whom, and when. This chapter summarizes the major considerations for implementing a successful public participation program, including the objectives and value of a public participation, the design and timing of a program, and topics generally of public concern regarding the land application of sewage sludge.

12.2 Objectives

The objectives of a public participation program are:

- Promoting a full and accurate public understanding of the advantages and disadvantages of land application of sewage sludge.
- Keeping the public well-informed about the status of the various planning, design, and operation aspects of the project.
- Soliciting opinions, perceptions, and suggestions from concerned citizens involving the land application of sewage sludge.

The key to achieving these objectives is to establish continuous two-way communication between the public and the land application site planners, engineers, and eventual operators (Canter, 1977). Officials need to avoid the common assumption that educational and other one-way communication techniques will promote adequate dialogue. A public participation plan should focus generally on moving people from the typical reactive response to sewage sludge issues to an informed response about sludge management (Lue-Hing et al., 1992).

To generate meaningful public participation in the decision-making process, the public agency or engineering firm directing the project needs to take particular steps at each stage of project development (see Section 12.3). The additional effort involved in soliciting community input for establishing a land application site should be considered when making an initial determination about the best approach for managing the community's sewage sludge.

12.3 Implementation of a Public Participation Program

A program for soliciting public participation in the siting of a sewage sludge land application site should be tailored to fit the scale and costs of the particular project.

Nonetheless, a basic framework for a program that would be applicable for most situations includes:

- The initial planning stage
- The site selection stage
- The site design stage
- The site preparation and operation stage

These four stages are described below. Beyond this basic framework, officials should use a common-sense approach for determining the extent of the public participation program and the frequency at which public input should be solicited. When time and money are constraining factors, officials will need to concentrate resources on the most effective mechanisms for community involvement (see Table 12-1). Regardless of its scope, however, the public participation program will need to be flexible enough to accommodate various issues that can arise in the course of establishing a sewage sludge land application site.

Table 12-1. Relative Effectiveness of Public Participation Techniques

	Communication Characteristics		
Public Participation Technique	**Level of Public Contact Achieved**	**Ability to Handle Specific Interest**	**Degree of Two-Way Communication**
Public hearings	M	L	L
Public meetings	M	L	M
Advisory Committee meetings	L	H	H
Mailings	M	M	L
Contact persons	L	H	H
Newspaper articles	H	L	L
News releases	H	L	L
Audiovisual presentations	M	L	L
Newspaper advertisements	H	L	L
Posters, brochures, displays	H	L	L
Workshops	L	H	H
Radio talk shows	H	M	H
Tours/field trips	L	H	H
Ombudsman	L	H	H
Task force	L	H	H
Telephone line	H	M	M

L = low value
M = medium value
H = high value

12.3.1 Initial Planning Stage

12.3.1.1 Establishing an Advisory Committee

During the initial planning stage, the scope and scale of the public participation program is decided, and implementation of the program is then initiated. To facilitate and follow through with this effort, officials in charge of the land application project should organize an advisory committee made up of members of the community. The committee should include, for example, representatives of local government, community organizations, and area businesses (Table 12-2). Since in rural communities the acceptance of local farmers is particularly important for a proposed land application program, this group should also be represented on the committee where appropriate (see Section 12.4.1). The Soil Conservation Service, county Extension Agents, and Farm Bureau can provide vital links with the farming community (U.S. EPA, 1984).

The primary responsibility of the advisory committee should be to organize the community's involvement in project planning. The overall strategy for informing the community about the land application project and responding to concerns should be put in writing. Additionally, the committee could be called upon to provide initial

Table 12-2. Potential Advisory Committee Members (Canter, 1977)

The following groups and individuals should be contacted about serving on the advisory committee:

- Local elected officials.
- State and local government agencies, including planning commissions, councils of government, and individual agencies.
- State and local public works personnel.
- Conservation/environmental groups.
- Business and industrial groups, including chambers of commerce and selected trade and industrial associations.
- Property owners and users of proposed sites and neighboring areas.
- Service clubs and civic organizations, such as the League of Women Voters.
- The media, including newspapers, radio, and television.

The following groups should also be contacted, where appropriate:

- State elected officials.
- Federal agencies.
- Farm organizations.
- Educational institutions, including universities, high schools, and vocational schools.
- Professional groups and organizations.
- Other groups and organizations, such as urban groups, economic opportunity groups, political clubs and associations.
- Labor unions.
- Key individuals who do not express their preferences through, or participate in, any groups or organizations.

feedback on various project proposals and to function generally as a liaison between the project staff and the community at large. In its role as liaison, an advisory committee would be responsible for receiving community input and obtaining responses to questions. A useful practice in this regard is to keep a log of requests for information and responses given. For especially large projects, it might be feasible to hire a public information professional to assist in this capacity.

When making its assessment about the appropriate extent of the public outreach effort, the advisory committee's planning should address when and how often to use particular mechanisms for encouraging participation in the land application project. The two general types of program mechanisms are:

- *Educational*. Those that allow project staff to present information to members of the community.
- *Interactive*. Those that are intended to solicit input from members of the community.

Throughout the public participation program, the advisory committee should be developing its mailing and telephone lists. Such lists, which should be continually updated and expanded by capturing the names of citizens who attend public meetings or otherwise make contact with the committee, can prove indispensable for keeping the community involved in the land application project. Contact by mail and telephone can be used to alert the community to meetings and developments, or to provide followup information to citizens who have expressed particular concerns about the project.

12.3.1.2 Educating the Community

After establishing an advisory committee, the next step in program implementation is to undertake a public education campaign, which typically is kicked off at a well-publicized public meeting or at a series of meetings targeted for specific groups within the community.

The level of interest in waste management issues for most people is fairly low. Thus, while members of the community at large should be targeted by the public education campaign, it is particularly important to reach members of environmental groups, the media, and elected officials. The participation of such members of the community is important because they are likely to have broad affiliations and the ability to affect public opinion on a large scale (WEF, 1992).

At a public meeting it is important to present general information about the land application project and to encourage the community to take an active interest in the project's development. Presenters at this meeting might include project staff and engineering consultants. The meeting is also a good opportunity to introduce the members of the advisory committee—stressing the breadth of representation from the various sectors of the community—and explain the committee's role. Information about the project presented at the community meeting should cover:

- The need for the land application program.
- The reason for selecting land application over other approaches for managing sewage sludge, such as surface disposal or incineration.
- The use of crops or other vegetation grown on the site.
- The general costs associated with design, construction, and operation of the program.
- The potential economic incentives, such as job creation and stimulation of the local economy.
- The program's general design and operation principles.

It may be useful to supplement presentations given at the meeting with handouts that provide, for instance, a brief explanation of sewage sludge and how it is generated; a nontechnical summary of the Part 503 rule; the professional experience of engineers and others designing the land application program; and a list project contacts. Video support, if available, might also be useful for providing additional general information at the meeting.

A community's specific concerns, particularly about protecting public health and safeguarding the environment, can be enough to undermine a technically strong plan for establishing a land application operation. Thus, it is advisable to make information available about how land application programs operating over long periods (e.g., 10 years or more) in other communities have addressed these concerns (Jacobs et al., 1993).

Once the sewage sludge land application project has been introduced at a public meeting to interested members of the community, informational outreach to the general public can be achieved primarily through the local media. Since public meetings are ineffective information outlets for certain segments of any community, however, the outreach effort should include placing paid advertisements, if feasible, as well as encouraging the media contacts made at the public meeting to report on the project. At some point after providing the media with general information about the proposed land application site, it may be useful to develop a press kit for distribution. Providing project-specific information to the media will increase the accuracy of information reported to the public (Lue-Hing et al., 1992).

The more types of media that are used to promote the project, the greater the likelihood of a successful outreach effort. For example, a variety of media could be used as follows:

- *Newspapers reports*. A series of articles on land application of sewage sludge could be timed to appear throughout the project to sustain public interest. Also, occasional news releases would keep the community informed about developments.

- *Television reports*. At a minimum, it should be possible to arrange for coverage of milestone project developments. It also might be possible to interest news producers in developing a series about the project.

- *Newspaper, television, and radio advertisements*. Informational advertisements can be used to publicize critical information about the project. Although television advertising tends to be expensive, it can be particularly effective for reaching a majority of the community. Radio advertising, especially if broadcast during the morning or afternoon commute, can be equally effective while less expensive.

- *Public service announcements and editorials*. Radio and television stations are required to offer a limited amount of broadcast time for airing announcements or editorials of general interest in the local area. Cable television stations may have specific programming devoted to local issues. Also, newspapers may welcome an informed opinion piece for the op-ed page.

Posters, brochures, and displays also can be highly effective educational tools, especially when designed creatively and placed in high-traffic areas or given wide distribution.

12.3.1.3 Soliciting Community Input and Addressing Concerns

After the public has been generally informed about the sewage sludge land application project, the advisory committee should begin concentrating its efforts on soliciting community input on the project plan. For this phase of the public participation program, various types of forums can be useful for focusing on and responding to the community's concerns about the project. Concerns that are likely to surface include:

- *Public safety and health*. As noted above, this issue can be of primary interest to the community. Thus, it is important to emphasize the extensive research on risk assessment and environmental impacts that serves as the basis for the Part 503 rule. Also, project-specific management systems should be explained. In particular, the community may need to be reassured that a system has been developed for avoiding spills of sewage sludge during transport.

- *Contamination of water supplies*. The public generally has developed a heightened awareness about water quality issues. As a result, the public is better prepared to raise water quality issues and to consider measures taken to safeguard water supplies. The community should be made aware that Part 503 specifically addresses protection of ground water and surface waters by, for instance, restricting runoff from application sites and limiting the potential for leaching of pollutants into ground water.

- *Accumulation of heavy metals and toxics*. The public may be inclined to assume that sewage sludge is associated with excessive contaminants, since "waste" is synonymous with "toxic" in many people's minds (Lue-Hing et al., 1992). Thus, public information efforts should stress the proven beneficial characteristics of sewage sludge and explain the regulatory limits on the loadings of 10 heavy metals associated with sewage sludge.

- *Regulatory compliance*. The community is likely to question whether the site will be monitored by public officials for regulatory compliance. This concern can be addressed by explaining the role of the permitting authority in enforcing the Part 503 rule and by reviewing the legal recourse available to officials (e.g., fines of up to $25,000 per day for a single violation).

- *Odor, noise, dust, and traffic*. Because odors are usually the first cause of complaints when a land application site is sited near a residential area, sewage sludge at such sites should be injected or disked into the soil immediately following application (Jacobs et al., 1993). The site management plan should specifically cover such measures, as well as measures to control noise and dust from the operation of machinery and limit traffic in and out of the site.

- *Land values*. The community is likely to be concerned about the impact of the land application operation on real estate values. This issue should be investigated and the community should be informed of any potential for a drop in values. Regarding this and other concerns, it may be useful to cite the experience of other communities with a land application program (Jacobs et al., 1993).

Both formal and informal approaches can be effective for soliciting and then responding to the community's concern about the land application project. Regardless of the forum, however, it is essential that advantages as well as disadvantages be addressed openly. When there is a void of information, it is likely to get filled with distorted portrayals based on assumptions and emotion. It is far better to fill that void with factual information (Lue-Hing et al., 1992).

Forums that can be effective for public participation include meetings and workshops, as well as site tours that include demonstrations. The appropriateness of a particular forum will depend on the stage of the project's development.

12.3.2 Site Selection Stage

The site selection process involves screening an array of potential locations for the land application facility, followed by detailed field investigations that include water and soil sampling at a handful of candidate sites. Once the project staff has narrowed the choices down to a few sites and gathered a reasonable amount of comparative data, the public should be brought into the process.

Depending on the scope of the project and the location of candidate sites relative to population density, the appropriate forum for public participation at this stage would be a targeted meeting or a workshop gathering. If a site close to a residential area is being seriously considered, neighboring residents will have a vested interest in selection and want detailed information about such issues as public safety, odor control, and impact on land values. Indeed, project staff may need to anticipate vocal, organized resistance to the site. Meeting with interested parties in smaller groups can be an effective means of diffusing such emotionally loaded issues. Targeted meetings and workshops have particular characteristics that are advantageous at this stage of project development:

- *Targeted meetings*. Meeting with members of the community who have a particular interest in the project can be an efficient means of addressing site-specific concerns. A useful approach is to give the community an opportunity to discuss issues directly with project engineers, the prospective site manager, and members of the advisory committee. These smaller meetings should be less structured than the initial, community-wide meeting so that dialogue can be encouraged. A sketchy outline should be used primarily to elicit a group's concerns, and the project staff should be fully prepared to respond to a range of issues.
- *Workshops*. When working with a group that is particularly interested in site-selection criteria, such as an environmental group or the media, a workshop is a useful forum for presenting and discussing information. A fairly structured agenda is appropriate for a workshop, as long as sufficient time is scheduled for open discussion. If a workshop is effective, participants are likely to disseminate the information more broadly within the community.

To generate participation in these more focused gatherings, the advisory committee might want to use its telephone and mailing lists to contact potentially interested individuals. Otherwise, opposition to the site finally selected could surface late in the process, when it may be less readily diffused. For the same reason, it is important to keep the community involved through completion of the selection process.

When opposition to the developing plan does arise, it is best to meet it head on. Recommended presentation tactics (Lue-Hing et al., 1992) include:

- Answer all questions candidly and publicly.
- Avoid arguing over emotionally charged questions; emphasize generalities.
- Never reiterate incorrect information, either verbally or in print.

12.3.3 Site Design Stage

Because the relevant information at this stage of the project is of a particularly technical nature, community interest will be less broad-based. Nonetheless, it is important to maintain some degree of public participation. This challenge is likely to fall to the advisory committee, which should consider various and innovative approaches for reaching the public with design information. Suggested approaches include:

- *Field trips*. A visit to a nearby operating land application site can be a useful means of informing special interest groups about design considerations. A project engineer should accompany the group on the visit so that the host site can be compared to the planned site.
- *Video presentations*. If available, a general video that explains site design in regard to eventual operation can be an effective means of involving the community in the project's design stage. The video could be screened for small groups and followed by a question and answer period with project staff.
- *Task forces*. Assigning members of the community to design-related tasks that address specific public concerns can generate important input for design planning. To be most effective, task force members should have a technical orientation.
- *Media campaign*. Information (e.g., press releases) should be provided to the media as design milestones are reached. A guest appearance on a radio call-in program or a cable news program by a project spokesperson might also be effective at this stage if it can be arranged.

Once the design for the land application site is final, it will need to be formally presented to the community at a public hearing. Such gatherings are often legally required, must be preceded by published notification to the community, and follow a set agenda. Also, relevant materials might need to be made available for public review prior to the hearing. The agenda for a public hearing usually includes presentations by project staff, after which the floor is opened for comments from the community. The effectiveness of the gathering can be enhanced when an elected official or other prominent, informed figure in the community chairs the hearing or at least participates.

12.3.4 Site Preparation and Operation Stage

While the selected land application site is being prepared for operations, the advisory committee should monitor activity at the site and maintain contact with the community. This is particularly important if buildings or treatment structures are being constructed, since the delivery of materials and operation of heavy equipment can create nuisances, especially for local residents. Committee members should be prepared to respond to complaints as they arise, either on their own or with the help of the project staff. If feasible, the project staff should assign an ombudsman to resolve issues that arise during site preparation and to continue in this capacity, at least initially, once operations are under way.

Once fully operational, the site should continue to be monitored for its actual or potential negative impacts on the community. After an initial period of operation, the advisory committee may want to conduct a limited telephone survey to gauge how the public is feeling about the site. The committee would then report results to the operations staff and follow up to see that any necessary modifications have been made. For example, better odor control practices may need to be adopted, or site traffic may need to be restricted to specified hours.

After the advisory committee has determined that the land application site has been generally accepted by the community, it should provide followup information to the media. This is the appropriate point to promote the success of the site and its advantages to the community—not the least of which should be the beneficial use of locally generated sewage sludge. For instance, the community should be interested in learning about the use of crops grown on the site and whether local gardeners are land applying sewage sludge.

12.4 Special Considerations

12.4.1 Agricultural Sites

Implementation of an agricultural land application project for sewage sludge can require acceptance and approval by local officials, farmers, landowners, and other affected parties. Public resistance to agricultural land application of sewage sludge can stem from fear that the sludge may contain concentrations of organic or inorganic substances that could be toxic to plants or accumulate in animals or humans consuming crops grown on sludge-treated lands.

The most critical aspect of a public participation program in such cases is securing the involvement of farmers who will use the sludge. How this involvement is to be secured during the planning process depends on the individual communities involved; their past experiences with land application systems; overall public acceptance of the concept; and the extent to which related or tangential environmental concerns are voiced in the community.

Generally, a low-key approach is most effective. The various approaches can consist of one or more of the following steps:

- Check with the wastewater treatment operator to see if any local farmers have requested sewage sludge in the past.
- Have the local Soil Conservation Service or Agricultural Extension Service agent poll various individuals in the area.
- Describe the project in the local newspaper, asking interested parties to contact the extension agent.
- Personally visit the identified parties and solicit their participation. A telephone contact will elicit little support unless followed by a personal visit.

The use of demonstration plots is very effective in promoting the land application of sewage sludge by farmers. If farmers can compare crops grown on sludge-treated soil with these grown with conventional fertilizer, their willingness to use sewage sludge will increase markedly (Miller et al., 1981). The following questions regarding sewage sludge land application need to be discussed with landowners:

- How long is the landowner willing to participate (e.g., a trial period of 1 or more years; open-ended participation; until one or both parties decide to quit; for a prescribed period of time)?
- What crops are traditionally planted, and what is the usual crop rotation?
- If the sewage sludge characteristics were such that a different crop is desirable, would the landowner be willing to plant that crop?
- Which fields would be included in the sewage sludge land application program?
- Under what conditions would the landowner accept the sewage sludge, what time of the year, and in what quantities?
- Is the landowner willing to pay a nominal fee for the sewage sludge, accept it free of charge, or must the municipality pay the landowner for accepting sludge?
- Is the landowner willing to engage in special procedures (e.g., maintaining soil pH at 6.5 or greater)?

The public participation program should emphasize both the benefits and the potential problems of applying sewage sludge on cropland.

12.4.2 Forest Sites

To help achieve acceptance, a program for the land application of sewage sludge at a forest site should satisfactorily address the following questions:

- How will public access be controlled in the application area for an appropriate period (normally 12 to 18 months) after sewage sludge application? Forested areas are often used for various recreational activities (e.g., picnicking, hiking, gathering of forest products). Even privately owned forest land often is viewed by the public as accessible for these purposes. The owner of the land, private or public, will have to agree to a method for controlling public access (e.g., fence, chain with signs). The public, through its representatives, must agree to restrictions if the land is publicly owned.
- Will public water supplies and recreational water resources be adequately protected against contamination? This concern should be covered by proper siting, system design, and monitoring. Public health authorities and regulatory agencies must be satisfied and involved in the public participation program. Careful consideration must be given to municipal watersheds and/or drinking water recharge areas to avoid contamination.
- Will the applied sewage sludge cause adverse effects to the existing or future trees in the application area? Based on the available data from research and demonstration projects, many tree species, with few exceptions, respond positively to sewage sludge application, provided the sludge is not abnormally high in detrimental constituents and proper management practices are followed.
- Unlike most agricultural applications, there is much less concern about possible food chain transmission of contaminants to humans. The consumption of wild animals by hunters and their families will occur, but there is little potential for contamination of meat from such animals through contact with a properly managed sludge application area.

12.4.3 Reclamation Sites

Prior to the initiation of any reclamation project using sewage sludge, it will likely be necessary to educate the public to gain public acceptability. The task may be difficult with lands disturbed by mining, because local opposition to mining activity already exists in many cases. This is particularly true if the mining activity has already created some adverse environmental problems, such as reduced local ground-water quality, acid mine drainage, or serious soil erosion and sedimentation of local streams.

Citizens, regulatory agencies, and affected private business entities need to participate in the planning process from the beginning. The most effective results are usually achieved when industry, citizens, planners, elected officials, and state and federal agencies share their experience, knowledge, and goals, and jointly create a plan acceptable to all.

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WEF. 1992. Proceedings of the future direction of municipal sludge (biosolids) management: Where we are and where we're going, Vol. 1, Portland, OR, July 26-30, 1992. Water Environment Federation, Alexandria, VA. No. TT041.

Chapter 13
Monitoring and Sampling

13.1 Overview

The Part 503 rule requires monitoring of sewage sludge that is land applied for metal concentrations, pathogen densities, and vector attraction reduction. In addition, soil testing for nutrients (N, P, and K) may be useful at land application sites to help determine plant nutrient needs. Additional monitoring (e.g., of water quality and vegetation) is not required by Part 503 for land application sites because the rule protects these resources through pollutant limits, management practices, pathogen reduction requirements, etc.

This chapter discusses Part 503 monitoring requirements for sewage sludge, including required analytical methods, and specifies sampling procedures that might be particularly useful for characterizing sewage sludge (Section 13.2). Soil monitoring and sampling methods for relevant parameters also are presented (Section 13.3). Brief discussions of surface water, ground-water, and vegetation monitoring are included in Sections 13.4 and 13.5. Monitoring and sampling concerns particular to reclamation sites are discussed in Section 13.6.

State regulatory programs may have specific requirements for monitoring sewage sludge land application sites. The appropriate regulatory agencies should be contacted to identify any applicable monitoring requirements.

13.2 Sewage Sludge Monitoring and Sampling

The Part 503 requirements related to monitoring for sewage sludge that is land applied focus primarily on sewage sludge characterization to determine pollutant concentration, pathogen density, and vector attraction reduction. Required monitoring includes:

- Monitoring of sewage sludge for 10 pollutants (As, Cd, Cr, Cu, Pb, Hg, Mo, Ni, Se, and Zn) to determine pollutant levels in sewage sludge, compared to Part 503 pollutant limits (see Chapter 3).
- Monitoring to determine pathogen densities in sewage sludge, as described in Chapter 3.
- Monitoring to ensure that conditions for vector attraction reduction are maintained.

Table 13-1 summarizes major considerations for monitoring metals, pathogens, and vector attraction reduction in sewage sludge. Another EPA document, *Environmental Regulations and Technology: Control of Pathogens and Vector Attraction in Sewage Sludge* (U.S. EPA, 1992), provides guidance for the monitoring, sampling, and analysis of pathogens and vector attraction reduction efforts under Part 503 in detail and should be consulted for further guidance. The remainder of this section focuses on sampling and analysis of sewage sludge for pollutants. For additional guidance on monitoring of sewage sludge for land application, see EPA's *Preparing Sewage Sludge for Land Application or Surface Disposal: A Guide for Preparers of Sewage Sludge on the Monitoring, Record Keeping, and Reporting Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge, 40 CFR Part 503* (U.S. EPA, 1993).

13.2.1 Sampling Location

Sewage sludge samples must be representative of the final sewage sludge that is land applied. To achieve this goal, samples must be representative of the entire amount of sewage sludge being sampled, collected after the last treatment process, and taken from the same, correct location each time monitoring is performed. Sampling locations should be as close as possible to the stage before final land application. Liquid sewage sludge can be sampled at the wastewater treatment plant from pipelines, preflushed pipeline ports, or lagoons. Dewatered sewage sludge can be sampled at a wastewater treatment plant from conveyors, front-end loaders moving a pile of sewage sludge, or during truck loading or unloading. At a land application site, dewatered samples can also be taken on the ground after unloading but preferably before application, or possibly after spreading.[1] Table 13-2 identifies recommended sampling points for various types of sewage sludge.

[1] Sampling after spreading poses the risk of penalties if samples exceed Part 503 pollutant limits and pathogen densities or do not comply with the regulation's vector attraction reduction requirements. Sampling after spreading should only be done if parameters of concern do not vary greatly in concentration and are known to fall well below Part 503 limits.

Table 13-1. Monitoring Considerations for Part 503 Requirements

Parameter	Validity of Analytical Data Over Time and When Sampling/Analysis Must Occur
	Metals
Metals	Data remain valid. Determine monitoring frequency in accordance with monitoring frequency requirements.
	Pathogens Class A
Applies to All Class A Pathogen Reduction Alternatives (PRA): Fecal Coliform & *Salmonella* sp.	Because regrowth of fecal coliform and *Salmonella* sp. can occur, monitoring should be done: (a) at the time of use or disposal, or, (b) when sewage sludge is prepared for sale or give-away in a bag or other container for land application, or (c) when sewage sludge is prepared to meet EQ requirements.
	Additional Information on Each Class A Pathogen Category
Class A PRA 1: Thermal Treatment, Moisture, Particle Size & Time Dependent	Data remain valid. Time, temperature, and moisture content should be monitored continuously to ensure effectiveness of treatment.
Class A PRA 2: High pH, High Temperature	Monitor to ensure that pH 12 (at 25°C) is maintained for more than 72 hours for all sewage sludge.
Class A PRA 3: Enteric Virus & Viable Helminth Ova to Establish Process	Once reduced, enteric virus or viable helminth ova does not regrow. To establish a process, determine with each monitoring episode until the process is shown to consistently achieve this status. Then continuously monitor process to ensure it is operated as it was during the demonstration.
Class A PRA 4: Enteric Virus & Viable Helminth Ova for Unknown Process	Once reduced, enteric virus or viable helminth ova does not regrow. Monitor representative sample of sewage sludge: (a) at the time of use or disposal, or (b) when prepared for sale or give-away in a bag or other container for land application, or (c) when prepared to meet EQ requirements.
Class A PRA 5: PFRP	Monitor at sufficient frequency to show compliance with time and temperature or irradiation requirements.
Class A PRA 6: PFRP Equivalent	Monitor at sufficient frequency to show compliance with PFRP or equivalent process requirements.
	Pathogens Class B
Class B PRA 1: Fecal Coliform	Measure the geometric mean of 7 samples at the time the sewage sludge is used or disposed.
Class B PRA 2:	Monitor at sufficient frequency to show that the PSRP requirements are met.
Class B PRA 3:	Monitor at sufficient frequency to show that the equivalent PSRP requirements are met.
	Vector Attraction Reduction
Vector Attraction Reduction (VAR) 1: 38% Volatile Solids Reduction (VSR)	Once achieved, no further attractiveness to vectors. Follow Part 503 frequency of monitoring requirements.
VAR 2: for Anaerobic Digestion: Lab Test	
VAR 3: for Aerobic Digestion: Lab Test	Once achieved, no further attractiveness to vectors. Follow Part 503 frequency of monitoring requirements.
VAR 4: SOUR Test for Aerobic Processes	
VAR 5: Aerobic >40°C	Monitor at sufficient frequency to show that sewage sludge is achieving the necessary temperatures over time.
VAR 6:[a] Adding Alkali	Determine pH over time. Data are valid as long as the pH does not drop such that putrefaction begins prior to land application.

Table 13-1. (continued)

VAR 7:[a] Moisture Reduction No Unstabilized Primary Solids	To be achieved only by the removal of water. VAR 7 has been achieved as long as the moisture level remains below 30%.
VAR 8:[a] Moisture Reduction Primary Unstabilized Solids	To be achieved only by the removal of water. VAR 8 has been achieved as long as the moisture level remains below 10%.
VAR 9:[b] Injection into Soil	No significant amount of sewage sludge remains on soil surface within 1 hour after injection.
VAR 10[b]: Incorporation into Soil	Sewage sludge must be incorporated into soil within 6 hours after being placed on the soil surface.
VAR 11[b]: Covered with Soil (Surface Disposal Only)	Surface disposed sewage sludge must be covered daily.
VAR 12[b]: Domestic Septage pH Adjustment	Preparer must ensure that pH is 12 for more than 30 minutes for every container of domestic septage treated with alkali.

[a] EPA is proposing that requirements for options 6, 7, and 8 be met at the time of use or disposal.
[b] Conditions for options 9-12 must be maintained at all times if one of these options is chosen to meet vector attraction reduction requirements.

13.2.2 Frequency of Monitoring

The Part 503 regulation establishes minimum frequency of monitoring requirements for sewage sludge that is land applied based on the amount of sewage sludge applied at a site in a year, as discussed in Chapter 3 and shown in Table 3-15. The permitting authority may require increased frequency of monitoring if certain conditions exist, such as if no previous sampling data are available on the sewage sludge to be land applied or if pollutant concentrations or pathogen densities vary significantly between measurements. The permitting authority also may reduce the frequency of monitoring to a minimum of once annually if certain conditions exist (i.e., after two years, the variability of pollutant concentrations or pathogen density is low and compliance is demonstrated).

Permitting requirements regarding frequency of monitoring may differ depending on whether sewage sludge is continuously land applied or is stored prior to land application, to ensure collection of a representative sample of the sewage sludge that is actually land applied.

Table 13-2. Sampling Points for Sewage Sludge

Sewage Sludge Type	Sampling Point
Anaerobically Digested	Collect sample from taps on the discharge side of positive displacement pumps.
Aerobically Digested	Collect sample from taps on discharge lines from pumps. If batch digestion is used, collect sample directly from the digester. Cautions: 1. If biosolids are aerated during sampling, air entrains in the sample. Volatile organic compounds may be purged with escaping air. 2. When aeration is shut off, solids may settle rapidly in well-digested sewage sludge.
Thickened	Collect sample from taps on the discharge side of positive displacement pumps.
Heat Treated	Collect sample from taps on the discharge side of positive displacement pumps *after* decanting. Be careful when sampling heat-treated sewage sludge because of: 1. High tendency for solids separation. 2. High temperature of sample (temperature < 60°C as sampled) can cause problems with certain sample containers due to cooling and subsequent contraction of entrained gases.
Dewatered, Dried, Composted	Collect sample from material collection conveyors and bulk containers. Collect sample from many locations within the sewage sludge mass and at various depths.
Dewatered by Belt Filter Press, Centrifuge, Vacuum Filter Press	Collect sample from sewage sludge discharge chute.
Dewatered by Sewage Sludge Press, (plate and frame)	Collect sample from the storage bin; select four points within the storage bin, collect equal amount of sample from each point and combine.
Dewatered by Drying Beds	Divide bed into quarters, grab equal amounts of sample from the center of each quarter and combine to form a composite sample of the total bed. Each composite sample should include the entire depth of the sewage sludge material (down to the sand).
Compost Piles	Collect sample directly from front-end loader while sewage sludge is being transported or stockpiled within a few days of use.

13.2.3 Sample Collection

Liquid sewage sludge from pipelines should be sampled as far downstream as possible to take advantage of maximum mixing, thus reflecting the most representative sample of sewage sludge to be land applied. If liquid sewage sludge must be sampled from a lagoon, floating, suspended, and sediment layers should be included in the sample.

For dewatered sewage sludge (10% to 40% solids), sampling is best done when the sewage sludge is being moved to maximize representativeness. A convenient way to collect samples might be to sample haul truck loads at a frequency that obtains the minimum number of samples needed, as required by the frequency of monitoring specified in the Part 503 regulation. This frequency can be determined by dividing the annual tonnage or cubic yards of sewage sludge by the calculated number of samples to determine how often haul trucks or spreaders should be sampled. For example, if 250 cubic yards of sewage sludge are hauled to the site annually in haul trucks with a 25-cubic-yard capacity, and if 10 samples are required, then one composite grab sample from every truck load might suffice, or several samples from each truckload might be needed to obtain a representative sample. If half that amount was hauled in a year, then two composite grab samples representing the front and back half of each truck would be needed. If the amount of sewage sludge requires more truck loads than samples, then samples would be taken of the required percentage of loads to obtain the requisite number of samples.

Other EPA documents (U.S. EPA, 1989, 1993, 1994) provide more detailed guidance on specific procedures for collecting sewage sludge samples.

Sample collection and handling procedures should be clearly defined and consistently followed to minimize sample errors attributable to the sampling process. This can be accomplished with a written sampling protocol that includes:

- Specification of personnel responsible for collecting samples, and training requirements to ensure that the sampling protocol is correctly followed.
- Specification of safety precautions to prevent exposure of sampling personnel to pathogenic organisms, such as use of gloves when handling or sampling untreated or treated sewage sludge and cleaning of sampling equipment, containers, protective clothing, and hands before delivering samples to others.
- Identification of the appropriate type of sampling device. For liquid sewage sludge, certain types of plastic (e.g., polyethylene) or glass (e.g., non-etched Pyrex) may be appropriate, depending on the type of sample (e.g., metals or pathogens); coliwasas can be used for sampling liquid sewage sludge from lagoons. For dewatered sewage sludge, soil sampling devices, such as scoops, trier samplers, augers, or probes can be used. If steel devices are used, stainless steel materials are best; chrome-plated samplers should be avoided.
- Description of sample mixing and subsampling procedures when grab samples of sludge are composited and only part of the composite sample is used for analysis. This usually requires use of a mixing bowl or bucket (stainless steel or Teflon) or a disposable plastic sheet on which samples can be mixed and from which a smaller sample can be taken.
- Specification of the size and material of sample containers. Table 13-3 identifies suitable containers and minimum volume requirements for sludge sampling. Sample containers can often be obtained from the person or laboratory responsible for doing the sample analysis.
- Specification of sample preservation procedures and sample holding times. Table 13-3 identifies these requirements for sludge samples. The appropriate regulatory agency, in coordination with the testing laboratory, should be contacted to identify any required sample preservation procedures and holding times for all constituents being monitored.
- Specification of sample equipment cleaning procedures to ensure that cross-contamination of samples does not occur. ASTM D5088 (*Standard Practice for Decontamination of Field Equipment Used at Nonradioactive Waste Sites*) provides guidance on these procedures.
- Specification of types and frequency of quality assurance/quality control (QA/QC) samples. Again, the appropriate regulatory agency should be contacted to determine which types of QA/QC samples may be required for the site.
- Description of sample chain-of-custody procedures to ensure that the integrity of samples is maintained during transport and analysis of samples.

13.2.4 Analytical Methods

Table 13-4 identifies analytical methods for pathogens, inorganic pollutants, and other sewage sludge parameters that are required by the Part 503 regulation. Specific methods for sewage sludge sample preparation and analysis for metals of interest are contained in *Test Methods for Evaluating Solid Waste* (U.S. EPA, 1986).

13.3 Soil Monitoring and Sampling

Soil sampling and analysis for constituents affecting plant growth (see Chapter 6) may be needed to ensure

Table 13-3. Sewage Sludge Sample Containers, Preservation, and Storage

Parameter	Wide-Mouthed Container	Preservative[a]	Maximum Storage Time[a]	Minimum Volume[b]
Metals				
Solid and semi-solid samples	P, G	Cool, 4°C	24 hours	300 mL
Mercury (liquid)	P, G	HNO_3 to pH < 2	28 days	500 mL
All other liquid metals	P, G	HNO_3 to pH < 2	6 months	1,000 mL
Pathogen Density and Vector Attraction Reduction				
Pathogens	G, P, B, SS	1. Cool in ice and water to <10°C if analysis delayed >1 hr, or	6 hours (bacteria)	1-4 liters[c]
		2. Cool promptly to < 4°C, or	24 hours (bacteria and viruses) 1 month (helminth ova)	
		3. Freeze and store samples to be analyzed for viruses at 0°C[d]	2 weeks	
Vector attraction reduction		Varies[b]	Varies[b]	1-4 liters[c]

[a] Preservatives should be added to sampling containers prior to actual sampling episodes. Storage times commence upon addition of sample to sampling container. Shipping of preserved samples to the laboratory may be, but is generally not, regulated under Department of Transportation hazardous materials regulations.
[b] Varies with analytical method. Consult 40 CFR Part 503. For dry sewage sludge, convert to dry weight (DW). DW = wet ÷ percent solids.
[c] Reduced at the laboratory to approx. 300 mL samples.
[d] Do not freeze bacterial or helminth ova samples.
P = Plastic (polyethylene, polypropylene, Teflon)
G = Glass (non-etched Pyrex)
B = Presterilized bags (for dewatered or free-flowing biosolids)
SS = Stainless steel (not steel- or zinc-coated)

Table 13-4. Analytical Methods for Sewage Sludge Sampling[a]

Sample Type	Method
Enteric Viruses	ASTM Designation: D 4994-89, Standard Practice for Recovery of Viruses from Wastewater Sludges, Annual Book of ASTM Standards: Section 11. Water and Environmental Technology, ASTM, Philadelphia, PA, 1992.
Fecal Coliform	Part 9221 E or Part 922 D, Standard Methods for the Examination of Water and Wastewater, 18th edition, American Public Health Association, Washington, DC, 1992.
Helminth Ova	Yanko, W.A., Occurrence of Pathogens in Distribution and Marketing Municipal Sludges, EPA/600/1-87/014, 1987. PB 88-154273/AS, National Technical Information Service, Springfield, VA; (800) 553-6847.
Inorganic Pollutants	Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, EPA Publication SW-846, 3rd edition (1986) with Revision I. 2nd edition. PB 87-120291, National Technical Information Service, Springfield, VA. 3rd edition Doc. No. 955-001-00000-1, Superintendent of Documents, Government Printing Office, Washington, DC.
Salmonella sp. Bacteria	Part 9260 D, Standard Methods for Examination of Water and Wastewater, 18th edition, American Public Health Association, Washington, DC, 1992; or, Kenner, B.A. and H.P. Clark, Detection and Enumeration of *Salmonella* and *Pseudomonas aeruginosa*, J. Water Pollution Control Federation, 46(9):2163-2171, 1974.
Specific Oxygen Uptake Rate	Part 2710 B, Standard Methods for the Examination of Water and Wastewater, 18th edition, American Public Health Association, Washington, DC, 1992.
Total, Fixed, and Volatile Solids	Part 2540 G, Standard Methods for the Examination of Water and Wastewater, 18th edition, American Public Health Association, Washington, DC, 1992.
Percent Volatile Solids Reduction Calculation	Environmental Regulations and Technology—Control of Pathogens and Vectors in Sewage Sludge, EPA/625/R-92/013, U.S. Environmental Protection Agency, Cincinnati, OH, 1992; (614) 292-6717.

[a] All of these analytical methods are required by the Part 503 rule, except the Percent Volatile Solids Reduction Calculation, which is provided as guidance in the Part 503 rule.

vigorous crop production. Soil monitoring is not a Part 503 requirement. As discussed in Chapter 6, soil sampling at sewage sludge land application sites is performed primarily to assist in determining soil chemical parameters (N, P, and K) for calculation of sewage sludge and supplemental fertilizer application rates to supply plant nutrient requirements. Additional site-specific analyses may be needed to monitor the status of some land application systems. For example, soils may need to be analyzed for soluble salts and/or boron in semiarid regions where irrigation is planned. Table 13-5 summarizes potential surface and subsurface soil parameters that may be useful to monitor prior to or after sewage sludge land application. Advice should be obtained from the local University Cooperative Extension Service, County Agricultural Agents, and/or others with expertise in sampling and analysis of soils in the sewage sludge land application site area.

Table 13-5. Potential Soil Surface Layer and Subsurface Parameters of Interest

Monitoring Prior to Sewage Sludge Application	
Surface Layer	**Subsurface Layers**
Particle size distribution	Particle size distribution
pH	pH
Electrical conductivity	Electrical conductivity
Cation exchange capacity (CEC)	Cation exchange capacity (CEC)
Lime requirement (acid soils)	
Plant available P and K	
Soil N parameters	
NO_3-N	
NH_4-N	
Organic matter	
Organic-N	
C:N ratio	
Soil microbial biomass C and N	
N mineralization potential	
Monitoring After Sewage Sludge Application	
pH	pH
Electrical conductivity	Electrical conductivity
Lime requirement (acid soils)	
Plant available P and K	
Soil N parameters	
Organic matter	
Organic-N	

13.3.1 Sampling Location and Frequency

Initially, soil samples can be collected from each field where sewage sludge will be land applied. Generally, if a given field exceeds 10 ha (25 ac), individual soil samples should be collected from each soil series within the field. The number and location of samples necessary to adequately characterize soils prior to sewage sludge land application is primarily a function of the spatial variability of the soils at the site. If the soil types occur in simple patterns, a composite sample of each major type can provide an accurate picture of the soil characteristics. The site soil map described in Chapter 6 will identify major soil types that should be sampled.

Soil pH measurements can be done in the field at relatively low cost. Thus, measuring the pH of soil samples taken on a grid pattern (e.g., 30 m [100 ft] sections), can serve as a useful indicator of the degree of spatial variability within soil map units. If pH is variable, drawing contours of equal pH will identify subareas in a soil type where separate composite samples should be collected. Such a map also is useful when the pH of soil needs to be adjusted.

Once initial sampling and analysis of soil samples is completed, the frequency of subsequent sampling will depend on land use and any state regulatory soil monitoring requirements. For agricultural crops, pH, P, and K soil tests are typically done every two years. Monitoring of these parameters typically is not required for forest land application sites. As discussed in Section 13.6.3, monitoring requirements at reclamation sites will typically be more extensive than at agricultural and forest sites.

If sewage sludge is applied at agronomic rates to supply plant N requirements (as is required by Part 503), periodic monitoring of soil-available N may be useful because of the difficulty in accurately predicting N mineralization rates of sewage sludge. Annual monitoring of soil N is appropriate for irrigated crops, as well as certain non-irrigated crops such as corn. Annual monitoring is less critical at forest sites because crops are not removed each year, but may be performed initially to gain an understanding of nitrogen dynamics at the site. Section 13.3.4 further discusses test methods for estimating N availability.

13.3.2 Number of Samples

In some states, the state regulatory agency stipulates the minimum number of soil borings which must be analyzed. New Jersey, for example, historically has based the minimum number of soil borings required based on the proposed sewage sludge land application site area, ranging from a minimum of 3 borings on small sites (up to 4 ha [10 ac]) to 24 borings on large sites (over 80 ha [200 ac]. Samples taken from similar soil horizons are usually composited for several borings located near each other in homogeneous soil. The composited samples are subsequently analyzed.

13.3.3 Sample Collection

The proper selection of tools for collection of soil samples depends in part on the texture and consistency of the soil, the presence or absence of rock fragments, the depth to be sampled, and the degree of allowable soil surface disturbance. Soil samples are most accurately taken from a freshly dug pit. Where field plots are to be sampled periodically, however, preferable sampling tools are those which disturb the plot the least. Cutaway soil sampling tubes, closed cylinder augers, and tiling spades (sharp-shooters) may be used depending on the size of the plot and allowable disturbance. The cutaway soil sampling tube creates the least disturbance, and works well in the plow layer and the upper subsoil of moist, stone-free, friable soils. Each sample collected should represent the cross section of the soil layer being sampled.

In sampling subsurface soils, care must be taken to remove loose particles of sewage sludge residue on the soil surface around the hole prior to and during sampling. In addition, any surface soil/sludge residue attached to the top and side of the core samples from lower depths should be removed by slicing with a knife. Where cores extend below the depth of the seasonal high water table, it is recommended that the holes be sealed by filling with bentonite pellets and tap water. A map showing sample points should be made.

The depth to which the soil profile is sampled and the extent to which each horizon is vertically subdivided depend largely on the parameters to be analyzed, the vertical variations in soil character, and the objectives of the soil sampling program. For initial characterization, samples are typically taken from each distinct soil horizon down to a depth of 120 to 150 cm (4 to 5 ft). For example, samples may be taken from four soil depths (horizons) as follows: 0 to 15 cm (0 to 6 in), 15 to 45 cm (6 to 18 in), 45 to 75 cm (18 to 30 in), and 75 to 120 cm (30 to 42 in). Usually, at a minimum, samples are taken from the upper soil layer (e.g., 0 to 15 cm [0 to 6 in]) and a deeper soil horizon (e.g., 45 to 75 cm [18 to 30 in]).

Subsequent samples for pH, P, and K monitoring are usually confined to the surface layer at 0-15 or 0-30 cm, depending on the thickness of the soil A horizon. Recommended sampling depths for developing NO_3 profiles generally vary from 0.6 to 1.2 m, depending on the crop and state. These variations are based on depths known to represent the best correlation between soil-NO_3 and crop yield in particular areas and with particular crops. Advice should be obtained from the local University Cooperative Extension Service, County Agricultural Agents, and/or others with expertise in sampling and analysis of soils in the locality of the sewage sludge land application site concerning recommended sampling depths for NO_3 profiles. Depths up to 60 cm can usually be collected by hand without much difficulty. Collection of samples exceeding 60 cm usually requires use of power-driven soil sampling equipment.

Estimation of N immobilization (see Chapter 8) associated with initial sewage sludge application at forest sites involves sampling of forest litter to measure the amount of C and N. Representative samples of twigs, leaves, and partially decomposed litter on the forest floor can be collected and weighed to determine the total amount of litter in kg/ha. It may also be desirable to quantify the macroorganic fraction of the soil surface (the sand-sized fraction of soil organic matter). Gregorich and Ellert (1993) discuss methods for measuring this fraction.

Soil samples should be air-dried (at temperatures less than 40°C), ground, and passed through a 2-mm sieve as soon as possible after collection. Chemical analyses are generally performed on air-dried samples, which do not require special preservation for most parameters. Samples collected for nitrate, ammonia, and pathogen analyses, however, should be refrigerated under moist field conditions and analyzed as soon as possible.

13.3.4 Analytical Methods

Major reference sources for standard methods for physical and chemical analysis of soil samples include: Carter (1993), Council on Soil Testing and Analysis (1992), Klute (1986), Page et al. (1982), Soil Conservation Service (1984), and Westerman (1990).

13.3.4.1 Nitrogen

Keeney (1982) provides a summary of soil analysis methods used in different states to develop N fertilizer recommendations. The most commonly used methods are: (1) NO_3 profiles, and (2) measurement of soil organic matter content in the surface soil. NO_3 profiles are most commonly used in western states where crops are grown under irrigation, but Sander et al. (1994) note that the pre-sidedress nitrate test (PSNT) has been demonstrated to be a useful test for corn crops in more humid climates. Measurement of organic matter content is used by a number of states in both the eastern and western United States to directly or indirectly estimate mineralizable N. Missouri has refined the use of organic matter by basing N mineralization rate estimates on soil texture (Keeney, 1982).

Measurements of the mineralization potential of soils and of soils amended with sewage sludge usually are accomplished using laboratory soil column biological incubation methods. Keeney (1982) and Campbell et al. (1993) describe these methods. Most of the references identified at the beginning of this section cover the wide variety of methods that are available for determination of organic and inorganic forms of N in soils.

13.3.4.2 Plant-Available Phosphorus and Potassium

The amount of plant-available P is determined by analyzing the amount of P removed from soil by a particular extractant. The extractant used varies in different regions of the United States, but typically is a dilute acid or a bicarbonate solution. Essentially, all P taken up by crops is present in insoluble forms in soils rather than being in the soil solution. In all states, it has been determined that there is a relationship between the amount of extractable P in a soil and the amount of P fertilizer needed for various yields of different crops. Such information may be obtained from extension services or universities.

As with P, an extractant is used to determine the plant-available K in a soil. Potassium available for plant uptake is present in the soil solution, and also is retained as an exchangeable cation on the cation exchange complex of the soil. The amount of plant-available K is then used to determine the K fertilizer rate for the crop grown. Most sewage sludge usually is deficient in K, relative to crop needs.

13.4 Surface-Water and Ground-Water Monitoring

The risk-based pollutant limits and the management practices for land application specified in the federal Part 503 rule are designed to be sufficiently protective of surface water and ground water so that onsite water quality monitoring usually is not required at land application sites. Some states may require surface or ground-water monitoring for special conditions at a land application site, as discussed below.

13.4.1 Surface-Water Monitoring

Properly designed sewage sludge land application sites are generally located, constructed, and operated to minimize the chance of surface-water runoff containing sewage sludge constituents. Surface-water monitoring rarely is required when sewage sludge is applied at agronomic rates. In some cases, a state agency may require monitoring for special situations. In these cases, the state usually will specify monitoring locations and procedures.

13.4.2 Ground-Water Monitoring

Sewage sludge land application at agronomic rates should pose no greater threat of NO_3^- contamination of ground water than does the use of conventional N fertilizers. Special conditions at a land application site may result in ground-water monitoring requirements by the state. In such cases, monitoring locations and procedures typically will be specified by the appropriate state agency.

13.5 Vegetation Monitoring

The federal Part 503 pollutant limits and management practices for land application specified in the Part 503 rule are designed to be sufficiently protective of vegetation regarding uptake of heavy metals so that onsite monitoring of vegetation is not required. Vegetation monitoring may be conducted for public relations purposes, when it is desirable to assure private crop or tree farm owners that their crops are not being adversely affected by the use of sewage sludge. Table 13-6 summarizes sampling procedures for field crops and pastures.

13.6 Monitoring and Sampling at Reclamation Sites

13.6.1 General

If a land application program at a reclamation site complies with applicable requirements, the sewage sludge will pose little potential for adverse effects on the environment, and no monitoring is necessary beyond the Part 503 frequency of monitoring requirements (see Chapter 3). Some states require monitoring at a reclamation site after the sewage sludge has been land applied. Special monitoring and sampling procedures may be needed for such monitoring because of more complex site geochemistry compared to undisturbed soils.

13.6.2 Disturbed Soil Sampling Procedures

Standard soil sampling procedures employed on agricultural fields can often be used for reclamation sites that have had topsoil replaced. For some unreclaimed sites, more intensive sampling may be necessary to characterize site conditions. In heterogenous materials, such as mine spoils, an adequate determination of conditions may require sampling on a grid pattern of approximately 30 m (100 ft) over the entire site.

Although the disturbed surface materials often are not soil in the generic sense, soil tests on disturbed lands have proven useful. Soil tests on drastically disturbed sites, however, do have some limitations that should be taken into consideration during site evaluation. Guidelines vary widely on the number of samples to be taken. Recommendations for sampling heterogeneous strip mine spoils in the eastern U.S. range from 4 to 25 individual samples per ha (1.5 to 10 per ac). It has also been suggested that one composite sample made up of a minimum of 10 subsamples for each 4 ha (10 ac) area may be adequate (Barnhisel, 1975). Many disturbed lands are not heterogeneous, however, and the range and distribution of characteristics of the surface material often is more important than the average composition. In general, it is recommended that material that is visibly different in color or composition should

Table 13-6. Suggested Procedures for Sampling Diagnostic Tissue of Crops (Walsh and Beaton, 1973)

Crop	Stage of Growth[a]	Plant Part Sampled	Number Plants/Sample
Corn	Seedling	All the aboveground portion.	20-30
	Prior to tasseling	Entire leaf fully developed below whorl.	15-25
	From tasseling to silking	Entire leaf at the ear node (or immediately above or below).	15-25
Soybeans and other beans	Seedling	All the aboveground portion.	20-30
	Prior to or during early flowering	Two or three fully developed leaves at top of plant.	20-30
Small grains	Seedling	All the aboveground portion.	50-100
	Prior to heading	The 4 uppermost leaves.	50-100
Hay, pasture or forage grasses	Prior to seed emergence	The 4 uppermost leaf blades.	40-50
Alfalfa, clover and other legumes	Prior to or at 1/10 bloom	Mature leaf blades taken about 1/3 of the way down the plant.	40-50
Sorghum-milo	Prior to or at heading	Second leaf from top of plant.	15-25
Cotton	Prior to or at 1st bloom, or at 1st square	Youngest fully mature leaves on main stem.	30-40
Potato	Prior to or during early bloom	3rd to 6th leaf from growing tip.	20-30
Head crops (e.g., cabbage)	Prior to heading	1st mature leaves from center of whorl.	10-20
Tomato	Prior to or during early bloom stage	3rd or 4th leaf from growth tip.	10-20
Beans	Seedling	All the aboveground portion.	20-30
	Prior to or during initial flowering	2 or 3 fully developed leaves at the top of plant.	20-30
Root crops	Prior to root or bulb enlargement	Center mature leaves.	20-30
Celery	Mid-growth (12-15 in. tall)	Petiole of youngest mature leaf.	15-30
Leaf crops	Mid-growth (12-15 in. tall)	Youngest mature leaf.	35-55
Peas	Prior to or during initial flowering	Leaves from 3rd node down from top of plant.	30-60
Melons	Prior to fruit set	Mature leaves at base of plant on main stem.	20-30

[a] Seedling stage signifies plants less than 12 in. tall.

be sampled as separate units (areas) if large enough to be treated separately in the reclamation program.

13.6.3 Suggested Monitoring Program

13.6.3.1 Background Sampling (Prior to Sewage Sludge Application)

Composite sewage sludge samples can be collected and analyzed to provide data for use in designing loading rates. Composite soil samples can be collected from the site to determine pH, liming requirements, CEC, available nutrients, and trace metals prior to sewage sludge addition.

13.6.3.2 Sampling During Sewage Sludge Application

When the sewage sludge is delivered, grab samples can be taken and analyzed for moisture content if there is variation in the moisture content of the sewage sludge. Composite sewage sludge samples also should be collected to assist in documenting the actual amounts of nutrients applied to the site (and trace metal amounts applied, if Part 503 CPLR pollutant limits are being met, see Chapter 3).

13.6.3.3 Post-Sewage Sludge Application Monitoring

Monitoring of the sewage sludge application site after the sewage sludge has been applied can vary from none to extensive, depending on state and local regulations and site-specific conditions. Generally, it is desirable to analyze the soil after 1 year for soil pH changes. In addition, periodic surface and ground water analysis may be useful to document any long-term changes in water quality.

Some states have very specific requirements for monitoring, and the designer should consult the appropriate regulatory agency. Monitoring requirements by the State of Pennsylvania (Pennsylvania Department of Environmental Resources, 1988) provide an example:

The Pennsylvania Department of Environmental Resources (DER) requires a ground-water monitoring system on mine land amended with sewage sludge. The system must consist of the following, at a minimum: (1) at least one monitoring well at a point hydraulically upgradient in the direction of increasing static head from the area in which sewage sludge has been applied; (2) at least three monitoring wells at points hydraulically downgradient in the direction of decreasing static head from the area treated with sewage sludge; and (3) in addition to the three wells, the DER may allow one or more springs for monitoring points if the springs are downgradient from the treated sewage sludge area. Surface water monitoring points may also be required by the DER if appropriate for the specific site.

Ground-water samples must be collected and analyzed at required frequencies for various parameters, including Kjeldahl nitrogen, ammonia-nitrogen, nitrate-nitrogen; certain metals, organics, and other water quality indicators; and ground-water elevation in monitoring wells. The DER may also require soil-pore water monitoring using lysimeters located in the unsaturated zone within 36 inches of the soil surface. Soil sampling for certain metals, pH, and phosphorus using DER procedures is required for mine reclamation sites that may be used for agriculture. For crops grown for animal consumption, the DER may require a crop analysis, usually for certain specified metals.

13.7 References

When an NTIS number is cited in a reference, that document is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-487-4650

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Chapter 14
General Design Considerations

14.1 Introduction

This chapter provides guidance for designing the components of a land application system, including:

- Sewage sludge transport systems
- Sewage sludge storage
- Land application methods
- Site preparation
- Supporting facilities

The designer should take into consideration each component's impact on overall system efficiency, reliability, and cost when selecting and designing each of these individual components of a land application system. For example, the most economical sewage sludge transportation method may not result in the lowest overall system cost because of associated high costs at the treatment plant and/or land application site.

14.2 Transportation of Sewage Sludge

14.2.1 Transport Modes

Efficient transport of sewage sludge should be a key design consideration. Potential modes of sewage sludge transportation include truck, pipeline, railroad, or various combinations of these three modes (Figure 14-1).

The method of transportation chosen and its costs depend on a number of factors, including:

- Characteristics and quantity of the sewage sludge to be transported.
- Distance from the treatment works to the application site(s).
- Availability and proximity of the transportation mode(s) to both origin and destination (e.g., roads, proximity of railroad spurs).
- Degree of flexibility required in the transportation method chosen.
- Estimated useful life of the land application site based on site characteristics (e.g., topography, vegetative cover, soil type, area available).
- Environmental and public acceptance factors.

To minimize the danger of spills, liquid sewage sludge should be transported in closed tank systems. Stabilized, dewatered sewage sludge can be transported in open vessels, such as dump trucks and railroad gondolas if equipped with watertight seals and anti-splash guards.

14.2.2 Vehicle Transport

14.2.2.1 Vehicle Types Available

Trucks are widely used for transporting both liquid and dewatered sewage sludge and are generally the most flexible means of transportation. Terminal points and haul routes can be readily changed with minimal cost. Trucks can be used for hauling sewage sludge either to the final application site(s) or to an intermediate transfer point such as railroad yards. Access to sewage sludge within a treatment plant is usually adequate for truck loading.

Many truck configurations are available, ranging from standard tank and dump bodies to specialized equipment for hauling and spreading sewage sludge. Depending on the type of sewage sludge to be hauled, different types of vehicles can be used, as described below.

Liquid Sewage Sludge

The following types of vehicles can be used to haul liquid sewage sludge (usually less than 10 percent solids, dry weight):

- Farm tractor and tank wagon, such as those used for livestock manure. Normally used only for short hauls and by small rural communities.
- Tank truck, available in sizes from 2,000 to 24,000 L (500 to 6,000 gal).
  - Tank truck adapted for field application of sewage sludge in addition to road hauling.
  - Tank truck used for road hauling to the land application site(s), with sewage sludge subsequently transferred to a field application vehicle or an irrigation system. Such tank trucks are often termed "nurse trucks."

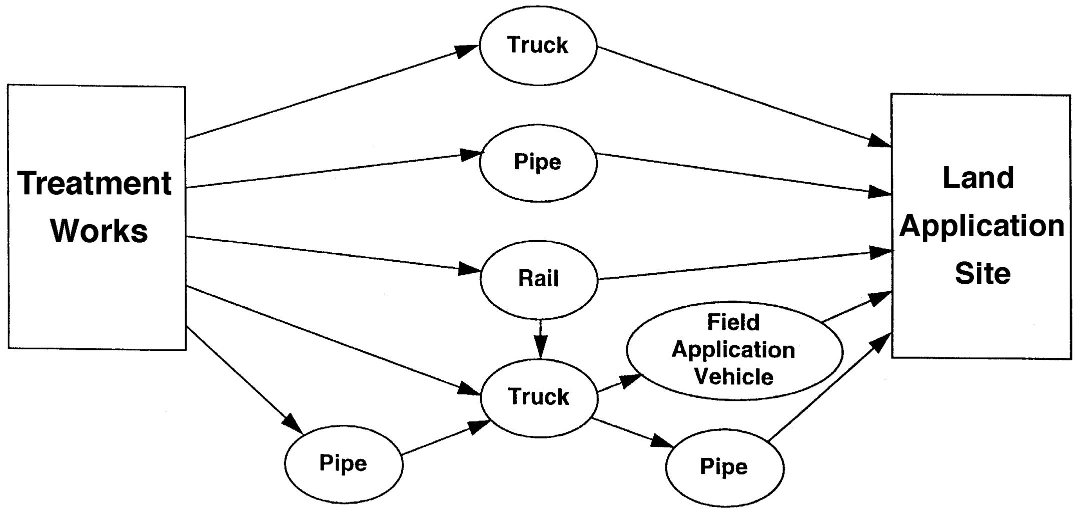

Figure 14-1. Examples of sewage sludge transportation modes to land application sites.

Dewatered or Composted Sewage Sludge

The following types of vehicles can be used to haul dewatered or composted sewage sludge (usually 20 to 60 percent solids, dry weight):

- Dump truck, available in sizes from 6 to 23 m^3 (8 to 30 yd^3).
- Hopper (bottom dump) truck, available in sizes from 12 to 19 m^3 (15 to 25 yd^3).
- Either of the above types of trucks can be used for hauling the sewage sludge to the land application site(s) and can also be adapted to spread sewage sludge.

Figure 14-2 shows photographs of some of the types of trucks listed above.

14.2.2.2 Vehicle Size and Number Required

To properly assess the size and number of vehicles needed for transporting sewage sludge from the treatment plant to the application site(s), the following factors should be considered:

- Quantity of sewage sludge, both present and future.
- Type of sewage sludge—liquid or dewatered/composted.
- Distance from treatment plant to application site(s) and travel time.
- Type and condition of roads to be traversed, including maximum axle load limits and bridge loading limits.
- Provisions for vehicle maintenance.
- Scheduling of sewage sludge application. In many areas, significant seasonal variations exist (due to weather, cropping patterns, etc.) regarding the quantity of sewage sludge that can be applied. The transport system capacity should be designed to handle the maximum anticipated sewage sludge application period, taking into consideration any interim sewage sludge storage capacity available.
- Percent of time when the transport vehicles will be in productive use. A study (U.S. EPA, 1977a) of trucks hauling sewage sludge at 24 small to medium size

Figure 14-2a. A 6,500-gallon liquid sludge tank truck (courtesy of Brenner Tank Company).

Figure 14-2b. A 3,300-gallon liquid sludge tank truck with 2,000-gallon pup trailer (courtesy of Brenner Tank Company).

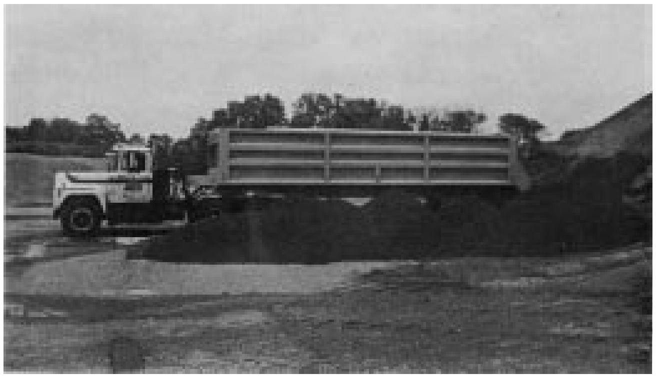

Figure 14-2c. A 25-cubic-yard dewatered sludge haul truck (courtesy of Converto Manufacturing Company).

Figure 14-2d. A 12-cubic-yard dewatered sludge spreader vehicle (courtesy of Ag-Chem Equipment Company).

communities showed that trucks hauling liquid sewage sludge were in productive use an average of 48 percent of the time (range of 7 to 90 percent) based on an 8-hour day and 5-day week. Average use for trucks hauling dewatered sewage sludge was reported at 29 percent.

Tables 14-1 and 14-2 provide guidelines for estimating the number of trucks needed for transporting liquid and dewatered sewage sludge, respectively. While the tables provide a means for making preliminary comparisons, they are only a starting point in the decisionmaking process for a specific project. For example, the tables can be used to quickly compare vehicle needs as a function of whether liquid sewage sludge at 5 percent solids or an equivalent quantity of dewatered sewage sludge at 25 percent solids will be transported. Assuming a liquid sewage sludge quantity of 57 million L/yr (15 Mgal/yr, which corresponds to 58,000 metric tons/yr or 64,000 Tons/yr) compared with an equivalent quantity of dewatered sewage sludge of 11,470 m^3/yr (15,000 yd^3/yr, which corresponds to 12,000 metric tons/yr or 13,000 Tons/yr). Also assume a one-way distance of 32 km (20 mi) from the treatment plant to the application site. Tables 14-1 and 14-2 indicate that for an 8 hr/day operation, approximately six 9,450 L (2,500 gal) tank trucks are necessary to transport the liquid sewage sludge, while only one 11.5 m^3 (15 yd^3) truck is necessary to transport the dewatered sewage sludge. The difference in fuel purchase would be 202,000 L/yr (53,500 gal/yr) for the liquid sewage sludge versus 50,300 L/yr (13,300 gal/yr) for the dewatered sewage sludge; driver time required for the liquid sewage sludge would be 15,500 hr/yr versus 2,600 hr/yr for the dewatered sewage sludge. The savings in transportation costs for dewatered sewage sludge versus liquid sewage sludge can then be compared to the cost of dewatering the sewage sludge.

The reader should be aware that the above example is highly simplified in that it assumes that the sewage sludge transport operation takes place 360 days a year, allows an average of only 10 percent for labor hours beyond actual truck operating hours, provides for only 2 hr/day for truck maintenance time, and gives no consideration to effects of sewage sludge type on operating costs at the application site(s).

14.2.2.3 Other Truck Hauling Considerations

The haul distance should be minimized to reduce costs, travel time, and the potential for accidents on route to the application site(s). Factors such as unfavorable topographic features, road load limits, and population patterns may influence routing so that the shortest haul distance may not be the most favorable.

Effective speed and travel time can be estimated from the haul distance, allowing for differences in speed for various segments of the route and the anticipated traffic conditions. Periods of heavy traffic should be avoided from a safety standpoint, for efficiency of operation, and for improved public acceptability.

The existing highway conditions must be considered in the evaluation of truck transport. Physical constraints, such as weight, height, and speed limits, may limit truck transport and will influence vehicle and route selection. Local traffic congestion and traffic controls will influence routing and also should be considered in determining the transport operation schedule. Public opinion on the use of local roadways, particularly residential streets, may have a significant effect on truck transport operations and routing.

Fuel availability and costs can have a profound impact on the operation and economy of sewage sludge hauling activities. Larger trucks tend to be more fuel efficient than smaller ones. Also, short haul distances over flat terrain will have lower fuel requirements than long haul distances over hills.

Truck drivers and mechanics as well as loading and unloading personnel will be required for large sewage sludge hauling operations. Small operations may combine these roles into one or two persons. Manpower requirements can be determined from the operating schedule.

Table 14-1. Truck Operation Summary, Liquid Sludge (Ettlich, 1976)

Annual Sludge Volume M gal	One-Way Distance (miles)	Trips Per Year			Trucks needed* 8 hr/day operation (22 hr/day operation)**			Truck Use 1,000 miles/yr			Truck Fuel 1,000 gal/year†			Truck Operators 1,000 Man-Hours/Yr#		
		1,200 gal	2,500 gal	5,500 gal	1,200 gal	2,500 gal	5,500 gal	1,200 gal	2,500 gal	5,500 gal	1,200 gal	2,500 gal	5,500 gal	1,200 gal	2,500 gal	5,500 gal
1.5	5	1,250	600	273	1(1)	1(1)	1(1)	13	6	3	2.9	1.3	0.8	1.6	0.8	0.3
	10	1,250	600	273	1(1)	1(1)	1(1)	25	12	6	5.6	2.7	1.6	0.1	1.0	0.5
	20	1,250	600	273	2(1)	1(1)	1(1)	50	24	11	11.1	5.3	3.1	3.2	1.6	0.7
	40	1,250	600	273	2(1)	1(1)	1(1)	100	48	22	22.2	10.7	6.3	4.8	2.3	1.0
	80	1,250	600	273	4(2)	2(1)	1(1)	200	96	44	44.4	21.3	12.6	7.9	3.8	1.7
5	5	4,167	2,000	909	2(1)	1(1)	1(1)	42	20	9	9.3	4.4	2.6	5.3	2.5	1.2
	10	4,167	2,000	909	3(1)	2(1)	1(1)	83	40	18	18.4	8.9	5.1	7.1	3.4	1.5
	20	4,167	2,000	909	4(2)	3(1)	1(1)	167	80	36	37.1	17.8	10.3	10.8	5.2	2.4
	40	4,167	2,000	909	6(3)	3(2)	2(1)	333	160	73	74.0	35.6	20.9	16.0	7.7	3.5
	80	4,167	2,000	909	12(4)	6(2)	3(1)	667	320	145	148.2	71.1	41.4	16.5	12.7	5.8
15	5	12,500	6,000	2,727	5(2)	3(1)	2(1)	125	60	27	27.8	13.3	7.7	15.8	7.6	3.5
	10	12,500	6,000	2,727	7(3)	4(2)	2(1)	250	120	55	55.6	26.7	15.7	11.3	10.2	4.6
	20	12,500	6,000	2,727	12(4)	6(2)	3(1)	500	240	109	111.1	53.3	31.1	32.3	15.5	7.0
	40	12,500	6,000	2,727	18(7)	9(4)	4(2)	1,000	480	218	222.2	106.7	62.3	48.0	23.0	10.5
	80	12,500	6,000	2,727	35(12)	17(6)	8(3)	2,000	960	436	444.4	213.3	124.6	79.5	38.1	17.3
50	5	41,667	20,000	9,091	17(6)	8(3)	4(2)	417	200	91	92.7	44.4	26.0	52.7	25.3	11.5
	10	41,667	20,000	9,091	24(9)	12(4)	6(2)	833	400	182	185.1	88.9	52.0	71.0	34.1	15.5
	20	41,667	20,000	9,091	39(13)	19(7)	9(3)	1,667	800	364	370.4	177.8	104.0	107.7	51.7	23.5
	40	41,667	20,000	9,091	58(24)	28(12)	13(6)	3,333	1,600	727	740.7	355.6	207.7	160.0	76.8	34.9
	80	41,667	20,000	9,091	116(39)	56(19)	26(9)	6,667	3,200	1,455	1,481.6	711.1	415.7	264.9	127.2	57.8
150	5	125,000	60,000	27,273	50(18)	24(9)	11(4)	1,250	600	273	277.8	133.3	78.0	15.81	75.9	34.5
	10	125,000	60,000	27,273	70(25)	34(12)	16(6)	2,500	1,200	546	555.6	266.7	156.0	213.1	102.3	46.5
	20	125,000	60,000	27,273	116(39)	56(19)	26(9)	5,000	2,400	1,091	1,111.1	533.3	311.7	323.1	155.1	70.5
	40	125,000	60,000	27,273	174(70)	84(16)	38(16)	10,000	4,800	2,182	2,222.2	1,066.7	623.4	479.9	230.3	104.7
	80	125,000	60,000	27,273	350(116)	167(56)	76(26)	20,000	9,600	4,364	4,444.4	2,133.3	1,246.9	794.8	381.5	173.4

* 360 days per year.
† Based on fuel use of 4.5 mpg for 1,200 and 2,500 gal trucks, and 3.5 mpg for 5,500 gal truck.
\# Based on truck operating hours plus 10 percent.
** Allows average of 2 hours per day for maintenance.
Metric conversions: 1 M gal - 3.78 mil l; 1 mile = 1.609 km; 1 gal = 3.78 l.

Table 14-2. Truck Operation Summary, Dewatered Sludge (Ettlich, 1976)

Annual Sludge Volume 1,000 cu yd	One-Way Distance Miles	Trips Per Year			Trucks Needed* 8 Hours/Day Operation (24 Hours/Day Operation)**			Truck Use 1,000 Miles/Year			Truck Fuel† 1,000 gal/Year			Truck Operators# 1,000 Man-Hours/Year		
		10 cu yd	15 cu yd	30 cu yd	10 cu yd	15 cu yd	30 cu yd	10 cu yd	15 cu yd	30 cu yd	10 cu yd	15 cu yd	30 cu yd	10 cu yd	15 cu yd	30 cu yd
1.5	5	150	100	50	1(1)	1(1)	1(1)	1.5	1	0.5	0.3	0.2	0.2	0.2	0.1	0.1
	10	150	100	50	1(1)	1(1)	1(1)	3	2	1	0.7	0.4	0.3	0.3	0.2	0.1
	20	150	100	50	1(1)	1(1)	1(1)	6	4	2	1.3	0.9	0.6	0.5	0.3	0.1
	40	150	100	50	1(1)	1(1)	1(1)	12	8	4	2.7	1.8	1.1	0.7	0.4	0.2
	80	150	100	50	1(1)	1(1)	1(1)	24	16	8	5.3	3.6	2.3	1.2	0.6	0.3
5	5	500	333	167	1(1)	1(1)	1(1)	5	3	2	1.1	0.7	0.6	0.6	0.4	0.2
	10	500	333	167	1(1)	1(1)	1(1)	10	7	3	2.2	1.6	0.9	0.9	0.6	0.3
	20	500	333	167	1(1)	1(1)	1(1)	20	13	7	4.4	2.9	2.0	1.3	0.9	0.4
	40	500	333	167	1(1)	1(1)	1(1)	40	27	13	8.9	4.0	3.7	1.9	1.3	0.6
	80	500	333	167	1(1)	1(1)	1(1)	80	53	27	17.8	11.8	7.7	3.2	1.1	1.1
15	5	1,500	1,000	500	1(1)	1(1)	1(1)	15	10	5	3.3	1.2	1.4	12.9	1.3	0.6
	10	1,500	1,000	500	1(1)	1(1)	1(1)	30	20	10	6.7	4.4	2.9	2.6	1.7	0.9
	20	1,500	1,000	500	2(1)	1(1)	1(1)	60	40	20	13.3	8.9	5.7	3.9	2.6	1.3
	40	1,500	1,000	500	3(1)	2(1)	1(1)	120	80	40	26.7	17.8	11.4	5.8	3.8	1.9
	80	1,500	1,000	500	5(2)	3(1)	1(1)	240	160	80	53.3	33.6	22.9	9.5	4.4	3.2
50	5	5,000	3,333	1,667	2(1)	2(1)	1(1)	50	33	17	11.1	7.3	4.9	6.3	4.2	2.1
	10	5,000	3,333	1,667	3(1)	2(1)	1(1)	100	67	33	22.2	14.9	9.4	8.5	5.7	2.8
	20	5,000	3,333	1,667	5(2)	4(2)	2(1)	200	133	67	44.4	19.6	19.1	12.9	8.6	4.3
	40	5,000	3,333	1,667	7(3)	5(2)	3(1)	400	267	133	88.9	59.3	38.0	19.2	12.8	6.4
	80	5,000	3,333	1,667	14(5)	10(4)	5(2)	800	533	267	177.8	118.4	76.3	31.8	11.2	10.6
150	5	15,000	10,000	5,000	6(3)	4(2)	2(1)	150	100	50	33.3	12.2	14.3	19.0	22.7	5.8
	10	15,000	10,000	5,000	9(3)	6(2)	3(1)	300	200	100	66.7	44.4	28.6	25.6	17.1	8.5
	20	15,000	10,000	5,000	14(5)	10(4)	5(2)	600	400	200	133.3	88.9	37.1	38.9	25.9	12.9
	40	15,000	10,000	5,000	21(9)	14(6)	7(3)	1,200	800	400	266.7	177.8	114.3	57.6	38.4	19.2
	80	15,000	10,000	5,000	42(42)	28(10)	4(5)	2,400	1,600	800	533.3	355.6	226.6	95.4	6.36	31.8

* 360 days per year.
† Based on fuelage of 4.5 mpg for 10 and 15 cu yd truck, and 3.5 mpg for 30 cu yd truck.
\# Based on truck operating hours plus 10 percent.
** Allows average of 2 hours per day for maintenance.
Metric conversions: 1 cu yd - 0.764 cu m; 1 mile = 1.609 km; 1 gal = 3.78 l.

Hauling Schedule

The operating schedule for sewage sludge hauling can be simple or very complex. An example of a simple hauling operation would be a case where all the sewage sludge generated each day is hauled to a reclamation site and discharged into a large capacity sewage sludge storage facility. In such a simple case, the designer can easily develop an operating schedule for sewage sludge hauling based on:

- Quantity of sewage sludge to be hauled.
- Average round-trip driving time required.
- Sewage sludge loading and unloading time required.
- Truck maintenance downtime.
- Estimated truck idle time and maintenance downtime.
- Haul truck capacity.
- Length of working shifts and number of laborers (e.g., drivers).
- Safety factor for contingencies (e.g., variations in sewage sludge quantity generated; impassible roads due to weather).

In contrast to the simple case described above, the development of a complex sewage sludge hauling schedule for an agricultural land application program may involve many privately owned sites. Such a program is complicated by the need to take into account the following additional factors:

- The variation in distance (driving time) from the treatment works to the privately owned farms accepting the sewage sludge.
- Existence or absence of sewage sludge storage capacity provided at the application sites.
- Weather, soil conditions, and cropping patterns that may significantly limit the number of days and locations for sewage sludge application at the sites.

An example of the large variations in sewage sludge hauling schedules for a complex agricultural land application program is shown in Table 14-3, which indicates the projected monthly sewage sludge distribution for the Madison, Wisconsin, "Metrogro" project. Table 14-3 shows that projected utilization is highest during the spring, summer, and fall months (e.g., April through October), whereas sludge is not applied during any of the winter months (December through March). The designer should provide for the necessary sewage sludge transport, application, equipment, and labor to handle the maximum sewage sludge distribution months. This heavy scheduling, however, then results in underutilization of equipment during the low demand distribution months, as well as the potential problem of shifting employees to other productive work. Some municipalities have supplemented their basic needs with private haulers during peak periods to help overcome this problem.

Table 14-3. Projected Monthly Sludge Distribution for Agricultural Sludge Utilization Program, Madison, Wisconsin (Taylor, 1994)

Month	% of Annual	Gal/Month (x 1000)	Gal/Day*
January	0	0	0
February	0	0	0
March	0	0	0
April	10.2	2,950	147,600
May	19.7	5,700	285,000
June	5.2	1,500	75,000
July	5.9	1,700	85,000
August	14.1	4,100	205,000
September	17.2	5,000	250,000
October	18.6	5,400	270,000
November	9.1	2,650	132,000
December	0	0	0

*Based on 20-day/month operation
Metric conversion: 1 gal = 3.78 L

Contract Hauling Considerations

Many municipalities, both large and small, use private contractors for hauling sewage sludge and sometimes for application of sewage sludge as well. For example, a contract operator transports, applies, and incorporates dewatered sewage sludge from the Atlantic Wastewater Treatment Plant in Virginia Beach, Virginia, to privately owned farmland. Incorporation is handled by the contractor because the farmers were not incorporating the sewage sludge promptly (Jacobs et al., 1993).

The economic feasibility of private contract hauling versus use of publicly owned vehicles and public employees should be analyzed for most new projects. If a private contractor is used, it is essential that a comprehensive contract be prepared that includes a total management plan and avoids municipality liability for mistakes made by the contractor. At a minimum, the contract should cover the following responsibilities:

- Liability and insurance for equipment and employees.
- Safety and public health protection procedures and requirements.
- Estimated sewage sludge quantities and handling procedures.
- Responsibility and methods for handling citizen complaints and other public relations.
- Procedures for accidents, spills, and violation notification and mitigation.

- Monitoring procedures, record keeping, and reporting requirements (see Chapter 13 for monitoring needs and Chapter 15 for recordkeeping and reporting required by the Part 503 regulation).
- Responsibility for obtaining and maintaining permits, licenses, and regulatory agency approvals.
- Standard legal provisions for non-performance relief, termination, etc.

In some instances, sewage sludge is hauled away from the treatment works or other facility generating or preparing sewage sludge by the user (e.g., farmer, commercial forest grower). Again, the municipality should obtain competent legal council to avoid potential liability due to negligence by the private user/hauler.

Additional Facilities Required for Hauling

Sewage sludge loading facilities at the treatment works or other sewage sludge facility should be placed in an accessible location. Depending on the type of sewage sludge being hauled, hoppers, conveyor belts, or pipelines will be needed to load the trucks. Vehicle storage and a maintenance/repair shop might be useful at the plant site. Equipment washdown facilities and parking should be nearby. Similar facilities for truck unloading and related activities may be necessary at the sewage sludge application site(s) and/or the sewage sludge storage facility.

14.2.3 Pipeline Transport

Generally, only liquid sewage sludge of 8 percent solids or less can be transported by pipeline (U.S. EPA, 1978). Sewage sludge with higher solids concentrations, however, have been pumped; for example, the city of Seattle, Washington has reportedly pumped sewage sludge containing up to 18 percent solids. Also, pipeline transport is not usually feasible if there are multiple, widely separated land application sites. Other important factors regarding pipeline transport include:

- Availability of land for sewage sludge application for projected long-term periods; if an application site has a short useful life, pipelines are not usually warranted.
- Sufficient sewage sludge volume to justify the high capital costs of a pipeline, pump station(s), and appurtenances. Generally, municipal sewage treatment plants sized below 19 million L/day (5 mgd) do not generate sufficient sewage sludge volume to justify pipeline transport unless the distance to the land application site is short, e.g., less than 3 km (2 mi).
- Existence of a relatively undeveloped and flat pipeline right-of-way alignment between the sewage treatment plant and the land application site. Constructing a new pipeline through developed residential/commercial areas or through hilly terrain is expensive.

If factors such as those listed above are favorable, transport of sewage sludge by pipeline often can be less expensive than truck transport per unit volume of sewage sludge.

14.2.3.1 Pipeline Design

The effect of solids concentration on sewage sludge flow characteristics is of fundamental importance in economically designing pipelines. Digested sewage sludge has been observed to exhibit both newtonian and plastic flow characteristics. Figure 14-3 shows the influence of sludge solids concentrations on minimum velocities required for full turbulent flow through a pipeline. The figure also indicates the frictional head loss and the range of velocities for economical transportation. Below approximately 5 percent solids, sewage sludge flow exhibits newtonian flow characteristics, whereas at concentrations above 5 percent, the flow begins to exhibit plastic flow characteristics. At a solids concentration below 5 percent, the economics of sewage sludge transport will resemble water transport costs with respect to frictional head loss and power requirements. The most cost-effective pipeline design usually assumes operation just within the upper limits for newtonian flow (approximately 5.5 percent solids) (Haug et al., 1977). An extensive discussion of head loss calculations and equations for sewage sludge pipelines and pumping can be found in Chapter 14 of the *Process Design Manual for Sludge Treatment and Disposal* (U.S. EPA, 1979).

Various pipeline materials are used for transporting sewage sludge, including steel, cast iron, concrete, fiberglass, and PVC. For long-distance, high-pressure sewage sludge pipelines, steel pipe is most commonly used. Corrosion can be a severe problem unless properly considered during design. External corrosion is a function of the pipe material and corrosion potential of the soil, and can be controlled by a suitable coating and/or cathodic protection system. Laboratory tests simulating several digested sewage sludge lines have indicated that with proper design, only moderate internal corrosion rates should be expected in long-distance pipelines conveying sewage sludge. If most of the grit and other abrasive materials are removed from the digested sewage sludge, wear due to friction is not a significant factor in pipeline design (U.S. EPA, 1979).

14.2.3.2 Pipeline Appurtenance Design

Commonly used sewage sludge pipeline appurtenances are discussed briefly below. More extensive discussion can be found in Chapter 14 of the *Process Design Manual for Sludge Treatment and Disposal* (U.S. EPA, 1979).

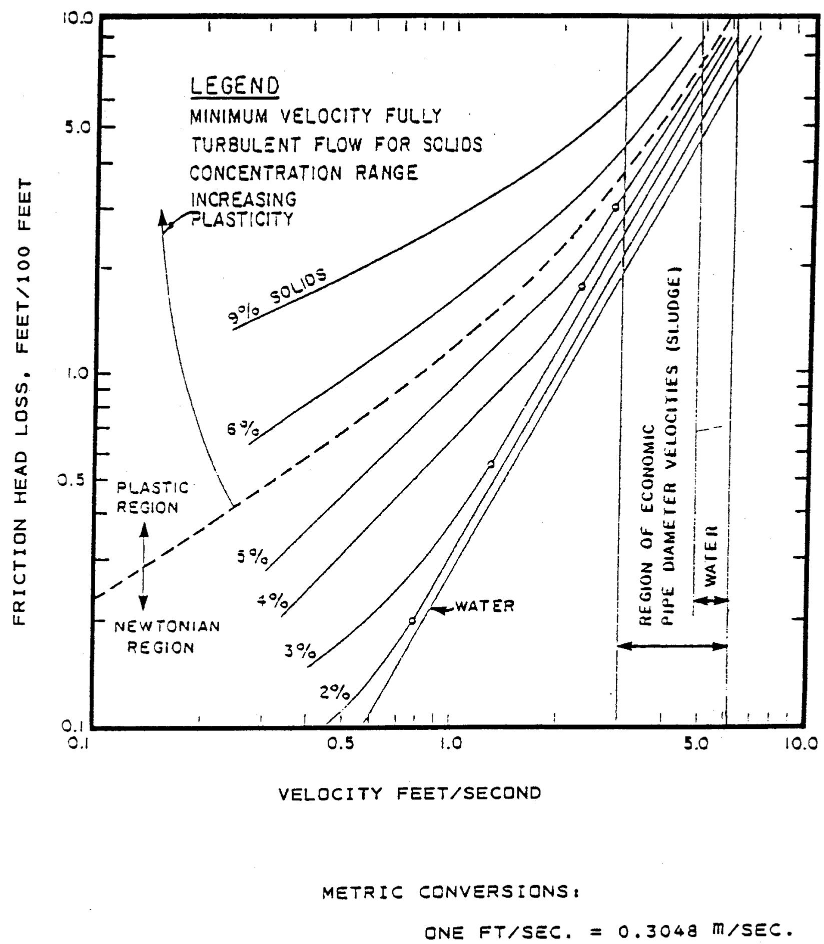

Figure 14-3. Hydraulic characteristics of sludge solids (U.S. EPA, 1977b).

Gauges

Pressure gauges are installed on the discharge side of all pumps. They also may be installed on the suction side of pumps for purposes of head determination. Protected, chemical-type gauges are generally used for sewage sludge pumping.

Sampling Provisions

Generally, 2.5 to 3.8 cm (1 to 1-1/2 in) sampling cocks with plug valves are provided either on the sewage sludge pump itself or in the pipe adjacent to the pump.

Cleanouts and Drains

Sewage sludge pipelines should include separate cleanouts and drains for easy clearance of obstructions. Blind flanges and cleanouts should be provided at all changes of direction of 45 degrees or more. Valved drains should be included at all low points in the pipeline, and pressure vacuum relief valves should be provided at all high points in the pipeline. Minimum size at cleanouts is 10 cm (4 in), with a 15 cm (6 in) size preferred for access of tools.

Hose Gates

A liberal number of hose gates should be installed in the piping, and an ample supply of flushing water under high pressure should be available for clearing stoppages.

Measuring Sewage Sludge Quantities

Pump running time totalizers provide a simple method of approximating the quantities of sewage sludge pumped. For more sophisticated measurement, Venturi meters, flow tubes, or magnetic meters with flushing provisions can be used. Sewage sludge meters should have provision for bypassing.

14.2.3.3 Pump Station Design

Pump stations used to pump sewage sludge through long-distance pipelines should be carefully designed by experienced engineers. This section is not intended to be a comprehensive guide to design of such stations, but rather highlights important design considerations and provides references for more extensive information. Important factors for designing long-distance sewage sludge pumping stations include:

- Characteristics of the sewage sludge (e.g., type, solids content, degree of stabilization, abrasive particle content, viscosity).
- The choice of variable versus constant speed pumps.
- Quantity of sewage sludge, and type and capacity of sewage sludge storage ahead of the pumps and at the pipeline terminus.
- Pressure that the pumps must overcome, including both pipeline friction loss and static (elevation difference) head.
- Anticipated pump station life.
- Need for future expansion of capacity (e.g., provision of space for future pumps, power supply, piping, etc.).
- Ease of operation and maintenance.
- Need for standby reliability (i.e., how long the pump station can be out of service for maintenance, power failure, etc., as determined by available storage, alternate means of transport, etc.).

The type of sewage sludge most easily pumped over long distances has the following characteristics: a solids content below 6 percent; good stabilization (i.e., relatively low in volatile solids); a low concentration of abrasive grit; and the absence of large particles and stringy material. Sewage sludge possessing other characteristics can be dealt with during design, but will normally result in increased construction, operation, and/or maintenance costs. In Arizona, a high-speed centrifugal pump is used to force dewatered sewage sludge (20 percent solids) and water into a pipe delivering the solids to the field. The sewage sludge is then reliquified to a solids content of 4 percent. The solids content of the sludge at this Arizona site can be adjusted by regulating the amount of water injected into the pump. The sewage sludge is then pumped to the application site through a system of fixed and movable pipes (Jacobs et al., 1993).

Maximum and minimum flow velocities are an important consideration in pipeline design. A comparison of variable versus constant speed pumps is important for determining the flow through a pipeline. Variable speed pumps allow for continuous operation and lower storage requirements. Although constant speed pumping will require more storage, it is usually more energy efficient for peak flow dampening by equalization. For sewage sludge transport, a flow rate of 1 m/s (3 ft/s) is a satisfactory value; slower rates can promote solids settling and decomposition, while higher rates can cause scouring and increase head loss. Since pipelines represent a significant investment and have long service lives, they should be sized to permit efficient operation under existing conditions and also provide adequate capacity for future growth.

The quantity of sewage sludge to be pumped determines the capacity of the pumps and the pump station. Capacity is measured by the maximum sewage sludge pumping rate required; therefore, it is desirable to provide as constant an output pumping rate as possible over long periods each day. Ideally, the pumps will withdraw the sewage sludge from a large volume storage facility (e.g., a digester) at a steady rate. If possible, avoid using small storage tanks that require the pumps to frequently start and stop. The storage facility supplying the pump with sewage sludge should have a liquid level higher than the elevation of the pump suction intake. Sewage sludge pumps work much more efficiently and reliably if they have a positive suction head.

The pressure that sewage sludge pumps must overcome is the elevation difference between the pump station and the highest point of the sewage sludge pipeline to the application site; also, friction loss exists in the pipe and fittings at the maximum sewage sludge pumping rate (when maximum pressure occurs). The elevation difference (static head) is fixed by the topography of the pipeline alignment. The head loss due to friction, however, will vary and can be expected to increase with time due to gradual deterioration of the pipeline, buildup of internal sewage sludge deposits, and other factors. The designer, therefore, should provide a safety factor in calculating total pressure loss due to friction in the pipe and fittings. An excellent discussion of sewage sludge pipeline head loss due to friction is found in Chapter 14 of the *Process Design Manual for Sludge Treatment and Disposal* (U.S. EPA, 1979).

Type and Number of Pumps

Various types of pumps are used to pump sewage sludge, including centrifugal, torque, plunger, piston, piston/hydraulic diaphragm, ejector, and air lift pumps. Table 14-4 presents a matrix that provides guidance regarding the suitability of each type of pump for handling different types of sewage sludge. Centrifugal pumps are commonly selected for long-distance sewage sludge pumping because they are more efficient (i.e., use less energy) and can develop high discharge pressures. Centrifugal pumps are generally not used for heavy, primary sewage sludge, however, because they cannot handle large or fibrous solids. See Chapter 14 in the *Process Design Manual for Sludge Treatment and Disposal* (U.S. EPA, 1979) for a more detailed description of pump types.

The number of pumps installed in a pump station will depend largely on the station capacity and the range in sewage sludge volumes to be pumped. It is customary to provide a total pumping capacity equal to the maximum expected inflow with at least one of the pumping units out of service. In stations handling small flows, two pumps are usually installed, with each pump capable of

Table 14-4. Use of Sewage Sludge Pumps (EPA, 1979)

	Miscellaneous Solids				Primary Sludges		Secondary Sludge				Digested Sludge		Lagooned Sludge		
									Thickened Sludge						
Pump Type	Screenings	Grit	Scum	Septage	Settled Sludge	Thickened Sludge	Trickling Filter	Activated Sludge	Float	Gravity	Mixed <6	Thickened <6	Wet <10	Dry <15	Comments
Centrifugal	1	1	1	1	1	2	4	4	0[a]	1	4	1	4	1	-[b]
Torque Flow	5	4	0	5	4	3	4	4	0[a]	4	4	3	3	0	-[b]; low efficiency
Plunger	0	0	4	4	4	4	4	1	1[c]	4	4	4[d]	4	0	Daily attention
Piston	1	1	1	1	1	1	3	3	3	3	3	3	3	0	High cost[e,f]
Progressive Cavity	4[g]	1	5	4[g]	5	5	5	5	5	5	4	5	5	5	-[h]
Piston/Hydraulic Diaphragm	0	0	0	2	3	3	3	3	3	3	3	3	3	0	
Diaphragm	4	0	4	4	5	5	5	5	5	5	5	4	3	0	
Rotary	0	0	0	0	1	1	1	3	3	3	3	3	3	0	High maintenance cost
Pneumatic Ejector	4[i]	4[i]	3	3	3	3	3	3	3	3	3	3	3	0	
Air Lift	0	2[j]	0	0	4	0	4	4	0	0	0	0	0	0	Low lift
Water	0	1[j]	0	0	0	0	0	0	0	0	0	0	0	0	Low lift

a Float may cause air binding.
b Varying quality and bead condition impairs positive flow control.
c Restricted to low flows.
d Maximum 15% solids.
e High discharge pressure only.
f Should be preceded by grinding.
g Large bore pumps may be used with in-line grinding.
h Requires special mechanical conditioning for dry sludge food.
i Batch pneumatic ejector type recommended.
j Short distance only.

Key:
0 - Unsuitable
1 - Use only under special circumstances
2 - Use with caution
3 - Suitable with limitations
4 - Suitable
5 - Best type to use

meeting the maximum inflow rate. For larger stations, the size and number of pumps should be selected so that the range of inflow can be met without starting and stopping pumps too frequently (Water Pollution Control Federation, 1981).

Unless the designer is certain that future pump station expansion will not be necessary, space, fittings, etc., should be provided in the pump station for future additional pumping capacity.

The design should assume that the pump station will occasionally be inoperative due to maintenance, power failure, etc. Sufficient storage capacity should be provided for sewage sludge, and/or standby power, to handle at least two days of pumping station shutdown. Emergency tank truck hauling by a private firm is one alternative that could be arranged in advance.

14.2.3.4 Decisionmaking Factors for Pipeline Transport

Major factors to consider in an initial evaluation of sewage sludge pipeline transport include:

- Lack of flexibility compared to truck transport. The pipeline has a fixed alignment and terminus. The land application site must have a sufficient useful life to justify the capital expense of the pipeline and pump station(s).
- Sufficient sewage sludge volume generation to justify the initial capital cost. If one or two tank trucks can do the job instead, truck transport will often be more cost-effective.
- Need to acquire pipeline right-of-way. Pipeline alignments that avoid right-of-way easement problems should be evaluated. Condemnation, when necessary, is expensive and time-consuming and may cause problems with community acceptance.

If pipeline transport is selected, the following factors should be considered when choosing pipeline routes.

Alternate Routes

Preliminary planning should be conducted to reduce the number of potential pipeline routes. Generally, one route will be clearly favorable over the others; however, due to unknown conditions, a certain amount of flexibility should be maintained until the final design is determined. Crossings can add significantly to the cost of the pipeline and complexity of construction. The shortest distance with the least elevation difference and fewest crossings should be the primary goal.

Pipeline Design

Pipeline friction losses should be minimized over the route of the pipeline since they contribute significantly to pumping requirements. Abrupt changes in slope and direction should be minimized. Depending on the nature of the sewage sludge and the characteristics of the soil, corrosion control features should be incorporated in the pipeline design. Frequently spaced isolation valves should be provided to allow shutdown during repair and in case of pipe failure.

Pumping Facilities

More than one pump station may be needed if the pipeline distance is long. The number of pump stations should be balanced with the size and number of pumps required to determine the most cost-effective combination. Pumps should be appropriate for the type of sewage sludge to be pumped, and standby pumping units must be provided.

Emergency Operation

Several days storage should be provided in case of equipment failure. Digesters can be used for this purpose, if available. Standby power should be provided if only one independent source of electricity to the pump stations is available. Additional storage may be substituted for standby power under certain conditions, although continuous operation is preferable.

Excavation Condition Verification

Field tests should be used to establish or verify the subsurface soil conditions. Borings should be taken after the pipeline route has been established but prior to final design. The field tests should be used to isolate areas where special design considerations are needed. If highly unusual localized conditions exist, they should be avoided, if possible, or additional field tests made.

Existing or planned underground utilities should be located and field-verified, if possible. If exact locations cannot be established, the contractor should be held responsible for locating them during construction.

Acquisition of Right-of-Way

Right-of-way easements must be acquired for pipelines on private property. This process should be initiated in the early stages of the project. The preferable method is to obtain access rights on easements owned or controlled by other utilities when possible, or to negotiate with landowners. Acquisition is a lengthy, complex procedure which should be avoided if possible.

14.2.4 Other Transport Methods

Rail car and barge transport are other possible methods for transporting sewage sludge. These methods are usually considered only by large cities for long-distance transport to land application sites. In Chicago, for example, sewage sludge has been dried to over 50 percent solids, barged, and then trucked to land application sites (Jacobs et al., 1993). For a detailed discussion of rail and barge transport, refer to Chapter 14 in the *Process Design Manual for Sludge Treatment and Disposal* (U.S. EPA, 1979).

14.3 Storage of Sewage Sludge

It is important to note that in the Part 503 regulation, an activity is considered storage if sewage sludge is placed on land for 2 years or less. If sewage sludge remains on land for longer than 2 years for final disposal, this land area is considered an active sewage sludge unit and the surface disposal requirements in Part 503 must be met, unless the sewage sludge preparer can demonstrate that the land on which the sewage sludge remains is not an active sewage sludge unit, as discussed in Part 503.20(b).

14.3.1 Storage Requirements

Sewage sludge storage is necessary to accommodate fluctuations in sewage sludge production rates, breakdowns in equipment, agricultural cropping patterns, and adverse weather conditions which prevent immediate application of sewage sludge to the land. Storage can potentially be provided at either the treatment plant, the land application site(s), or both. Chapter 15 in the *Process Design Manual for Sludge Treatment and Disposal* (U.S. EPA, 1979) presents methods for estimating sewage sludge storage capacity and describes various storage facilities.

14.3.2 Storage Capacity

Storage capacity associated with land application sites is based on the volume and characteristics of the sewage sludge and on climate considerations. In a 1993 study of 10 POTWs, most had extensive sewage sludge storage capacities or other systems in place (Jacobs et al., 1993). For example, a facility in Madison, Wisconsin, has a large storage lagoon system that will soon be replaced with new storage tanks capable of storing 6 months (18 million gallons) of sewage sludge. In Denver, Colorado, the Metro Wastewater Reclamation District (MWRD) currently composts about 10 percent of the sewage sludge it produces; while composting is more expensive than direct land application, the MWRD maintains the composting facilities to enhance the flexibility and reliability of the land application program (Jacobs et al., 1993).

Many states have regulations governing the provision of storage capacity for sewage sludge at land application sites, with requirements varying from state to state. Indiana, for example, requires storage with a minimum of 90-days capacity at land application sites; Michigan requires that field storage be less than 7 days unless the stored sludge is covered and a seepage barrier is provided; in Oklahoma, storage at a land application site is not permitted (U.S. EPA, 1990).

14.3.2.1 Effect of Sewage Sludge Volume and Characteristics on Storage Capacity

Storage capacity is primarily dependent on the amount of sewage sludge needed at the land application site and the volume of sludge received from the treatment works. Storage capacity should be large enough to handle the volume of sludge generated during the longest projected time interval between applications (Elliott et al., 1990) and may need to be larger depending on climatic factors (see below). For agricultural systems, the time period between applications can range from 3 months to a year, whereas time spans between applications to forest land may be greater than 1 year (Elliott et al., 1990).

The characteristics of sewage sludge also affect storage (e.g., liquid sludge might be stored in tanks, while sludge solids may be stockpiled). Sewage sludge characteristics vary with source, type of sewage sludge treatment, and retention time. Data on typical quantities and characteristics of sewage sludge produced from various treatment processes are presented in Chapter 4.

14.3.2.2 Climate Considerations for Evaluating Sewage Sludge Storage

The designer of a land application system should consider the following climatic factors:

- Historical precipitation and temperature records for the application site.
- Regulatory agency requirements pertinent to the land application of sewage sludge on frozen, snow-covered, and/or wet soil.
- Ability of the sewage sludge application equipment being used to operate on wet or frozen soil.
- Drainage characteristics of the application site and associated effects on the time required after precipitation for the soil to dry sufficiently to accommodate equipment.

If left uncovered, large volumes of sludge may be exposed to the elements during storage (Elliott et al., 1990). Therefore, precipitation volume (minus evaporation) must be added to the storage area required for sewage sludge. In addition, the Part 503 rule sets restrictions on the land application of certain types of sewage sludge to flooded, frozen, or snow-covered lands (see Chapter 3). Many states also have seasonal limits on land application of sewage sludge, which greatly influence storage requirements at land application sites. These limits generally forbid the application of sewage sludge to saturated ground, ice- or snow-covered ground, or during rainfall (U.S. EPA, 1990).

The effect on wet soils of heavy vehicle traffic transporting sludge from storage to application areas also should be considered. The weight of vehicles may damage the soil structure, increase the bulk density of soil, and decrease infiltration. These changes in the physical characteristics of soil may increase the potential for soil erosion and surface runoff (Lue-Hing et al., 1992).

The climatic considerations that affect sewage sludge storage capacity are greatly influenced by site-specific factors. A review of land application system designs in the United States indicates that sewage sludge storage capacity ranges from a minimum of 30 days in hot, dry climates up to 200 days in cold, wet climates.

EPA conducted a computer analysis of approximate storage requirements for wastewater-to-land application systems in the United States (Loehr et al., 1979), as shown in Figure 14-4. This information is included in this manual to show general regional variations in storage requirements due to climate. For most sewage sludge land application systems, the actual storage requirement will usually exceed the days shown in Figure 14-4.

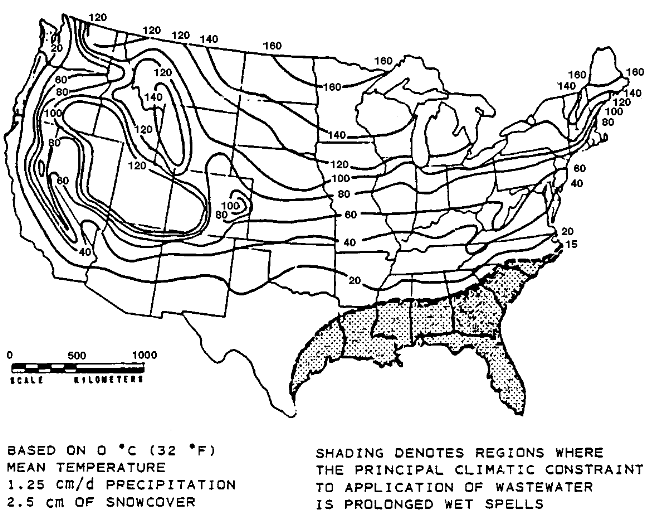

Figure 14-4. Storage days required as estimated from the use of the EPA-1 computer program for wastewater-to-land systems. Estimated storage based only on climatic factors.

14.3.2.3 Relationship Between Scheduling and Storage

The majority of existing land application systems in the United States are applying sewage sludge to privately owned land. This requires a flexible schedule to conform with local farming practices. Scheduling limitations will result from cropping patterns, and typically the designer will find that much of the agricultural land can only receive sewage sludge during a few months of the year. Applications of sewage sludge should be scheduled to accommodate the growing season of the selected plant species (Lue-Hing et al., 1992). The Madison, Wisconsin, program (Table 14-3), for example, applies over 80 percent of its sewage sludge to farmland during the 6-month period from May through October (Taylor, 1994).

Land application to forest sites should be scheduled to conform with tree grower operations and the annual growth-dormant cycle of the tree species. Land application at reclamation sites must be scheduled to conform with vegetative seeding and growth patterns and also with private landowners' operational schedules. At all of these types of sites, adequate storage capacity must be provided to accommodate the variability in scheduling.

14.3.2.4 Calculation of Sewage Sludge Storage Capacity Required

A simple method for estimating sewage sludge storage capacity required involves estimating the maximum number of days needed to store the volume of sewage sludge generated. The estimate of the maximum number of days is based on climate and scheduling considerations discussed in the previous subsections, as well as a safety factor. Often, the responsible regulatory agency will stipulate the minimum number of days of sewage sludge storage that must be provided. Calculations for this simple approach are shown below:

Assume:

1. Average rate of dry sewage sludge generated by POTW is 589 kg/day (1,300 lb/day).
2. Average sewage sludge contains 5 percent solids.
3. One hundred days storage to be provided.

Solution:

1. $\frac{589 \text{ kg/day}}{0.05}$ = 11,780 kg/day (26,000 lb/day) of liquid sewage sludge.
2. 11,780 kg/day = 11,780 L/day (3,116 gal/day) of liquid sewage sludge produced.
3. 11,788 L/day × 100 days = 1.2 million L (312,000 gal) of storage required.

A more sophisticated method for calculating sewage sludge storage requirements is to prepare a mass flow diagram of cumulative generation and projected cumulative application of sewage sludge to the land application site, as shown in Figure 14-5. The figure shows that the minimum sewage sludge storage requirement for this site is approximately 1.2×10^6 gal (4.54×10^6 L), which represents 84 days of sewage sludge storage volume. The project designer should increase the minimum storage requirement by a safety factor of 20 to 50 percent to cover years with unusual weather and other contingencies.

Even more accurate approaches can be used to calculate required sewage sludge storage volume. For example, if open lagoons are used for sewage sludge storage,

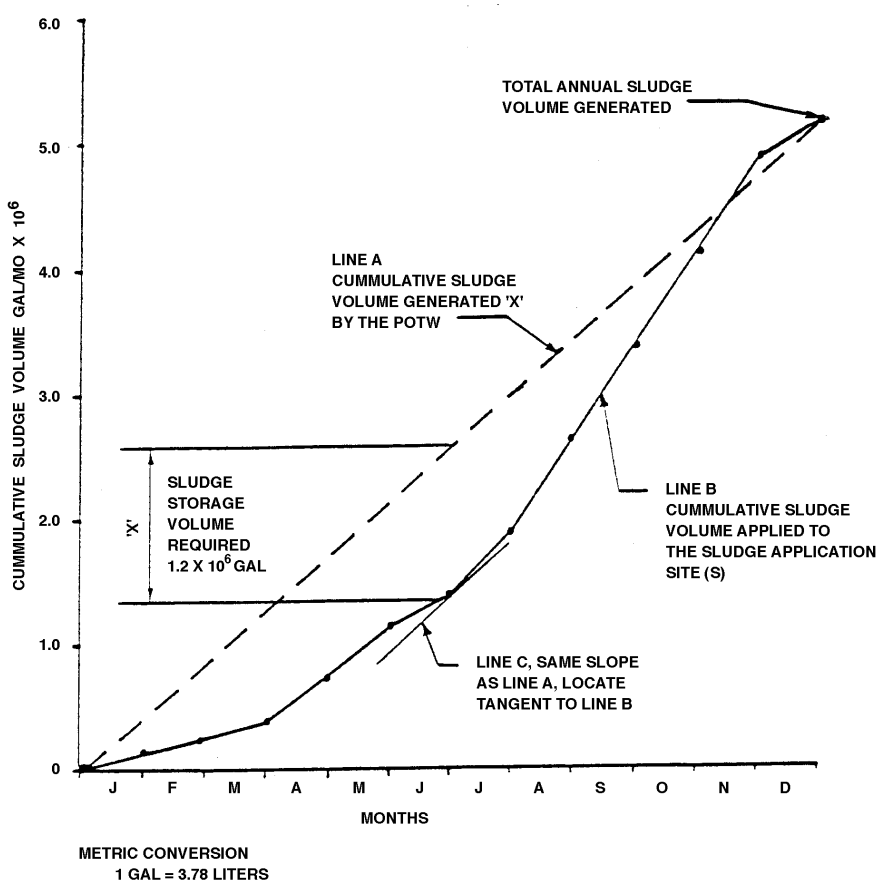

Figure 14-5. Example of mass flow diagram using cumulative generation and cumulative sludge application to estimate storage requirement.

the designer can calculate volume additions resulting from precipitation and volume subtractions resulting from evaporation from the storage lagoon surface.

14.3.3 Location of Storage

In general, the following factors should be considered when siting sewage sludge storage facilities:

- Maximize the use of potential storage in the existing sewage treatment plant units. If the treatment plant has aerobic or anaerobic digestion tanks, it is often possible to obtain several weeks storage capacity by separating the digester(s) to increase solids content and sewage sludge storage. In addition, older POTWs often have phased-out tanks, sewage sludge drying beds, and other areas that are idle and could be used for sewage sludge storage if properly modified.
- If possible, locate long-term sewage sludge storage facilities at the POTW site to take advantage of the proximity of operating personnel, ease of vandalism control, and the possibility of sewage sludge volume reduction, which will reduce transportation costs.
- Minimize the number of times the sewage sludge must be handled (e.g., transferred, stored) because costs are incurred each time handling occurs.

14.3.4 Storage Design

Storage capacity can be provided by:

- Stockpiles
- Lagoons
- Tanks, open top or enclosed
- Digesters

It is important to remember that if sewage sludge remains on land (e.g., in stockpiles or lagoons) for longer than 2 years, the surface disposal requirements in the Part 503 rule must be met. Chapter 15 of the EPA *Process Design Manual for Sludge Treatment and Disposal* (U.S. EPA, 1979) contains a comprehensive discussion of sewage sludge storage design options and applicable detention times for each type of storage structure (see Table 15-1 in that manual) and should be consulted for more details. The different types of storage systems are summarized below.

14.3.4.1 Stockpiles

Stockpiling involves the temporary storage of sewage sludge that has been stabilized and dewatered or dried to a concentration (about 20 to 60 percent solids) suitable for mounding with bulldozers or loaders. The sewage sludge is mounded into stockpiles 2 to 5 m (6 to 15 ft) high, depending on the quantity of sewage sludge and the available land area. Periodic turning of the sewage sludge helps to promote drying and maintain aerobic conditions. The process is most applicable in arid and semiarid regions, unless the stockpiles are covered to protect against rain. Enclosure of stockpiles may be necessary to control runoff.

14.3.4.2 Lagoons

Lagoons are often the least expensive way to store sewage sludge. With proper design, lagoon detention also provides additional stabilization of the sewage sludge and reduces pathogens.

14.3.4.3 Tanks

Various types of tanks can be used to store sewage sludge. In most cases, tanks are an integral part of sewage sludge treatment processes at a POTW, and the design for these processes usually includes storage capabilities. A mobile storage tank (nurse tank) in the field can serve as a buffer between the transportation and application of sewage sludge, allowing the operators to work somewhat independently of one another. The Madison, Wisconsin, program uses such a system and as a result has observed a 25 percent increase in its productivity (Jacobs et al., 1993). Liquid sewage sludge is transported at the Madison site using 5,500-gallon vacuum trucks that discharge the sewage sludge into a 12,000-gallon mobile storage tank located at the application site. A 3,500-gallon application vehicle withdraws sewage sludge from the storage tank and injects the sludge 6 to 8 inches beneath the soil surface. Two truckloads normally fill one storage tank and application vehicle (Jacobs et al., 1993).

14.3.4.4 Treatment Plant Digester Capacity

Many sewage treatment plants do not have separate sewage sludge retention capacity, but rely on portions of the digester volume for storage. When available, an unheated sewage sludge digester may provide short-term storage capacity. In anticipation of periods when sewage sludge cannot be applied to the land, digester supernatant withdrawals can be accelerated to provide storage of sewage sludge for several weeks.

14.4 Land Application Methods

14.4.1 Overview

The technique used to apply sewage sludge to the land can be influenced by the means used to transport the sludge from the treatment works to the land application site. Commonly used methods include:

- The same transport vehicle hauls the sewage sludge from the treatment works to the application site and applies the sewage sludge to land.
- One type of transport vehicle, usually with a large volume capacity, hauls sewage sludge from the treatment works to the application site. At the application site, the haul vehicle transfers the sewage sludge either to an application vehicle, into a storage facility, or both.
- Sewage sludge is pumped and transported by pipeline from the treatment works to a storage facility at the application site. Sewage sludge is subsequently transferred from the storage facility to an application vehicle.

Sewage sludge land application methods involve either surface or subsurface application. Each has advantages and disadvantages that are discussed in the following subsections. With all of the application techniques, the sewage sludge eventually become incorporated into the soil, either immediately by mechanical means or over time by natural means.

Sewage sludge is applied either in liquid or dewatered form. The methods and equipment used are different for land application of these two types of sewage sludge, and each has advantages and disadvantages that are highlighted below.

Regardless of the type of application system chosen at a land application site, attention must be paid to potential physical problems of the soil at the site. One study of sewage sludge land application programs determined that farmers who participate in such programs are very concerned about soil compaction (Jacobs et al., 1993). Programs in Wisconsin, Colorado, and Michigan using private farmland have found that attention to potential soil compaction as well as deep tilling the staging areas when land application is completed is important. Long-term working relationships with farmers have been enhanced in these programs by managing equipment and field applications to avoid soil compaction (Jacobs et al., 1993).

14.4.2 Application of Liquid Sewage Sludge

Application of sewage sludge to land in liquid form is relatively simple. Dewatering processes are not required, and the liquid sewage sludge can be readily pumped. Liquid sewage sludge application systems include:

- Vehicular surface application by:
  - Tank truck spreading, or
  - Tank wagon spreading
- Subsurface application by:
  - Subsurface injection, or
  - Plow furrow or disking methods
- Irrigation application by:
  - Spray application, or
  - Flood irrigation (gravity flooding)

14.4.2.1 Surface Application

Surface application of liquid sewage sludge involves spreading without subsequent incorporation into the soil. Surface application of sewage sludge has been shown to reduce nutrient and soil loss on no-till cropland that would otherwise occur through surface water runoff using other application methods. Surface application may also have similar benefits on conventionally tilled cropland (Elliott et al., 1990).

Vehicle Types Available

Table 14-5 describes the methods, characteristics, and limitations of applying liquid sewage sludge by surface application. Liquid sewage sludge can be spread on the soil surface using application vehicles equipped with splash plates, spray bars, or nozzles. Uniform application is the most important criterion in selecting which of the three attachments are best suited to an individual site. Figure 14-6 depicts a tank truck equipped with splash plates. Figure 14-7 depicts a tank truck with a rear-mounted “T” pipe. For these two methods, application rates can be controlled either by valving the manifold or by varying the speed of the truck. A much heavier application will be made from a full truck than from a nearly empty truck or wagon unless the speed of the truck or wagon advancing across the field is steadily decreased to compensate for the steadily decreasing hydraulic head (U.S. EPA, 1977). Figure 14-8 depicts a spray nozzle mounted on a tank truck. By spraying the liquid sewage sludge under pressure, a more uniform coverage is obtained.

Table 14-5. Surface Application Methods for Liquid Sewage Sludge (Cunningham and Northouse, 1981)

Method	Characteristics	Topographical and Seasonal Limitations
Tank truck	Capacity 500 to more than 2,000 gallons; flotation tires desirable; can be used with temporary irrigation set-up; can achieve a uniform application rate with pump discharge.	Tillable land; not usable at all times with row crops or on very wet ground.
Farm tank wagon	Capacity 500 to 3,000 gallons; wagon flotation tires desirable; can be used with temporary irrigation set-up; can achieve a uniform application rate with pump discharge.	Tillable land; not usable at all times with row crops or on very wet ground.

Metric conversion factor: 1 gal = 3.78 L

Hauling a full tank of sludge across the application site compacts the soil (Elliott et al., 1990). Conveyance of

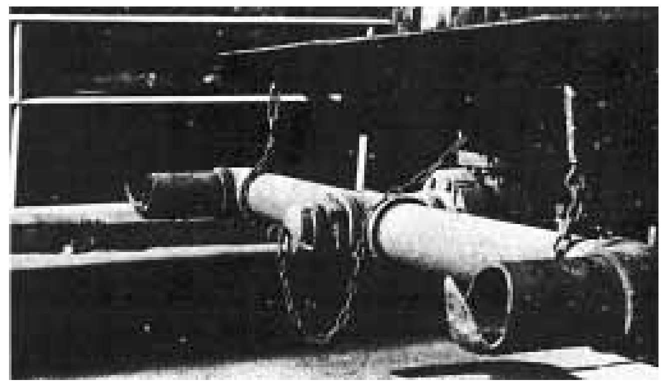

Figure 14-6. Splash plates on back of tanker truck (U.S. EPA, 1978).

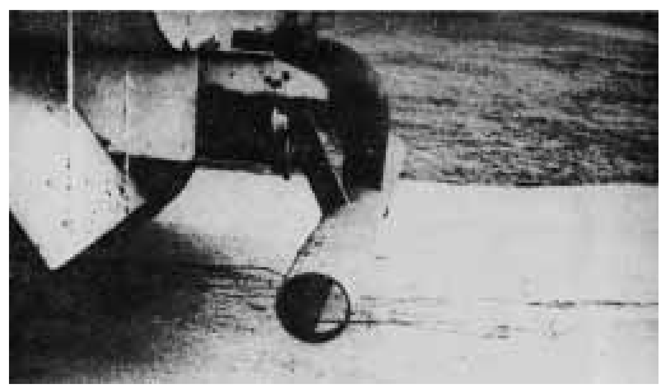

Figure 14-7. Slotted T-bar on back of tanker truck (U.S. EPA, 1978).

Figure 14-8. Tank truck with side spray nozzle for liquid sludge surface application (U.S. EPA, 1978).

the tank can be eliminated by using a travelling spray gun connected directly to the sludge delivery vehicle. Distribution and drift problems can be reduced by using a "traveling beam" with multiple sprinklers (Elliott et al., 1990).

14.4.2.2 Subsurface Application

Subsurface application of liquid sewage sludge involves either subsurface injection or subsurface incorporation using plow furrow or disking methods. One study found that the majority of 10 land application programs analyzed use subsurface injection or surface spreading followed by incorporation because these procedures have proven to be the most effective means of reducing odors and improving public acceptability of the program (Jacobs et al., 1993). Therefore, the study recommended the incorporation of sewage sludge into the soil at land application sites as soon as possible.

Subsurface injection or soil incorporation of liquid sewage sludge has a number of advantages over surface application, including:

- Potential health and nuisance problems generally can be avoided. The vector attraction reduction requirements of Part 503 can be met using these subsurface methods of land application when sewage sludge or domestic septage is applied to certain types of land (see Chapter 3).
- Nitrogen is conserved because ammonia volatilization is minimized.
- Public acceptance may be better.

Injection of sewage sludge beneath the soil places a barrier of earth between the sewage sludge and vectors such as flies or rodents that could transmit disease (U.S. EPA, 1992). In addition, when sewage sludge is injected, the soil quickly removes water from the sewage sludge, which reduces its mobility and odor (U.S. EPA, 1992). As a result, the requirements for vector attraction reduction in the Part 503 rule can be demonstrated for certain types of land by injecting the sewage sludge below the ground. Under this option, no significant amount of the sewage sludge can be present on the land surface within 1 hour after injection, and, if the sewage sludge is Class A with respect to pathogens, it must be injected within 8 hours after discharge from the pathogen-reduction process (see Chapter 3).

The requirements for vector attraction reduction under the Part 503 rule also can be demonstrated for certain types of land by incorporating sewage sludge applied to the land within 6 hours after application (see Chapter 3). If the sewage sludge is Class A with respect to pathogens, the time between processing and application must not exceed 8 hours. After application, the sewage sludge has to be incorporated into the soil within 6 hours. When applied at agronomic rates, the loading of sewage sludge solids typically is about 1/200th of the mass of soil in the plow layer. If mixing is reasonably good, the dilution of sewage sludge in the soil surface from incorporation is equivalent to that achieved with soil injection (U.S. EPA, 1992).

The 6 hours allowed in the regulation to complete the incorporation of sewage sludge into the soil should be adequate to allow for proper incorporation. As a practical matter, it may be wise to complete the incorporation in a much shorter time. Clay soils tend to become unmanageably slippery and muddy if the liquid sewage sludge is allowed to soak into the first inch or two of topsoil (U.S. EPA, 1992).

Some state requirements for the incorporation of sewage sludge once it is land applied may be more stringent than federal requirements. For example, Kentucky requires incorporation of sewage sludge within 2 hours of application for odor control (U.S. EPA, 1990).

Subsurface injection or soil incorporation of liquid sewage sludge also has potential disadvantages, however, compared to surface application of liquid sewage sludge, including:

- Potential difficulty in achieving even distribution of the sewage sludge.
- Higher fuel consumption costs.

Vehicle Types Available

Table 14-6 describes the methods, characteristics, and limitations of applying liquid sewage sludge by subsurface application. Figures 14-9 and 14-10 illustrate equipment specifically designed for subsurface injection of sewage sludge, which involves tank trucks with special injection equipment attached. Tanks for the trucks are generally available with 6,000, 7,500, and 11,000 L (1,600, 2,000, and 3,000 gal) capacities. Figure 14-11 shows another type of unit, a tractor with a rear-mounted injector unit; sewage sludge is pumped from a storage facility to the injector unit through a flexible hose attached to the tractor. Discharge flow capacities of 570 to 3,800 L/min (150 to 1,000 gal/min) are used. The tractor requires a power rating of 40 to 60 hp.

It is not usually necessary to inject liquid sewage sludge into the soil when the sludge is applied to existing pasture or hay fields; however, injection systems are available that can apply liquid sewage sludge to these areas with a minimum of crop and soil disturbance (see Figure 14-10).

Soil compaction problems still exist when using injectors. The use of a heavy tank in the field can be avoided by attaching injectors directly to a tractor tool bar. Sludge can then be pumped to the injectors from a storage area or nurse truck using an umbilical hose (Elliott et al., 1990).

Table 14-6. Subsurface Application Methods for Liquid Sewage Sludge (Keeney et al., 1975)

Method	Characteristics	Topographic and Seasonal Limitations
Flexible irrigation hose with plow or disk cover	Use with pipeline or tank truck with pressure discharge; hose connected to manifold on plow or disc.	Tillable land; not usable on very wet or frozen ground.
Tank truck with plow or disk cover	500-gallon commercial equipment available; sludge discharged in furrow ahead of plow or disk mounted on rear on four-wheel-drive truck.	Tillable land; not usable on very wet or frozen ground.
Farm tank wagon with plow or disk cover	Sludge discharged into furrow ahead of plow mounted on tank trailer; application of 170 to 225 wet Tons/acre; or sludge spread in narrow band on ground surface and immediately plowed under; application of 50 to 120 wet Tons/acre.	Tillable land; not usable on very wet or frozen ground.
Subsurface injection	Sludge discharged into channel opened by a chisel tool mounted on tank truck or tool bar; application rate 25 to 50 wet Tons/acre; vehicles should not traverse injected area for several days.	Tillable land; not usable on very wet or frozen ground.

Metric conversion factors: 1 gal = 3.78 L, 1 Ton/acre = 2.24 metric tons/hectare

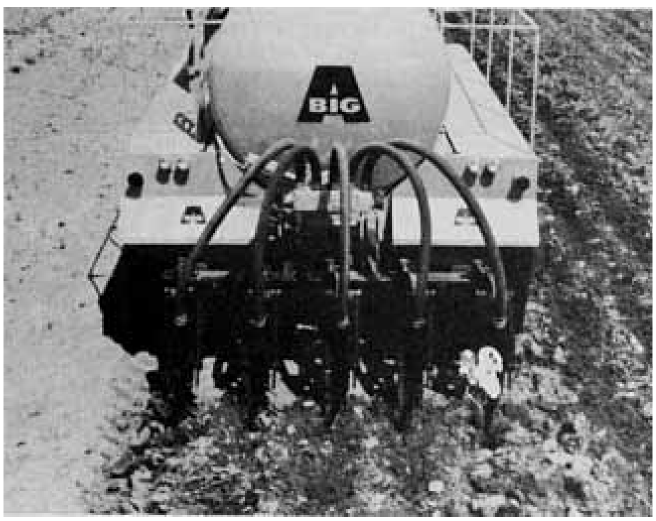

Figure 14-9. Tank truck with liquid sludge tillage injectors (courtesy of Rickel Manufacturing Company).

Figure 14-10. Tank truck with liquid sludge grassland injectors (courtesy of Rickel Manufacturing Company).

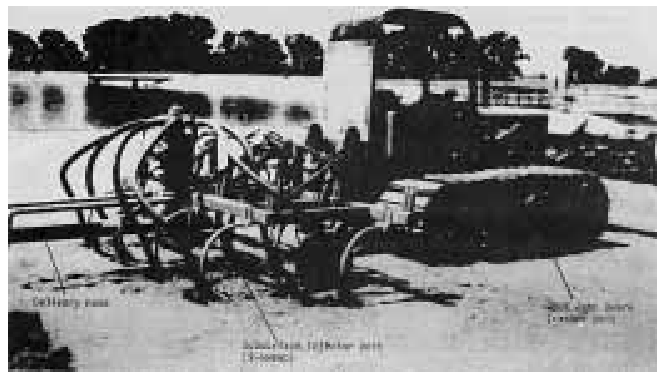

Figure 14-11. Tractor-pulled liquid sludge subsurface injection unit connected to delivery hose (courtesy of Briscoe Maphis Company).

An example of a land application program using injection is the Madison, Wisconsin, program. The sewage sludge injection vehicles used in this program have been modified by increasing the number of injection shanks to 6 per vehicle and by adding a drag behind the injectors to smooth the disturbed soil (Jacobs et al., 1993). Another example is an Arizona program in which sewage sludge is land applied with a tractor-mounted injector. The injectors are supplied with sludge through a hose connected to the pipe system. A second tractor pulls the hose out of the way as the injecting tractor traverses the application fields. Sewage sludge is injected in a triple crosshatch pattern for uniform distribution (Jacobs et al., 1993).

The plow or disk and cover method involves discharging the sewage sludge into a narrow furrow from a wagon or flexible hose linked to a storage facility through a manifold mounted on the plow or disk; the plow or disk then immediately covers the sewage sludge with soil. Figure 14-12 depicts a typical tank wagon with an attached plow. These systems seem to be best suited for high loading rates, i.e., a minimum of 3.5 to 4.5 t/ha (8 to 10 dry T/ac) of 5 percent slurry.

Figure 14-12a. Tank wagon with sweep shovel injectors (Cunningham and Northouse, 1981).

Figure 14-12b. Sweep shovel injectors with covering spoons mounted on tank wagon (Cunningham and Northouse, 1981).

14.4.2.3 Irrigation Application

Irrigation application of liquid sewage sludge has been accomplished using spray irrigation and flood irrigation. Spray irrigation has been used primarily for forest land applications; its usefulness for agricultural applications may be limited by cropping schedules and public acceptance (see Chapter 7). Flood irrigation of sewage sludge generally has not been successful and is usually discouraged by regulatory agencies.

Spray Irrigation

Spray irrigation has been used to disperse liquid sewage sludge on clearcut openings and in forest stands. Liquid sewage sludge is readily dispersed through spray systems if properly designed equipment is used. Solids must be relatively small and uniformly distributed throughout the sewage sludge to achieve uniform application and to avoid system clogging. A typical spray application system consists of the use of a rotary sprayer (rain gun) to disperse the liquid sewage sludge over the application site. The sludge, pressurized by a pump, is transferred from storage to the sprayer via a pipe system. Design of the system can be portable or permanent and either mobile or stationary. Available spray irrigation systems include (Loehr et al., 1979):

- Solid set, both buried and above ground
- Center pivot
- Side roll
- Continuous travel
- Towline laterals
- Stationary gun
- Traveling gun

The utility of these systems within the application site depends on the application schedule and management scheme utilized. All the systems listed, except for the buried solid system, are designed to be portable. Main lines for systems are usually permanently buried, providing protection from freezing weather and heavy vehicles.

The proper design of sewage sludge spray application systems requires thorough knowledge of the commercial equipment available and its adaptation for use with liquid sewage sludge. It is beyond the scope of this manual to present engineering design data for these systems, and it is suggested that qualified irrigation engineers and experienced irrigation system manufacturers be consulted.

Figures 14-13, 14-14, and 14-15 illustrate some of the spray systems listed above.

Flood Irrigation

In general, land application of sewage sludge by flood irrigation, also known as gravity flooding, has not been successful where attempted and is discouraged by regulatory agencies and experienced designers. Problems arise from (1) difficulty in achieving uniform sewage sludge application rates; (2) clogging of soil pores; and (3) tendency of the sewage sludge to turn septic, resulting in odors.

14.4.3 Application of Dewatered Sewage Sludge

Dewatered sewage sludge is applied to land by surface application techniques. The principal advantages of using dewatered sewage sludge are:

- Reduced sewage sludge hauling and storage costs.

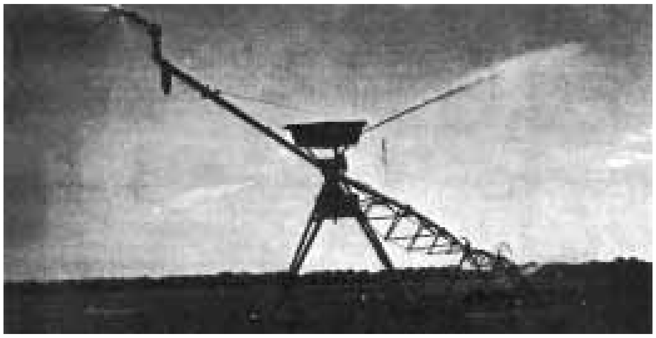

Figure 14-13. Center pivot spray application system (courtesy of Valmont Industries Inc.).

Figure 14-14. Traveling gun sludge sprayer (courtesy of Lindsay Manufacturing Company).

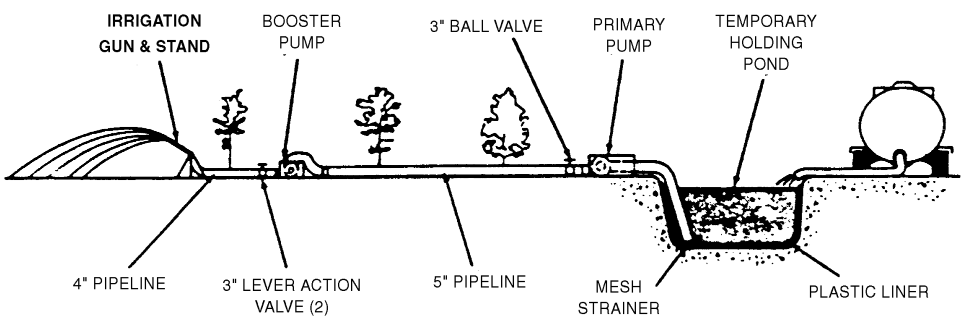

Figure 14-15. Diagram of liquid sludge spreading system in forest land utilizing temporary storage ponds (Water Pollution Control Federation, 1981).

- The ability to apply sewage sludge at higher application rates with one pass of the equipment.

Potential disadvantages of applying dewatered sewage sludge are:

- Generally, substantial modification of conventional spreading equipment is necessary to apply dewatered sludge.
- More operation and maintenance is generally incurred in equipment repairs compared to many liquid sewage sludge application systems.

Table 14-7 describes methods and equipment for applying dewatered sewage sludge to the land.

Table 14-7. Methods and Equipment for Application of Dewatered Semisolid and Solid Sludges

Method	Characteristics
Spreading	Truck-mounted or tractor-powered box spreader (commercially available); sludge spread evenly on ground; application rate controlled by PTD and/or over-the-ground speed; can be incorporated by disking or plowing.
Piles	Normally hauled by dump truck; spreading and leveling by bulldozer or grader needed to give uniform application.

14.4.3.1 Vehicle Types Available

Spreading of dewatered sewage sludge is similar to surface application of solid or semisolid fertilizers, lime, or animal manure. Dewatered sewage sludge cannot be pumped or sprayed. Spreading is done by box spreaders, bulldozers, loaders, or graders, and the sludge is then plowed or disked into the soil. The box spreader is most commonly used, with the other three equipment items generally being used only for sites with high sewage sludge application rates.

Figures 14-16 and 14-17 illustrate the specially designed trucks used to spread dewatered sewage sludge. For small quantities of dewatered sludge, conventional tractor-drawn farm manure spreaders may be adequate (Loehr et al., 1979). Surface spreading of dewatered sludge on tilled land usually is followed by incorporation of the sludge into the soil. It is not usually necessary to incorporate dewatered sludge into the soil when the sludge is applied to existing pasture or hay fields. Standard agricultural disks or other tillage equipment pulled by a tractor or bull dozer can incorporate the dewatered sludge into the soil, such as the disk tiller, disk plow, and disk harrow (Figures 14-18 and 14-19).

In Denver, Colorado, spreaders were custom-built to provide a more even application of dewatered sewage

Figure 14-16. A 7.2-cubic-yard dewatered sludge spreader (courtesy of Big Wheels Inc.).

Figure 14-17. Large dewatered sludge spreader (courtesy of BJ Manufacturing Company).

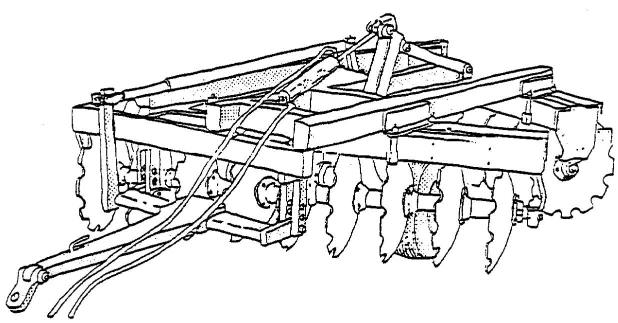

Figure 14-18. Example of a disk tiller.

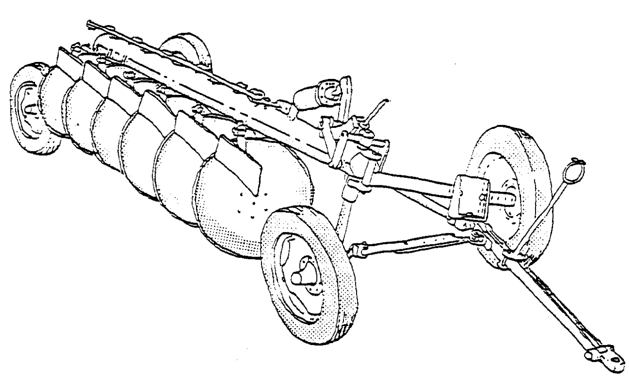

Figure 14-19. Example of a disk plow.

sludge than commercially available spreaders (Jacobs et al., 1993). The district's spreaders have a metering screw and gauge that allow the operator to achieve relatively even applications. In addition, the district installed a heating system on the spreader box, which allowed the sewage sludge to be spread during the winter months. Following surface application, the sewage sludge at the Denver site is incorporated into the soil by disking or plowing (Jacobs et al., 1993).

In Sparks, Nevada, dewatered sewage sludge is unloaded at the application site into a windrow at the edge of the spreading area. The sludge unloading area changes as the spreading area changes, thus avoiding the development of "hot spots" with extremely high sewage sludge loadings (Jacobs et al., 1993). From the windrow, a front-end loader places the sludge into a side-slinger manure spreader, which spreads the sludge onto the field. The same person operates the front-end loader and the spreader. Fields are spread in sections, with the length of a section determined by the distance required to empty a spreader; a spreader swath usually is approximately 80 feet wide by 200 feet long. The tractor to which the spreader is attached is equipped with hydraulic drive to facilitate speed changes. The side-slinger design enables the tractor and spreader to travel on ground that has not yet received sludge application, thus keeping the equipment clean. At the end of each day, the field is disked twice to completely cover the sewage sludge with soil (Jacobs et al., 1993).

14.5 Site Preparation

14.5.1 General

For agricultural land application systems where sewage sludge is applied to privately owned farms at low agronomic application rates, site modifications are not typically cost-effective. At forested systems, usually there is much more forest land available within the local area than is needed for sewage sludge land application, so unsuitable land can be avoided rather than modified. In the case of land application of sewage sludge at reclamation sites, extensive site grading and soil preparation often are necessary. These site preparation costs, however, are usually borne by the land owner (e.g., mining company, ore processor, etc.) and not by the municipality (see Chapter 9 for a discussion of land application of sewage sludge at reclamation sites).

14.5.2 Protection of Ground Water and Surface Water Quality

One of the major environmental tasks at a sewage sludge land application site is the prevention of surface and subsurface water contamination by constituents in sewage sludge. Nitrogen and phosphorus in surface waters and nitrate in ground water are usually the constituents of most concern. The Part 503 pollutant limits and agronomic rate requirement address these water quality concerns. Good management practices, such as incorporating or injecting sewage sludge, minimize the amount of sludge that can come into contact with rain, thus reducing potential water contamination (Lue-Hing et al., 1992). If runoff might occur from a land application site, the water quality of the runoff should be within acceptable limits, or the water can be detained in a holding structure and reapplied to land or treated (Lue-Hing et al., 1992). Ways to reduce potential water contamination include grading and erosion control, as discussed below.

14.5.3 Grading

The purpose of establishing surface grades is to ensure that runoff water and/or liquid sewage sludge do not pond. Design plans should emphasize that depressions can be filled with soil from adjoining ridges and mounds. If an excessive amount of filling is required for low areas, or if sufficient soil is not readily available, field ditches can be installed and the surfaces warped towards them. In areas with little or no slope, grades can be established or increased by grading between parallel ditches with cuts from the edge of one ditch and fills from the next.

Terraces may be needed to protect lower lands from surface water runoff that can cause soil erosion. Terraces generally are dug across a slope or at the toe of a slope, with the borrow material diked on the lower side for efficiency. Diversion terraces generally are graded and grass-covered so that the collected water may be delivered at non-erosive flows to a controlled discharge point.

A number of states have requirements for the maximum grade allowable at land application sites and for runoff control (U.S. EPA, 1990). Requirements for runoff control range from forbidding application on saturated ground, as in Mississippi, to specifying designs for runoff control systems (e.g., capacity for a 10-year, 1-hour storm), as in Texas.

14.5.4 Erosion Control

The measures used to prevent soil erosion include strip cropping, terraces, grassed waterways, and reduced tillage systems (e.g., chisel plowing, no-till planting). Strip cropping involves planting alternating strips (e.g., hay and corn) so that when one crop is harvested, soil erosion from the harvested strips is contained by the strips that remain vegetated. The strips are alternated periodically. The presence of vegetation and/or crop residues on the soil surface is effective in reducing runoff from steeply sloping soils. For many cropping systems (e.g., corn, soybeans, small grains), liquid sludge applied to the surface is incorporated into the soil by plowing or disking prior to crop planting, further reducing the potential for loss of sludge constituents via surface runoff. In essence, selection of the proper sludge application method (surface or incorporation) in conjunction with currently recommended practices for control of soil erosion will essentially eliminate the potential contamination of surface waters or adjacent lands by sewage sludge constituents.

Every land application site should be designed to minimize soil erosion. The MWRD in Denver, Colorado, for example, performs soil management practices recommended by the Department of Agriculture Natural Resources Conservation Service (NRCS) and the Consolidated Farm Service Agency (formerly Agriculture Stabilization and Conservation Service) to help reduce the potential for soil erosion. Information on proper slopes, effective conservation tillage, and wind erosion techniques for agricultural lands can be obtained from the NRCS.

14.6 Design of Supporting Facilities

The cost of supporting facilities, such as permanent all-weather access roads and fences, can usually be justified only for sites with high sewage sludge application rates that will be used over a long project life. These conditions rarely apply to privately owned agricultural land application sites.

14.6.1 Access Roads

A permanent road should be provided from the public road system to the land application site. For large sites, the roadway should be 6.5 to 8 m (20 to 24 ft) wide to allow for two-way traffic; for smaller sites, a 5 m (15 ft) wide road should suffice. To provide all-weather access, the roadway, at a minimum, should be gravel-surfaced, preferably with asphalt pavement. Grades should not exceed equipment limitations. For loaded vehicles, uphill grades should be less than 7 percent.

14.6.2 Public Access: Site Fencing and Security

Under the Part 503 rule, public access restrictions apply to land application sites where sewage sludge meeting Class B pathogen requirements is applied (see Chapter 3). Access to lands with a high potential for public exposure, such as parks or ballfields, must be restricted for 1 year after sewage sludge application. Examples of restricted access include remoteness, posting with "no trespassing" signs, and/or fencing. Access to land with a low potential for public exposure (e.g., private farmland) must be restricted for 30 days after sewage sludge application.

Depending on the topography and vegetation of the site and adjoining areas, entrance gates may suffice to prevent unauthorized vehicular access. At some sites, it will be necessary to construct peripheral fences to restrict trespassers and animals. Fencing requirements are influenced by the relative isolation of the site. Sites close to residences will require fencing. Facilities that are in relatively isolated, rural areas may require a less sophisticated type of fence or only fencing at the entrance and other select places to keep unauthorized vehicles out.

14.6.3 Equipment and Personnel Buildings

Application equipment and staging areas should be managed at land application facilities in ways that avoid compaction of soils receiving sewage sludge (Jacobs et al., 1993). Avoidance of potential compaction problems will enhance the long-term working relationship between a treatment works and crop producers.

At larger facilities, or where climates are extreme, buildings may be necessary for office space, equipment, and employees. Where land application sites are operated throughout the year, some protection from the elements for employees and equipment may be necessary. Sanitary facilities should be provided for both site and hauling personnel. At smaller facilities where buildings cannot be justified, trailers may be warranted.

14.6.4 Lighting and Other Utilities

If land application operations occur at night, portable lighting should be provided at the operating area. Lights may be affixed to haul vehicles and on-site equipment. These lights should be situated to provide illumination to areas not covered by the regular headlights of the vehicle. If the facility has structures (e.g., employee facilities, office buildings, equipment repair or storage sheds) or if the access road is in continuous use, permanent security lighting may be needed.

Larger sites may need electrical, water, communication, and sanitary services. Remote sites may have to extend existing services or use acceptable substitutes. Portable chemical toilets can be used to avoid the high cost of extending sewer lines; potable water may be trucked in; and an electrical generator may be used instead of having power lines run on-site.

Water should be available for drinking, dust control, washing mud from haul vehicles before entering public roads, and employee sanitary facilities. Telephone or radio communications may be necessary since accidents or spills can occur that necessitate the ability to respond to calls for assistance.

14.7 References

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Chapter 15
Management, Operational Considerations, and Recordkeeping and Reporting

15.1 Sewage Sludge Management Plans

In accordance with the Clean Water Act of 1987, EPA must include sludge requirements in NPDES permits to protect public health and the environment. To determine appropriate requirements for land application, EPA requests information from the applicant receiving a permit on current sewage sludge handling and use practices, and a 5-year sludge operating plan that describes an applicator's sludge marketing areas and planning procedures for new sites (U.S. EPA, 1993a). This Sludge Management Plan must be included with the permit application. In addition, the Plan acts as a blueprint for sludge activities (U.S. EPA, 1993a), and fulfills the requirement of 40 CFR Part 501 that both NPDES and non-NPDES entities prepare a land application plan for sewage sludge. The major elements of a Sludge Management Plan are summarized in Figure 15-1.

EPA will discuss current practices and new site operating procedures outlined in a Sludge Management Plan with personnel in state environmental programs and with the USDA Soil Conservation Service and/or State Extension Service in counties where sludge might be marketed as part of the permitting process (U.S. EPA, 1993a). Upon approval of a Sludge Management Plan by EPA, the plan becomes an enforceable part of the permit.

In addition to sludge management plans, all land application operation managers should prepare an operation program, with responsibility clearly defined for its implementation. Essential elements of the operation program include:

- Flexible scheduling of sludge transport, storage, and application activities to accommodate a treatment works need to remove sludge, as well as design needs for land application of the sludge to the site(s).
- Design, management, operation, and maintenance of the sludge transport system to minimize potential nuisance and health problems. The system should include a procedure for rapid response to accidents, spills, and other emergency conditions that may arise during routine sludge transport operations.
- Design, management, operation, and maintenance of the sludge application site(s) and equipment to minimize potential nuisance and health problems. Where privately owned and operated land is involved (e.g., farms, commercial forest land, mined lands), the owner/operator is a key participant in the overall application site management and operation program.
- Recordkeeping, including adequate documentation of program activities. See Section 15.6 for a discussion on recordkeeping at land application sites.
- Health and safety, including necessary, routine procedures for protecting the general public and operations personnel.

15.2 Part 503 Requirements Affecting Land Application Site Operation

Under the Part 503 regulation, Class B site restrictions must be met at land application sites where sewage sludge meeting Class B pathogen requirements is applied (U.S. EPA, 1994a). The Class B site restrictions in Part 503 include restrictions for harvesting crops and turf, grazing animals, and limiting public access to these sites. Figure 15-2 describes these restrictions, while Figure 15-3 includes examples of crops impacted by the Class B site restrictions. Also, see Chapter 3 for required Part 503 management practices.

15.3 Nuisance Issues

Minimizing adverse aesthetic impacts of a sewage sludge land application system will aid in maintaining public acceptance of the project. Conscientious housekeeping can help make the difference between public perception of the operation as a professional endeavor and public disapproval of the project. The following features reflect good housekeeping (Elliott et al., 1990):

- Well maintained, clean vehicles.
- Application and storage areas that are well kept, clean, and fenced, if necessary.
- Satisfied land owners.
- Well kept records.

As part of the NPDES permit application, submit to EPA a Sludge Management Plan (Plan). The Plan includes current sludge practices and a 5-year sludge operating plan as listed below.

A. A description of the permittee's sludge production and any current and known future land application sites.

B. A list of the counties (and states if applicable) where the permittee may want to market or distribute its sludge over the life of the permit (5 years minimum). A copy of the plan must be submitted to the respective State Health Department, and should be submitted to the State Extension Service Office in the counties where sludge may be marketed.

C. Site selection criteria to be used when identifying new land application sites.

D. Site management practices being followed relating to, at a minimum: floodplain, slope, depth to ground water, weather conditions, soil conditions (compaction, permeability, saturated, frozen, snow-covered), site access, and protection of surface waters, wetlands, endangered species, and underground drinking water sources at current sites; and operating procedures (e.g., qualified soils consultant, Soil Conservation Service, State Extension Service) for annual adjustments and for setting site management practices for future sites.

E. Buffer zones between sludge application sites and: surface waters, drinking water wells, drainage ditches, property lines, residences, schools, playgrounds, airports, public roadways, and any necessary site-specific buffer zones for current sites; and operating procedures (e.g., qualified soils consultant, Soil Conservation Service, State Extension Service) for making annual adjustments and for setting buffer zones for future sites.

F. Storage provision for sludge during periods when sludge cannot be land applied.

G. Either Part 503 pollutant concentration limits, or maximum acceptable total cumulative application rates, expressed as kilograms per hectare (kg/ha) (or annual application rates for bagged sewage sludge, kg/ha/yr), for arsenic, cadmium, chromium, copper, lead, mercury, molybdenum nickel, selenium, and zinc, and any other pollutants regulated by the Part 503 rule.

H. Maximum acceptable sludge application rate to assure that the amount of sludge applied does not exceed the nutrient requirements of the particular crop grown on the application site (agronomic rates) for current year crops, and operating procedures (e.g., by qualified soils consultant, Soil Conservation Service, State Extension Service) for making annual agronomic rate adjustments and for setting agronomic rates for future sites.

I. A description of the pathogen treatment, vector attraction control, record keeping, monitoring, certifications, and notifications as required by the 40 CFR Part 503 regulation.

J. Reference to applicable regulations (40 CFR Part 503) and procedures the permittee intends to use to ensure that the sludge practices and limits outlined are followed.

K. Information described in 40 CFR 501.15(2) (states may require additional information).

L. Public notice procedures and procedures for advanced notice to EPA (at least 60 days) of proposed new land application sites.

M. Procedures, or copies of documents specifying procedures (e.g., contracts) that will be used to ensure compliance with this permit and applicable regulations if the permittee contracts with others for assistance to select and/or manage the land application sites itself.

N. Contingency plans that describe sludge disposal options for any sludge which does not meet the requirements for land application or exceeds storage capacity.

O. A statement (e.g., city ordinance) that the permittee will comply with the Sludge Management Plan, as approved by EPA.

P. A statement that the Plan will be amended to reflect any applicable practices or limits EPA promulgates pursuant to Section 405 of the Act.

Figure 15-1. Sludge Management Plan (U.S. EPA, 1993a).

Restrictions for the harvesting of crops* and turf:

1. Food crops, feed crops, and fiber crops shall not be harvested until *30 days* after sewage sludge application.
2. Food crops with harvested parts that touch the sewage sludge/soil mixture and are totally above ground shall not be harvested until *14 months* after application of sewage sludge.
3. Food crops with harvested parts below the land surface where sewage sludge remains on the land surface for 4 months or longer prior to incorporation into the soil shall not be harvested until *20 months* after sewage sludge application.
4. Food crops with harvested parts below the land surface where sewage sludge remains on the land surface for less than 4 months prior to incorporation shall not be harvested until *38 months* after sewage sludge application.
5. Turf grown on land where sewage sludge is applied shall not be harvested until *1 year* after application of the sewage sludge when the harvested turf is placed on either land with a high potential for public exposure or a lawn, unless otherwise specified by the permitting authority.

Restriction for the grazing of animals:

1. Animals shall not be grazed on land until *30 days* after application of sewage sludge to the land.

Restrictions for public contact:

1. Access to land with a high potential for public exposure, such as a park or ballfield, is restricted for *1 year* after sewage sludge application. Examples of restricted access include posting with no trespassing signs, and fencing.
2. Access to land with a low potential for public exposure (e.g., private farmland) is restricted for *30 days* after sewage sludge application. An example of restricted access is remoteness.

*Examples of crops impacted by Class B pathogen requirements are listed in Figure 15-3.

Figure 15-2. Restrictions for the harvesting of crops and turf, grazing of animals, and public access on sites where Class B biosolids are applied.

Harvested Parts That:

Usually Do Not Touch the Soil/Sewage Sludge Mixture	Usually Touch the Soil/Surface	Are Below the Soil/Surface
Peaches	Melons	Potatoes
Apples	Strawberries	Yams
Oranges	Eggplant	Sweet Potatoes
Grapefruit	Squash	Rutabaga
Corn	Tomatoes	Peanuts
Wheat	Cucumbers	Onions
Oats	Celery	Leeks
Barley	Cabbage	Radishes
Cotton	Lettuce	Turnips
Soybeans		Beets

Figure 15-3. Examples of crops impacted by site restrictions for Class B sewage sludge (U.S. EPA, 1994a).

Continuous efforts should be made to avoid or reduce nuisance problems associated with sludge hauling, application, and related operations. Potential nuisances of concern include odor, spillage, mud, dust, noise, road deterioration, and increased local traffic, as discussed below.

15.3.1 Odor

All sludge management systems must consider objectionable odor as a potential problem. Objectionable odors could result in an unfavorable public reaction and reduced acceptance of land application practices.

It is important to note that when pathogen reduction and vector attraction reduction is achieved according to requirements specified in the Part 503 rule (see Chapter 3 for a complete discussion of these requirements), odor should not pose a problem at land application sites. For example, injection of sewage sludge beneath the soil (Option 9 for demonstrating reduced vector attraction of sewage sludge) places a barrier of earth between the sewage sludge and vectors. The soil quickly removes water from the sludge, which reduces the mobility and odor of the sewage sludge. Odor is usually present at the site during the injection process, but it quickly dissipates when injection is completed (U.S. EPA, 1992).

Potential for odors also can be reduced or eliminated by:

- Incorporation of sludge as soon as possible after delivery and application to the site.
- Daily cleaning (or more frequently, if needed) of trucks, tanks, and other equipment.
- Avoiding sludge application to waterlogged soils or when other soil or slope conditions would cause ponding or poor drainage of the applied sludge.
- Use of proper sludge application rates for application site conditions.
- Avoiding or limiting the construction and use of sludge storage facilities at the land application site, or designing and locating the sludge storage facilities in a way that prevents odor problems. Experience has shown that sludge storage facilities are a major cause of odor problems at land application sites.
- Isolation of the sludge application site from residential, commercial, and other public access areas.

Prevention of odor problems by using the recommendations listed above is important for public acceptance of land application programs. If odor problems resulting in citizen complaints do occur, the project management should have established procedures for correcting the problems and responding to complaints.

15.3.2 Spillage

All trucks involved in handling sludge on highways should be designed to prevent sludge spillage. Liquid sludge tankers generally do not present a problem. For sludge slurries (10 to 18 percent solids), specially designed haul vehicles with anti-spill baffles have been effectively employed. Sludge spillage on-site can generally be best controlled using vacuum transfer systems. If mechanical or human errors during transport or at the application site do result in spillage of sludge, cleanup procedures should be employed as soon as possible.

Major spills may result from traffic accidents, faulty or poorly maintained equipment, or inadequate storage facilities (Elliott et al., 1990). Major spills can be minimized by properly training drivers and applicators; locating application sites along well maintained roads; providing adequate storage for equipment so that it is not exposed to bad weather conditions; properly designing storage facilities; and regularly maintaining equipment (Elliott et al., 1990).

Small, minor spills should also be avoided. Minor spills can occur as hoses are uncoupled between a nurse truck and a tank wagon, when equipment is overfilled, when the seal on a dumptruck tailgate wears out, and numerous other situations (Elliott et al., 1990). Minor spills can be prevented with proper equipment maintenance and careful material handling.

15.3.3 Mud

Tracking of mud from the field onto highways, as well as field or access road rutting by sludge transport or applicator equipment are nuisance concerns. Mud can be a particularly severe problem in areas with poor drainage, but can occur at any site during periods of heavy rain or spring thaws. Choose all-weather site access roads or modify access roads with gravel or other acceptable weight-bearing material. To minimize problems with mud, the following management steps should be considered:

- Use vehicles with flotation tires.
- Use vehicles with smaller capacity, or temporarily reduce volume of sludge being hauled.
- Remove mud tracked on roads.
- Wash down vehicles regularly when moving between sites to prevent tracking of mud on highways. This process also improves the public image of sludge hauling and handling systems and enhances continued community acceptance.

15.3.4 Dust

Dust movement off-site increases with wind or movements of haul vehicles and equipment. To minimize dust generation, access roads may need to be graveled, paved, oiled, or watered.

15.3.5 Noise

Noise levels from use of heavy equipment (e.g., tractors, subsurface injector vehicles) at land application sites may be a concern in some communities. In agricultural areas, noise (and dust) should generally be no worse than expected from normal farming operations and should not create problems. In more populated areas, use of buffer zones and vegetative screening (trees and shrubs around the site) may be needed to mitigate public impact.

15.3.6 Road Maintenance

The breakup of roads by heavy sludge hauling vehicles can be a problem, particularly in northern climates, and can result in public complaints. Project management should have provisions to repair roads or a fund available to help finance cost of road repairs resulting from project activity.

15.3.7 Selection of Haul Routes

Routes for sludge haul trucks should avoid residential areas to prevent nuisance caused by truck and air brake noise, dangers to children, and complaints regarding frequency of hauling.

15.4 Safety Concerns

Managers of sewage sludge land application systems have an obligation to maintain safe and secure working conditions for all personnel and residents, including individuals working directly with the sludge (e.g., POTW personnel, sludge haulers, farmers, heavy equipment operators), as well as persons living or working near an application site or visiting the site. It is important that safety rules are written, published, distributed to all employees, and enforced. A safety training program, covering all aspects of site safety and proper equipment operation, as required by OSHA, should be conducted on a regular basis.

Safety features should be incorporated into every facet of the land application system design. Certain practices should be followed routinely to assure safe working conditions. The official operations program should contain specific safety guidelines for each operation and feature of the system.

The operation of sludge hauling and application equipment presents the greatest potential for accidents. Regular equipment maintenance and operational safety checks should be conducted.

The stability of the soil can present a potential safety problem, particularly when operating large equipment. Vehicles should approach disturbed or regraded sites, muddy areas, or steep slopes cautiously to prevent tipping or loss of control.

As with any construction activity, safety methods should be implemented in accordance with Occupational Safety and Health Administration (OSHA) guidelines. In accordance with OSHA guidelines, the following precautions and procedures should be employed for sludge land application projects:

- A safety manual should be available for use by employees, and all employees should be trained in all safety procedures.
- Appropriate personal safety devices, such as hardhats, gloves, safety glasses, and footwear, should be provided to employees.
- Appropriate safety devices, such as rollbars, seatbelts, audible reverse warning devices, and fire extinguishers, should be provided on equipment used to transport, spread, or incorporate sludge.
- Fire extinguishers should be provided for equipment and buildings.
- Communications equipment should be available onsite for emergency situations.
- Work areas and access roads should be well marked to avoid on-site vehicle mishaps.
- Adequate traffic control should be provided to promote an orderly traffic pattern to and from the land application site to maintain efficient operating conditions and avoid traffic jams on local highways.
- Public access to the sludge application site should be controlled. The extent of the control necessary will depend on the sludge application practice being used, the time interval since sludge was last applied, and other factors (see applicable process design chapters 7 through 9). In general, public access to application sites should be controlled during sludge application operations and for an appropriate time period after the sludge is applied.

15.4.1 Training

It is important for land application facilities to employ well trained personnel. Qualified personnel can be the difference between a well organized, efficient operation and a poor operation. New employees should not only learn the tasks required for their positions, but also understand the purposes and importance of the overall land application operation. Equipment should be operated only by fully trained and qualified operators.

A training program should be conducted for site personnel by the engineer who designed the land application program or someone well acquainted with the operation.

Training programs should incorporate the following (Elliott et al., 1990):

- All aspects of operation, from sludge production to growth of crops, should be discussed.
- Equipment operators should fulfill licensing requirements.
- Applicators should be taught to calculate application rates and calibrate equipment.
- Good housekeeping should be stressed during all phases of training.

15.5 Health Concerns

15.5.1 General

A discussion of pathogens and vectors that may be associated with sewage sludge is contained in Chapters 3 and 4. Although bacteria, viruses, and parasites are generally present in sewage sludge, the requirements in Subpart D of the Part 503 regulation protect public health and the environment through requirements designed to reduce the density of organisms in sewage sludge to below detectable levels, or, through a combination of organism reduction and site restrictions, allow the environment to further reduce organisms to below detectable levels (U.S. EPA, 1992).

In addition, research by EPA and others has shown no significant health problems for personnel who are in contact with sewage sludge on a regular basis at POTWs or land application sites (Burge and Marsh, 1978; Clark et al., 1980). Furthermore, epidemiological studies have shown no significant health problems for people living or working close to sites receiving land applied sewage sludge or wastewater (U.S. EPA, 1985; Kowal, 1983; Pahren et al., 1979).

15.5.2 Personnel Health Safeguards

It is recommended that project management include health safeguards for personnel involved with sludge transport and handling, including:

- Provide regular typhoid and tetanus inoculations and poliovirus and adenovirus vaccinations.
- Limit direct contact with aerosols as much as possible where liquid sludge application techniques are used.
- Encourage proper personal hygiene.
- Provide annual employee health checkups.
- Record reported employee illnesses; if a pattern (trend) of illnesses potentially associated with sludge pathogens develops, investigate and take appropriate action.

15.6 Recordkeeping and Reporting

15.6.1 General

The Part 503 regulation requires that certain records be kept by the person who *prepares* sewage sludge for land application and the person who *applies* sewage sludge to the land. The regulation defines the person who prepares sewage sludge as "either the person who generates sewage sludge during the treatment of domestic sewage in a treatment works or the person who derives a material from sewage sludge." This definition covers two types of operations—those that generate sewage sludge and those that take sewage sludge after it has been generated and change the quality of the sewage sludge (e.g., blend or mix it with another material) prior to use or disposal. Any time the sewage sludge quality (e.g., pollutant concentrations, pathogens levels, or vector attraction characteristics) is changed, the person responsible for the change is defined as a person who prepares sewage sludge. Recordkeeping requirements for preparers and appliers of sewage sludge are summarized in Table 15-1, and specific requirements are discussed in Sections 15.6.2 and 15.6.3. Dewatering sewage sludge is not considered to be changing the quality of the sewage sludge.

Preparers and appliers of sewage sludge should be aware that failure to keep adequate records is a violation of the Part 503 regulation and subject to administrative, civil, and/or criminal penalty under the Clean Water Act.

15.6.2 Part 503 Recordkeeping Requirements for Preparers of Sewage Sludge

Part 503 requires the person who prepares sewage sludge to evaluate sewage sludge quality, maintain records, submit compliance reports (for some preparers), and distribute sludge quality information to subsequent preparers and appliers who need the information to comply with the other requirements of the regulation. With respect to pollutants, the Part 503 regulation requires the preparer to maintain records documenting the concentration of regulated pollutants in the sewage sludge. With respect to pathogens and vector attraction, the records must describe how the pathogen and vector attraction reduction requirements were met (if one of the vector attraction reduction options 1 through 8 was met, see Chapter 3) and include a signed certification of their achievement. The regulation specifies that records be maintained for a period of at least 5 years.

U.S. EPA (1993b) presents a detailed discussion of the recordkeeping responsibilities for preparers of sewage sludge under Part 503.

Table 15-1. Part 503 Recordkeeping and Reporting Requirements (U.S. EPA, 1994a)

Type of Sewage Sludge	Records That Must Be Kept	Person Responsible for Recordkeeping: Preparer	Person Responsible for Recordkeeping: Applier	Records That Must Be Reported[a]
EQ Sewage Sludge	Pollutant concentrations	✔		✔
	Pathogen reduction certification and description	✔		✔
	Vector attraction reduction certification and description	✔		✔
PC Sewage Sludge	Pollutant concentrations	✔		✔
	Management practice certification and description		✔	
	Site restriction certification and description (where Class B pathogen requirements are met)		✔	
	Pathogen reduction certification and description	✔		✔
	Vector attraction reduction certification and description	✔	✔[b]	✔[c]
CPLR Sewage Sludge	Pollutant concentrations	✔		✔
	Management practice certification and description		✔	
	Site restriction certification and description (if Class B pathogen requirements are met)		✔	
	Pathogen reduction certification and description	✔		✔
	Vector attraction reduction certification and description	✔	✔[b]	✔[c]
	Other information:			
	- Certification and description of information gathered (information from the previous applier, landowner, or permitting authority regarding the existing cumulative pollutant load at the site from previous sewage sludge applications)		✔	✔[d]
	- Site location		✔	✔[d]
	- Number of hectares		✔	✔[d]
	- Amount of sewage sludge applied		✔	✔[d]
	- Cumulative amount of pollutant applied (including previous amounts)		✔	✔[d]
	- Date of application		✔	✔[d]
APLR Sewage Sludge	Pollutant concentrations	✔		✔
	Management practice certification and description	✔		✔
	Pathogen reduction certification and description	✔		✔
	Vector attraction reduction certification and description	✔		✔
	The AWSAR for the sewage sludge	✔		✔

[a] Reporting responsibilities are only for treatment works with a design flow rate equal to or greater than 1 mgd, treatment works that serve a population of 10,000 or greater, and Class I treatment works.
[b] The preparer certifies and describes vector attraction reduction methods other than injection and incorporation of sewage sludge into the soil. The applier certifies and describes injection or incorporation of sewage sludge into the soil.
[c] Records that certify and describe injection or incorporation of sewage sludge into the soil do not have to be reported.
[d] Some of this information has to be reported when 90 percent or more of any of the CPLRs is reached at a site, if the applier is a Class I treatment works, a treatment works serving a population of 10,000 or more, or a treatment works with a 1 mgd or greater design flow.

15.6.2.1 Records of Pollutant Concentrations

The preparer is responsible for documenting the sampling and analysis of pollutant concentrations in sewage sludge; to demonstrate this, the records outlined in Figure 15-4 should be maintained.

When sewage sludge or material derived from sewage sludge that is destined for land application does not meet the pollutant concentration limits in Chapter 3, Table 3-4, additional records must be kept to demonstrate compliance with either the cumulative pollutant loading rate limits or the annual pollutant loading rate limits outlined in Table 3-4, as appropriate.

If the preparer plans to sell or give away the sewage sludge in a bag or other container for application to the land, he or she must develop and retain the following additional records (if the sewage sludge does not meet "exceptional quality" criteria, as discussed in Chapter 3):

- Calculation of an annual whole sludge application rate (AWSAR) that will not exceed the annual pollutant loading rate limits in Chapter 3, Table 3-4.
- A copy of the label or information sheet provided to persons who will land apply the sewage sludge.

15.6.2.2 Certification of Pathogen Reduction

The Part 503 regulation requires the maintenance of records that include a certification by the preparer that the pathogen requirements were met and a description of how compliance was achieved. The general certification statement that must be used is provided in Figure 15-5. Usually, the description should explain the treatment process for pathogen reduction and be supported by analytical results for pathogens and indicator organisms and log books documenting operational parameters for sludge treatment units. The following paragraphs discuss the types of records used to demonstrate compliance for each pathogen reduction alternative. A discussion of Class A and Class B alternatives is provided in Chapter 3.

Class A Alternatives

Table 15-2 summarizes the recordkeeping requirements for each Class A alternative.

Alternative 1: Thermally Treated Sewage Sludge

This alternative requires that sludge treatment units be operated to maintain the sludge at a specific temperature for a specific period of time. To demonstrate compliance with the operational parameters, the preparer should check the temperature in the sludge treatment unit(s) and record it to demonstrate that the sludge was held at a constant temperature for the required number of days. If the temperature is not recorded continuously, it should be checked and recorded during each work shift or at least twice a day. The objective is to obtain temperature readings that are representative of the temperature maintained throughout the treatment process.

In addition, records should document the detention time of the sludge in the treatment unit, the daily input of sludge, and the withdrawal of supernatant and processed sludge from the treatment unit. The size (gallons) of the unit(s) should also be documented.

This alternative also requires documentation of monitoring for either *Salmonella* sp. bacteria or fecal coliform in sewage sludge at the time of use. To this end, the preparer should keep the records outlined in Figure 15-4 documenting sampling and analysis.

Parameters: Pollutant Concentrations (metals), *Salmonella* sp. or Fecal Coliform bacteria, Percent Solids, Enteric Viruses and Viable Helminth Ova (for certain pathogen reduction alternatives)

- **Sampling Records.** Date and time of sample collection, sampling location, sample type, sample volume, name of sampler, type of sample container, and methods of preservation, including cooling.
- **Analytical Records.** Date and time of sample analysis, name of analyst, and analytical methods used.
- **Raw Data.** Laboratory bench sheets indicating all raw data used in the analyses and the calculation of results (unless a contract laboratory performed the analyses for the preparer).
- Name of contract laboratory, if applicable.
- **QA/QC.** Sampling and analytical quality assurance/quality control (QA/QC) procedures.
- Analytical results expressed in dry weight.

Figure 15-4. Required Records for Preparers of Sewage Sludge to Document Sampling and Analysis (U.S. EPA, 1993b).

Alternative 2: Sewage Sludge Treated in a High pH-High Temperature Process

Alternative 2, like Alternative l, requires the analysis of sludge quality and the evaluation of operating parameters. As with Alternative 1, the sludge must be monitored for either *Salmonella* sp. bacteria or fecal coliform. Use of this alternative requires that operating logs be kept that document pH, temperature, residence time, and percent total solids. The temperature of the sewage sludge should be checked and recorded to document it is above 52°C for 12 continuous hours during the required 72-hour holding period. If the temperature is not continuously monitored, it should be checked hourly when feasible. At a minimum, it should be recorded at the beginning, middle, and end of treatment. Similarly, the pH of the sewage sludge should be recorded at the beginning, middle, and end of the required 72-hour holding period. The percent total solids also should be determined for each batch. The preparer must keep the records outlined in Figure 15-4 to document that sludge was analyzed at the time of use or disposal for either *Salmonella* sp. bacteria or fecal coliform at the frequency specified in Chapter 3, Table 3-15.

"I certify under penalty of law, that the *[insert each of the following requirements that are met: Class A or Class B pathogen requirements, vector attraction reduction requirements, management practices, site restrictions, requirements to obtain information]* in *[insert the appropriate section number/s in Part 503 for each requirement met]* have/have not been met. This determination has been made under my direction and supervision in accordance with the system designed to ensure that qualified personnel properly gather and evaluate the information used to determine that the requirements have been met. I am aware that there are significant penalties for false certification, including the possibility of fine and imprisonment."

Signature   Date

Note: The exact language of the certification should be tailored to accurately describe which requirements have been met and which have not been met, when applicable.

Figure 15-5. Certification statement required for recordkeeping.

Table 15-2. Recordkeeping Recommendations for Class A Pathogen Reduction Alternatives (U.S. EPA, 1993b)

Alternative A1—Time and Temperature	
• Analytical results for density of Salmonella sp. bacteria or fecal coliform (most probable number) • Sludge temperature (either continuous chart or two readings per day, at least one per shift) • Time (days, hours, minutes) temperature maintained	
Alternative A2—Alkaline Treatment	
• Analytical results for density of Salmonella sp. bacteria or fecal coliform (most probable number) • Sludge pH (beginning, middle, and end of treatment) • Time (hours) pH maintained above 12 (at least 72 hours) • Sludge temperature (beginning, middle, and end of treatment and hourly to demonstrate 12 hours above 52°C) • Percent solids in sludge after drying (at least 50 percent)	
Alternative A3—Analysis and Operation	
• Analytical results for density of Salmonella sp. bacteria or fecal coliform (most probable number) • Analytical results for density of enteric viruses (plaque forming unit/4 grams total solids) prior to pathogen reduction and, when appropriate, after treatment • Analytical results for density of viable helminth ova (number/4 grams total solids) prior to pathogen reduction and, when appropriate, after treatment • Values or ranges of values for operating parameters to indicate consistent pathogen reduction treatment	
Alternative A4—Analysis Only	
• Analytical results for density of Salmonella sp. bacteria or fecal coliform (most probable number) • Analytical results for density of enteric viruses (plaque forming unit/4 grams total solids) • Analytical results for density of viable helminth ova (number /4 grams total solids)	
Alternative A5—Processes to Further Reduce Pathogens (PFRP)	
• Heat Drying - Analytical results for density of Salmonella sp. bacteria or fecal coliform (most probable number) - Moisture content of dried sludge <10 percent - Logs documenting temperature of sludge particles or wet bulb temperature of exit gas exceeding 80°C (either continuous chart or two readings per day, at least one per shift) • Thermophilic Aerobic Digestion - Analytical results for density of Salmonella sp. bacteria or fecal coliform (most probable number) - Logs documenting temperature maintained at 55-60°C for 10 days (either continuous chart or two readings per day, at least one per shift) • Heat Treatment - Analytical results for density of Salmonella sp. bacteria or fecal coliform (most probable number) - Logs documenting sludge heated to temperatures greater than 180°C for 30 minutes (either continuous chart or three readings at 15 minute intervals) • Pasteurization - Analytical results for density of Salmonella sp. bacteria or fecal coliform (most probable number) - Temperature maintained at or above 70°C for at least 30 minutes (either continuous chart or two readings per day, at least one per shift)	• Composting - Analytical results for density of Salmonella sp. bacteria or fecal coliform (most probable number) - Description of composting method - Logs documenting temperature maintained at or above 55°C for 3 days if within vessel or static aerated pile composting method (either continuous chart or two readings per day, at least one per shift) - Logs documenting temperature maintained at or above 55°C for 15 days if windrow compost method (minimum of two readings per day, at least one per shift) - Logs documenting compost pile turned at least five times per day, if windrow compost method • Gamma Ray Irradiation - Analytical results for density of Salmonella sp. bacteria or fecal coliform (most probable number) - Gamma ray isotope used - Gamma ray dosage at least 1.0 megarad - Ambient room temperature log (either continuous chart or two readings per day, at least one per shift) • Beta Ray Irradiation - Analytical results for density of Salmonella sp. bacteria or fecal coliform (most probable number) - Beta ray dosage at least 1.0 megarad - Ambient room temperature log (either continuous chart or two readings, at least one per shift)
Alternative A6—PFRP Equivalent	
• Operating parameters or pathogen levels as necessary to demonstrate equivalency to the PFRP • Analytical results for density of Salmonella sp. bacteria or fecal coliform (most probable number)	

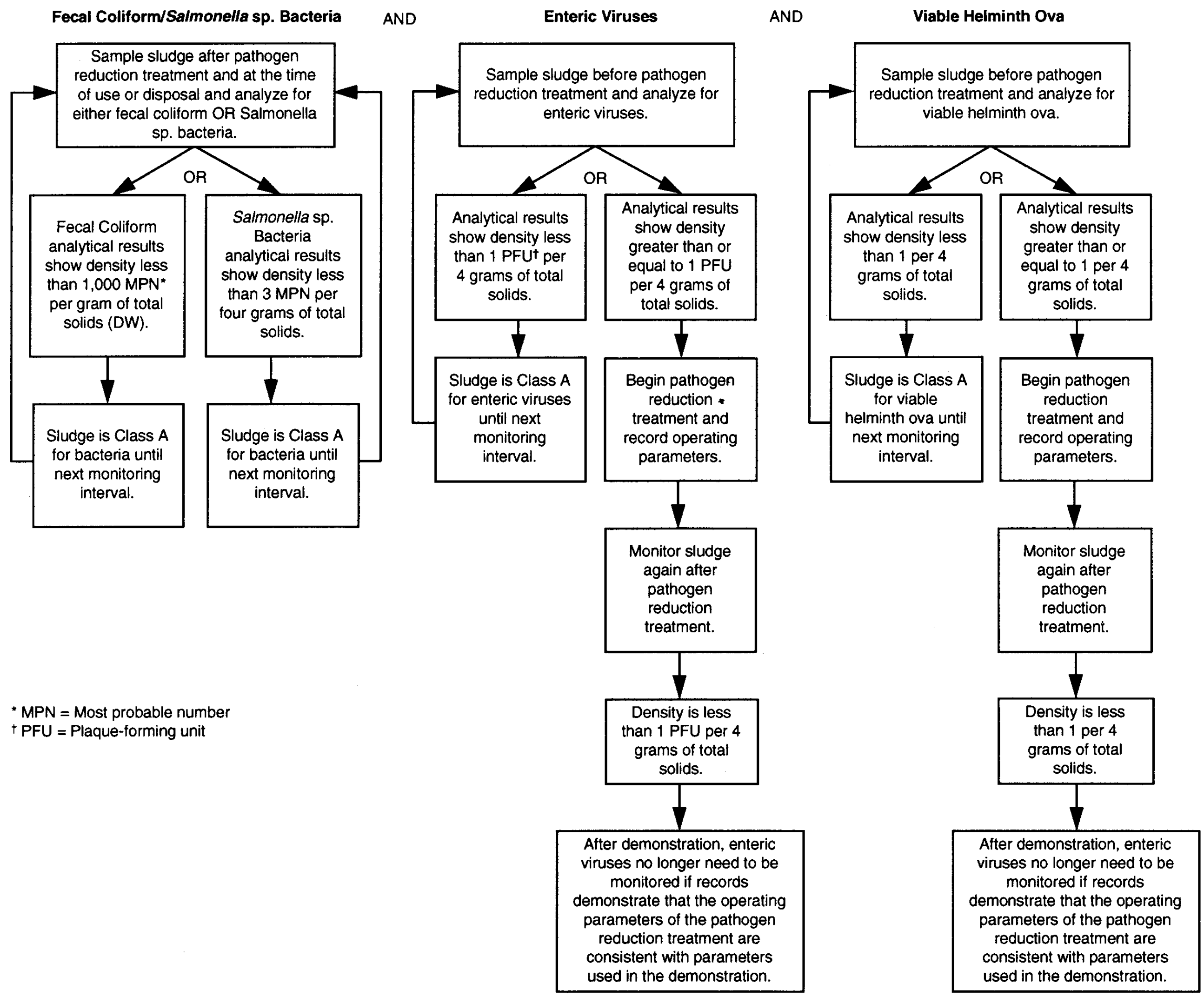

Figure 15-6. Pathogen reduction alternative 3—analysis and operation (U.S. EPA, 1993b).

Alternative 3: Sewage Sludge Treated in Other Processes

Alternative 3, like the first two alternatives under Class A, utilizes a combination of sludge quality analysis and documentation of operating parameters. In addition to monitoring for either fecal coliform or *Salmonella* sp. bacteria under this alternative, preparers must monitor for enteric viruses and viable helminth ova. If the preparer follows the steps outlined in Figure 15-6, he or she can substitute documentation of operating parameters for periodic analysis of enteric viruses and viable helminth ova (U.S. EPA, 1993b). Regardless of how the preparer demonstrates compliance with the enteric virus and viable helminth ova requirement, the final sludge must be sampled and analyzed at the time of use for either fecal coliform or *Salmonella* sp. bacteria according to the frequency specified in Chapter 3, Table 3-15.

The preparer must maintain the records outlined in Figure 15-4 to document sludge sampling and analysis before and after pathogen reduction treatment. These records also must define the values used for operating parameters between the before- and after-treatment sludge analyses. If operating parameters are substituted for periodic sludge monitoring, records must also document that these values are maintained consistently. The specific operating parameters that must be recorded to demonstrate compliance may vary depending on the particular pathogen reduction process used (e.g., composting, pasteurization).

Alternative 4: Sewage Sludge Treated in Unknown Processes

Alternative 4 relies solely on the analysis of sewage sludge for pathogens (i.e., *Salmonella* sp. bacteria, enteric viruses, and viable helminth ova) and indicator organisms (i.e., fecal coliform) to demonstrate pathogen reduction. Records must document that these parameters were sampled and analyzed at least as often as specified in the Part 503 regulation (see Chapter 3,

Table 3-15). The preparer should keep the records outlined in Figure 15-4 for each sampling event.

Alternative 5: Use of a Process to Further Reduce Pathogens (PFRP)

This alternative requires a combination of sludge analysis for either fecal coliform or *Salmonella* sp. bacteria and documentation of operating parameters. The specific operating parameters that must be evaluated are defined by the particular PFRPs. Table 15-2 outlines the seven different PFRPs and the specific operating parameters for each. Records should include a description of the pathogen reduction process, documentation of sampling and analysis of the sludge for fecal coliform or *Salmonella* sp. bacteria (see Figure 15-4), and log books documenting proper operation of pathogen reduction processes.

Alternative 6: Use of a Process Equivalent to a PFRP

Alternative 6 requires a combination of sludge analysis and documentation of operating parameters. As with the other Class A alternatives, the sludge must be monitored for either fecal coliform or *Salmonella* sp. bacteria. Alternative 6 requires sewage sludge to be treated in a process equivalent to a PFRP, as determined by the permitting authority. The permitting authority should indicate appropriate information that has to be kept. The records could include temperature in sludge treatment units, retention time, pH, solids or moisture content, and dissolved oxygen (DO) concentration.

Table 15-3. Recordkeeping Requirements for Class B Pathogen Reduction Alternatives (U.S. EPA, 1993b)

Alternative B1—Fecal Coliform Count
• Number of samples collected during each monitoring event • Analytical results for density of fecal coliform for each sample collected
Alternative B2—Processes to Significantly Reduce Pathogens (PSRP)
• Aerobic Digestion - Dissolved oxygen concentration - Mean residence time of sludge in digester - Logs showing temperature was maintained for sufficient period of time (ranging from 60 days at 15°C to 40 days at 20°C) (continuous charts or two readings per day, at least one per shift) • Air Drying - Description of drying bed design - Drying time in days - Daily average ambient temperature • Anaerobic Digestion - Mean residence time of sludge in digester (between 15 days at 35°C to 55°C and 60 days at 20°C) - Temperature logs of sludge in digester (continuous charts or two readings per day, at least one per shift) • Composting - Description of composting method - Daily temperature logs documenting sludge maintained at 40°C for 5 days (either continuous chart or two readings per day, at least one per shift) - Hourly readings showing temperature exceeded 55°C for 4 consecutive hours • Lime Stabilization - pH of sludge immediately and then 2 hours after addition of lime
Alternative B3—PSRP Equivalent
• Operating parameters or pathogen levels as necessary to demonstrate equivalency to PSRP

Class B Alternatives

Table 15-3 summarizes the recordkeeping requirements for each Class B alternative.

Alternative 1: Monitoring of Fecal Coliform

Alternative 1 requires the analysis of the sewage sludge for fecal coliform. In addition to maintaining the records outlined in Figure 15-4 to document compliance with the fecal coliform level, the preparer should maintain the calculation of the geometric mean of the seven samples analyzed under this alternative (see Alternative 1 in Chapter 3).

Alternative 2: Use of a Process to Significantly Reduce Pathogens (PSRP)

This alternative requires a combination of sewage sludge analysis and documentation of operating parameters. As with the PFRP alternative, the specific operating parameters that must be evaluated vary depending on the sludge treatment process used, as listed in Table 15-3. Records should include a description of the pathogen reduction process and log books documenting regular and frequent evaluations of the operating parameters.

Alternative 3: Use of a Process Equivalent to a PSRP

Alternative 3 requires sewage sludge to be treated in a process equivalent to a PSRP, as determined by the permitting authority. The permitting authority should have specified the appropriate records to demonstrate compliance with this alternative. The records could include temperature in sludge treatment units, retention time, pH, solids or moisture content, and DO concentration.

15.6.2.3 Records of Vector Attraction Reduction

When sewage sludge is land applied, the Part 503 regulation requires a certification (see Figure 15-5) that the vector attraction reduction requirements were met and a description of how these requirements were achieved. The description should be supported by documentation of process controls for treatment processes that achieve vector attraction reduction. As with the pollutant and pathogen records, this documentation must be kept for 5 years.

There are 10 options to comply with the vector attraction reduction requirements for land application. The first eight apply to the sewage sludge and are performed by the preparer (the final two are met at the land application site). These eight options are referred to as the sludge processing options and involve sludge treatment to reduce vector attraction characteristics. They are performed by preparers during or immediately after pathogen reduction. Each of these processing options is discussed in Chapter 3; the related records required are described below.

Option 1: Reduction in Volatile Solids Content

Under this option the preparer must demonstrate that the volatile solid concentrations in sewage sludge are reduced by 38 percent between the raw sludge and the sewage sludge that is used or disposed. The preparer needs to maintain records on the volatile solids content (mg/kg) of the raw sludge and the sewage sludge that is used or disposed, and the calculation of volatile solids reduction. While most preparers evaluate these parameters regularly to document constant process operation, records must show that volatile solids reduction was evaluated at least as frequently as specified in Table 3-15 in Chapter 3.

Option 2 and 3: Additional Digestion of Anaerobically and Aerobically Digested Sewage Sludge

Options 2 and 3 are methods to demonstrate that vector attraction reduction is achieved even though 38 percent volatile solids reduction was not attained (as required under Option 1). The following records demonstrate that options 2 and 3 are met:

- A description of the bench-scale digester and its operation.
- The time (days) that the previously digested sludge sample was further digested in the bench-scale digester.
- The temperature (degrees Celsius) maintained in the bench-scale digester for the time (days) the sample was being further digested; the temperature should either be recorded continuously or it should be checked and recorded during each work shift or during at least two well-spaced intervals during each day.
- Volatile solids concentration of the sewage sludge in mg/kg before and after bench-scale digestion.

Option 4: Specific Oxygen Uptake Rate (SOUR) for Aerobically Digested Sewage Sludge

The preparer should perform the SOUR test and record the following information to demonstrate compliance under this option:

- Dissolved Oxygen (DO) readings of the sludge taken at 1-minute intervals over a 15-minute period or until the DO is reduced to 1 mg/L, and the average DO value used in the SOUR calculation.
- Calibration records for the DO meter.
- Total solids determination for the sludge in g/L.
- Temperature (degrees Celsius) taken at the beginning and end of the procedure.

- Temperature correction to 20°C, if other temperatures are used.
- Calculation of SOUR using the following equation:

$$\text{SOUR} = \frac{\text{oxygen consumption rate per minute } \left(\frac{\text{DO mg/L}}{\text{min}}\right)}{\text{total solids (g/L)}} \text{ (60 min/hour)}$$

While most preparers evaluate this parameter regularly to document constant process operation, the records must demonstrate that the SOUR was evaluated at least as frequently as specified in Chapter 3, Table 3-15.

Option 5: Aerobic Processes at Greater Than 40°C

Under this option, the preparer should record the following information to demonstrate compliance:

- Sludge residence time.
- Temperature (degrees Celsius) of the sewage sludge; the temperature should either be recorded continuously or checked and recorded at least once per work shift or at least twice a day over a 14 day period.

Option 6: Addition of Alkali Material

The preparer should maintain the following records to document alkaline treatment under this option:

- pH (standard units) recorded at least at 0-, 2-, and 24-hour intervals of treatment.
- Duration of time (hours) that pH is maintained at or above specified minimum levels.
- Amount (pounds or gallons) of alkali material added.
- Amount of sludge treated (e.g., gallons, kilograms).

Options 7 and 8: Moisture Reduction

Under these options, the preparer should determine percent total solids for each batch of sludge and keep the following records to demonstrate compliance:

- Results of solids analysis of sewage sludge prior to mixing with other material (as dry weight) expressed as percent of final sludge.
- Presence of unstabilized solids generated during primary treatment.

Records should demonstrate that the analysis of percent total solids was performed at least as frequently as specified in Chapter 3, Table 3-15.

15.6.3 Part 503 Requirements for Appliers of Sewage Sludge

For Part 503 requirements for appliers of sewage sludge, see the *Land Application of Sewage Sludge—A Guide for Land Appliers on the Recordkeeping and Reporting Requirements of the Federal Standards for the Use and Disposal of Sewage Sludge Management in 40 CFR Part 503* (U.S. EPA, 1994b).

15.6.4 Notification Requirements for Preparers and Appliers of Sewage Sludge

When sewage sludge is prepared for land application in bulk form or sold or given away in a bag or other container for application to the land, the preparer must inform the applier of the sewage sludge quality. The notification requirements are different if the sludge is sold or given away in a bag or other container rather than being land applied in bulk, as described below. The notice and necessary information requirement does not apply when the sewage sludge or the material derived from sewage sludge meets the "exceptional quality criteria" discussed in Chapter 3.

15.6.4.1 Bulk Sewage Sludge

When bulk sewage sludge that is not "exceptional quality" is prepared for land application, both the preparer and the land applier have notification requirements. The preparer must provide the following sewage sludge quality information to the land applier:

- Pollutant concentrations.
- Nitrogen concentration (TKN, ammonia, and nitrate nitrogen).
- Pathogen reduction level achieved (Class A or Class B).
- Vector attraction reduction option used (Options 1-8).
- Required management practices and recordkeeping.

The land applier must have this information to comply with the Part 503 regulation when land applying the sewage sludge. If the pollutants do not meet the pollutant concentration limits in Chapter 3, Table 3-4, then the land applier must track the cumulative pollutant loading rates. If a Class B pathogen reduction alternative was used, then the land applier must ensure that the site restrictions are met. If the preparer did not perform one of the sludge processing vector attraction reduction options (Options 1-8), then the land applier must perform one of the sludge management vector attraction reduction options (Options 9-10).

The land applier is also responsible for providing the land owner or lease holder of the land notice and necessary information to comply with the Part 503 requirements. For example, if the sludge met Class B pathogen reduction requirements, then the land owner or lease holder must be informed of the associated site use and access restrictions. If the land applier is tracking the cumulative pollutant loading rates (see above paragraph), he or she should document and provide the land owner or lease holder with the following information:

- Location of land application site.

- Date bulk sewage sludge was applied.
- Time bulk sewage sludge was applied if vector attraction reduction option 9 or 10 was used.
- Number of hectares where the sewage sludge was applied.
- Amount of bulk sewage sludge applied.

Part II — To Be Completed by LAND APPLIERS of Sewage Sludge

A. If the pollutant levels in the sewage sludge do not meet the pollutant concentration limits in Table 3, then the land applier must record and retain the following information which should be given to the land owner.

1. Location of land application site ______
2. Number of hectares where the sludge was applied ______
3. Date and time bulk sewage sludge was applied ______
4. Amount of bulk sludge applied ______
5. Record the amount of each metal and nitrogen applied in pounds per acre or kilogram per hectare.

Units	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Molybdenum	Nickel	Selenium	Zinc	Nitrogen

B. If a Class B pathogen reduction alternative was used (see Part I), then the following site restrictions must be met. Please check the boxes if any of the site restrictions apply.

1. Food crops that may touch the sewage sludge/soil mixture cannot be harvested before the end of the following waiting period:
   - ☐ a. If harvested parts are totally above the land, wait to harvest for 14 months after the application of sludge.
   - ☐ b. If harvested parts are below the land surface and the sludge sat on top of the soil for 4 months before the field was plowed, wait to harvest for 20 months after the initial application of sludge.
   - ☐ c. If harvested parts are below the land surface and the sludge was incorporated into the soil within 4 months of being applied, wait to harvest for 38 months after the initial application.
2. ☐ Feed crops cannot be harvested for 30 days after application of the sludge.
3. ☐ Animals cannot graze on the land for 30 days after application of the sludge.
4. ☐ If harvested turf is used for a lawn or other purpose where there is a high potential for public exposure, then the turf cannot be harvested for 1 year after the application of the sludge to the land.
5. ☐ Public access to land with a high potential (parks, playgrounds, golf courses) for public exposure will be restricted for 1 year after the application of the sludge.
6. ☐ Public access to land with a low potential (private property, remote or restricted public lands) for public exposure will be restricted for 30 days after the application of the sludge.

C. If the preparer did not perform vector attraction reduction options (see Part I), then either option 9 or 10 must be performed by the land applier. Please indicate if option 9 or 10 was performed. Check appropriate box.

☐ Option 9—Subsurface Injection ☐ Option 10—Incorporated (plowed) into the Soil ☐ N/A

D. CERTIFICATION

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

A. Name and Official Title *(type or print)*	B. Area Code and Telephone Number
C. Signature	D. Date Signed

Figure 15-7. Notice and necessary information (U.S. EPA, 1993b)

- Cumulative amount of each pollutant (i.e., kilograms) applied.

The land owner or tenant may request specific information, such as analytical results on sludge quality or documentation on how sludge management practices are met. In general, the form in Figure 15-7 may be used to satisfy the notification requirements of both the preparer and the land applier.

15.6.4.2 Sewage Sludge Sold or Given Away in a Bag or Other Container for Application to the Land

When sewage sludge that does not meet the Part 503 pollutant concentration limits is sold or given away in a bag or other container for application to the land, it must be accompanied by a label or instruction sheet. The label or instruction sheet must contain the following information:

- Name and address of the person who prepared the sewage sludge.
- Statement that land application is prohibited except in accordance with the instructions.
- The annual whole sludge application rate that ensures that none of the annual pollutant loading rates in Chapter 3, Table 3-4, are exceeded.

15.6.5 Notice of Interstate Transport

When bulk sewage sludge that does not meet the "exceptional quality" criteria is going to be applied to land outside a state in which the sludge was prepared, the preparer is required to provide written notice to the permitting authority for the state in which the bulk sewage sludge is proposed to be applied, prior to the initial application of the sewage sludge to a site. The written notice must include the following information:

- Location, by either street address or latitude and longitude, of each land application site.
- Approximate time when bulk sewage sludge will be applied to the site.
- Name, address, telephone number, and National Pollutant Discharge Elimination System (NPDES) permit number for the person who prepares the bulk sewage sludge.
- Name, address, telephone number, and NPDES permit number for the person who will apply the bulk sewage sludge.

15.6.6 Notification by Appliers

The person who applies bulk sewage sludge subject to the cumulative pollutant loading rates in Part 503.13(b)(2) to the land must provide written notice to the permitting authority for the state in which the bulk sewage sludge will be applied, including:

- The location, by either street address or latitude and longitude, of the land application site.
- The name, address, telephone number, and NPDES permit number for the person who will apply the bulk sewage sludge.

15.6.7 Annual Reports

Most preparers are required by Part 503 to report annually to the permitting authority. Annual reports cover information and data collected during the calendar year (January 1 to December 31). Reports on sewage sludge quality must include the results of monitoring pollutant concentrations and pathogen levels, a description of operating parameters for pathogen reduction and vector attraction reduction, and certifications that pathogen and vector attraction reductions were achieved. Permits issued by EPA or a state may contain additional reporting requirements.

15.6.7.1 Persons Responsible for Submitting Reports Under Part 503

Persons responsible for reporting annually are described in the Part 503 regulation as:

- Publicly owned treatment works (POTW) with an average design influent flow rate equal to or greater than 1 million gallons per day.
- POTWs serving a population of 10,000 or more.
- Class I sludge management facilities.

Class I sludge management facilities include POTWs required to have an approved pretreatment program or that have elected to institute local limits, and treatment works processing domestic sewage that EPA or the state have classified as Class I because of the potential for the use of sewage sludge to negatively affect public health and the environment. Reports must be submitted to the permitting authority (either EPA or a state with an EPA-approved sludge management program).

15.6.7.2 Information Required in Annual Reports

The Part 503 regulation specifies the information preparers are required to keep in their records. This includes background information on the generation and use of sludge; the results of sludge quality analysis; and a description and certification for pathogen and vector attraction reduction requirements (see Figure 15-5).

Specific information to be contained in annual reports include the amount of sewage sludge generated, in metric tons expressed as a dry weight (see Appendix D for equations to convert sludge volume to metric tons); the name and address of the preparer who will receive the sludge next, if applicable; and the name and address of the land applier if different from the generator.

The reporting requirements for pollutant limits include submission of the analytical results from monitoring pollutant concentrations in the sewage sludge. Reports should include the results of all analyses performed during the reporting period using the prescribed analytical method(s) (see Chapter 13). Analytical results must be reported as milligrams per kilogram (dry weight). Reports should also indicate which analytical methods were used, how frequently sludge was monitored, and the types of samples collected.

Preparers also are required to submit a certification (see Figure 15-5) and description of how the pathogen reduction requirements were met. A detailed description of the pathogen reduction treatment process should include the type of process used, standard operating procedures, a schematic diagram, and should identify specific values for all operating parameters.

Finally, preparers are required to report information regarding vector attraction reduction when one of the sludge processing options (Option 1-8). The report must contain a description and certification (see Figure 15-5) that the vector attraction reduction requirements were met.

The general certification statement that must be used by preparers and appliers (Figure 15-5) certifies that, among other things, the preparer or applier and his or her employees are qualified to gather information and perform tasks as required by the Part 503 rule. A person is qualified if he or she has been sufficiently trained. The certifier should periodically check the performance of his or her employees to verify that the Part 503 requirements are being met. The preparer is required to keep these records for 5 years for sewage sludge meeting Part 503 pollutant concentration limits or annual pollutant loading rate limits, and the applier is required to keep records for the life of the site (indefinitely) for sewage sludge meeting Part 503 cumulative pollutant loading rate limits. These required records may be requested for review at any time by the permitting or enforcement authority.

15.6.7.3 Submitting Annual Reports

As of 1994, annual reports required under Part 503 are due February 19 every year. Annual reports must be submitted to the Permitting Authority, which is the EPA Regional Water Compliance Branch Chief until state sludge management programs are delegated the responsibilities of the federal program.

15.7 References

When an NTIS number is cited in a reference, that document is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-487-4650

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Clark, C. et al. 1980. Occupational hazards associated with sludge handling. In: Bitton, G. et al., eds. Health risks of land application. Ann Arbor Science, pp. 215-244.

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Kowal, N. 1983. An overview of public health effects. Presented at Workshop on the utilization of municipal wastewater and sludge on land, Denver, CO.

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U.S. EPA. 1993a. Biosolids management handbook for small to medium size POTWs. U.S. EPA Regions 8 and 10. (September 3).

U.S. EPA. 1993b. Preparing sewage sludge for land application or surface disposal: A guide for preparers of sewage sludge on the monitoring, record keeping, and reporting requirements of the federal standards for the use or disposal of sewage sludge, 40 CFR Part 503. EPA/831/B-93/002a. Washington, DC.

U.S. EPA. 1992. Control of pathogens and vector attraction in sewage sludge. EPA/625/R-92/013. Washington, DC.

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Chapter 16
Cost Estimate Guidance for Land Application Systems

16.1 Introduction

This chapter provides information on estimating costs for sewage sludge land application systems. The cost algorithms presented are taken from EPA's *Handbook: Estimating Sludge Management Costs* (U.S. EPA, 1985) and are updated using (1994) cost indexes. The costs presented in this chapter can be updated to later years by the reader using the appropriate cost indexes (discussed below). The algorithms cover both capital costs and annual operating and maintenance (O&M) costs for land application at agricultural, forest, and land reclamation sites, as well as for transportation (truck hauling and pipeline transport) of sewage sludge to land application sites and onsite.

Certain key sludge management costs are not included in this chapter, such as costs of sludge storage (e.g., lagoons, tanks, piles) and sludge treatment (e.g., stabilization, dewatering, composting). This information must be added to land application costs if total sludge management costs are to be accurately represented. The reader should refer to EPA's 1985 cost estimation handbook cited above for sludge treatment and storage cost information.

The cost estimation algorithms present a logical series of calculations using site-specific, process design, and cost data for deriving base capital and base annual operation and maintenance costs. Default values are provided for many calculations. Most of the algorithms can be hand-calculated in less than 20 minutes per trial. Design parameters presented are "typical values" intended to guide the user; the more accurate design information to which a user has access, the more accurate the resulting costs.

The cost algorithms generally cover a range up to 100 million gallons of sludge per year, which is approximately equivalent to a wastewater treatment plant of at least 50 mgd. This range was selected to include plants where supplemental cost information might be most useful.

16.1.1 Information Needed Prior to Using Cost Algorithms

Before using the cost algorithms in this chapter, the reader must obtain certain data and perform the preliminary steps described below; otherwise, the resulting cost estimates may be over- or underestimated.

- Develop a sludge management process chain that shows the sequence of processes to be used, starting with the raw sludge and ending with final land application practice.
- Develop a mass balance of sludge volume and sludge concentration entering and leaving each process. This is necessary because many of the cost algorithms in this chapter require as input data the volume and the suspended solids content of the sludge entering the process (which often is not the raw sludge solids concentration). Thus, an approximate mass balance must first be computed to obtain the sludge volume and sludge solids concentration entering and leaving each process (e.g., treatment).

The volume of raw sludge usually is not the same as the volume of final treated sludge leaving a treatment process, because each successive treatment process generally tends to reduce the mass and volume of sludge. Therefore, the mass and volume of the final treated sludge is typically only a fraction of the initial raw sludge volume. Similarly, the sludge solids concentration changes as the sludge proceeds through a series of treatment processes. The steps involved in performing a mass balance are described in EPA's 1985 cost handbook (U.S. EPA, 1985).

After completing the mass balance procedure, the reader may use the cost algorithms in this chapter to estimate the base capital cost and base annual O&M cost for different land application practices.

16.1.2 Economic Variables

16.1.2.1 Use of Indices for Inflation Adjustment

Numerous estimates of the costs of facility construction, site preparation, and equipment purchase were developed by the authors of EPA's 1985 cost handbook (U.S. EPA, 1985). The base year for these costs, however, was 1984; hence it is necessary to adjust these estimates to reflect 1994 price levels and costs. For construction-related costs, the standard index used is the

Engineering News Record Construction Cost Index (ENRCCI). The ratio of the 1994 to 1984 index number is used here to adjust construction-related cost items. For equipment purchase costs, the 1984 prices have been inflated using the Marshall and Swift Equipment Cost Index (MSECI). The ratio of the 1994 to 1984 index number is used here to adjust equipment-related cost items.

Adjustment for inflation can be made to the following cost algorithms using:

- The ENRCCI for total base capital costs and total base annual O&M costs. The ENRCCI appears weekly in *Engineering News Record*, published by McGraw Hill, Inc. (Base 1994 ENRCCI index is 5,445.83.)
- The MSECI to adjust equipment costs or combined costs in which equipment is the major cost component. MSECI is available from *Chemical Engineering* magazine. (Base 1994 MSECI index is 990.8.)

16.1.2.2 Labor Rates

The 1985 EPA cost handbook assumed an hourly wage of $13.00 for operators of heavy equipment which requires considerable skill and training. This rate has been inflated to 1994 levels using the ENRCCI index, and adjusted using a factor of 1.3 to account for non-wage benefits paid by the employer. The effective wage rate, therefore, is $22.97 per hour.

16.1.2.3 Cost of Diesel Fuel

Diesel fuel costs are assumed to average $1.09 per gallon, based on average end-user prices for 1994 obtained from the September 12, 1994 edition of *Oil and Gas Journal*.

16.1.3 Total Base Capital Cost Estimates

Total base capital costs (TBCC) for sewage sludge land application systems in this chapter include sludge application vehicles, lime addition, grading, brush clearance, facilities, and acreage required. Costs for engineering design, construction supervision, legal and administration expenses, interest during construction, and contingencies are not included. These non-construction costs must be estimated and added to the process TBCC costs derived from the cost algorithms to estimate the total project construction cost.

16.1.4 Total Annual O&M Cost Estimates

The annual O&M costs for sewage sludge land application in this chapter do not include costs for administration and laboratory sampling/analysis. These costs must be estimated and added to the process O&M costs derived from the cost algorithms to obtain the total estimated annual O&M cost. Total annual O&M costs can be 30 percent higher than the costs derived from the algorithms in this chapter.

The total estimated O&M cost calculations in this chapter also do not include revenues generated through the sale and/or use of sludge, composting products, or sludge by-products (i.e., methane produced in anaerobic digestion). If the user has information available on revenues generated through usage or sale, O&M costs may be decreased by subtracting any revenues generated on an annual basis from the fixed annual O&M cost for that process.

16.1.5 Calculating Cost Per Dry Ton

In sludge processing, it is often desirable to express costs in terms of annual cost per dry ton. This cost is obtained by summing the amortized capital cost and base annual O&M costs and dividing by the annual dry sludge solids processed (TDSS, as presented in Calculation #1 for agricultural, forest, and reclamation sites later in this chapter) and then performing the following calculation:

CPDT = (ACC + COSTOM)/TDSS

where:

CPDT	=	Cost per dry ton, $/ton.
ACC	=	Annual amortized capital cost, $/yr
COSTOM	=	Base annual O&M cost, $/yr.
TDSS	=	Dry solids applied to land, Tons/yr.

If information on salvage values and revenues generated from sludge usage is available, it can be subtracted from the numerator in the above equation.

16.2 Agricultural Land Application

16.2.1 General Information and Assumptions Made

The cost algorithms for agricultural land application of sewage sludge presented below assume that the sewage sludge application vehicles at the application site are *not* the same vehicles which transported the sludge from the treatment plant to the application site. In many cases, however, the same vehicle is used to both transport sewage sludge and apply it to the application site. *If the same vehicle is used for sludge transport and application, then a zero value should be used for the cost of the onsite sludge application vehicle (the COSTPV factor) since the cost of that vehicle has already been included in the previous sludge hauling process.*

The cost algorithms for agricultural land application below include calculations for the costs of land, lime addition, and site grading. At many agricultural land application sites, however, all or some of these costs are not applicable to the municipality, since these factors are either unnecessary or paid for by the farmer. *If the latter applies, a zero value should be used in the cost algorithms, where appropriate.*

Operation and maintenance (O&M) costs include labor, diesel for the operation of vehicles, vehicle maintenance, and site maintenance.

If the farm(s) accepting sewage sludge for agricultural land application are numerous and widespread, an expensive and complicated sludge distribution system may be required.

16.2.2 Process Design and Cost Calculations

(1) Calculate dry solids applied to land per year.

TDSS = [(SV)(8.34)(SS)(SSG)(365)]/(2,000)(100)

where:

TDSS	=	Dry solids applied to land, Tons/yr.
SV	=	Daily sludge volume, gpd.
SS	=	Sludge suspended solids concentration, percent.
SSG	=	Sludge specific gravity, unitless. If an input value is not available, default value can be calculated using the following equation:

SSG = 1/[(100 - SS)/100) + (SS)/(1.42)(100)]

where:

1.42	=	Assumed sludge solids specific gravity, unitless.
8.34	=	Density of water, lb/gal.
2,000	=	Conversion factor, lb/Ton.

(2) Sludge application area required.

SDAR = (TDSS)/(DSAR)

where:

SDAR	=	Farm area required for sludge application, ac.
TDSS	=	Dry solids applied to land, Tons/yr (see Calculation #1 above).
DSAR	=	Average dry solids application rate, Tons of dry solids/ac/yr. This value normally ranges from 3 to 10 for typical food chain crop growing sites depending on crop grown, soil conditions, climate, and other factors. Default value = 5 Tons/ac/yr. (See Chapter 7.)

(3) Hourly sludge application rate.

HSV = (SV)(365)/(DPY)(HPD)

where:

HSV	=	Hourly sludge application rate, gal/hr.
SV	=	Daily sludge volume, gpd. (See Calculation #1 above.)
DPY	=	Annual sludge application period, days/yr. This value normally ranges from 100 to 140 days/yr depending on climate, cropping patterns, and other factors. See Table 16-1 for typical values. Default value = 120 days/yr.
HPD	=	Daily sludge application period, hr/day. This value normally ranges from 5 to 8 hr/day depending on equipment used, proximity of application sites, and other factors. Default value = 6 hr/day.

Table 16-1. Typical Days Per Year of Food Chain Crop Sludge Application

Geographic Region	Typical Days/Yr of Sludge Application
Northern U.S.	100
Central U.S.	120
Sunbelt States	140

(4) Capacity of onsite mobile sludge application vehicles.

It is assumed that the sludge has already been transported to the private farm land application site by a process such as a large-haul vehicle, etc. The onsite mobile application vehicles accept the sludge from the transport vehicle, pipeline, or onsite storage facility, and proceed to the sludge application area to apply the sludge. Typical onsite mobile sludge application vehicles at farm sites have capacities ranging from 1,600 to 4,000 gal, in the following increments: 1,600, 2,200, 3,200, and 4,000 gal.

(4a) Capacity and number of onsite mobile sludge application vehicles.

The capacity and number of onsite mobile sludge application vehicles required is determined by comparing the hourly sludge volume, (HSV), with the vehicle sludge handling rate, (VHRCAP), as shown in Table 16-2.

Above 26,000 gal/hr, the number of 4,000-gal capacity vehicles required is calculated by:

NOV = HSV/6,545 (round to the next highest integer)

where:

NOV	=	Number of onsite sludge application vehicles.
HSV	=	Hourly sludge application rate, gal/hr (see Calculation #3).

Table 16-2. Capacity and Number of Onsite Mobile Sludge Application Vehicles Required

Hourly Sludge Application Rate (HSV)	Vehicle Number of Each Capacity (NOV) Capacity (CAP) (gal)			
HSV (gal/hr)	1,600	2,200	3,200	4,000
0 - 3,456	1	-	-	-
3,456 - 4,243	-	1	-	-
4,243 - 5,574	-	-	1	-
5,574 - 6,545	-	-	-	1
6,545 - 8,500	-	2	-	-
8,500 - 11,200	-	-	2	-
11,200 - 13,100	-	-	-	2
13,100 - 19,600	-	-	-	3
19,600 - 26,000	-	-	-	4

(4b) Average round trip onsite cycle time for mobile sludge application vehicles.

CT = [(LT) + (ULT) + (TT)]/0.75

where:
CT = Average round trip onsite cycle time for mobile sludge application vehicle, min.
LT = Load time, min, varies with vehicle size (see Table 16-3).
ULT = Unload time, min, varies with vehicle size (see Table 16-3).
TT = Onsite travel time to and from sludge loading facility to sludge application area, min (assumed values are shown in Table 16-3).
0.75 = An efficiency factor.

Table 16-3. Vehicle Load, Unload, and Onsite Travel Time

Vehicle Capacity (CAP) (gal)	LT[a] (min)	ULT[a] (min)	TT[a] (min)	CT[a] (min)
1,600	6	8	5	25
2,200	7	9	5	28
3,200	8	10	5	31
4,000	9	11	5	33

[a] LT = Loading time.
ULT = Unloading time.
TT = Onsite travel time.
CT = Average round-trip onsite cycle time.

(4c) Single vehicle sludge handling rate.

The actual hourly sludge throughput rates for an onsite mobile sludge application vehicle is dependent on the vehicle tank capacity, the cycle time, and an efficiency factor.

VHRCAP = [(CAP)(60)(0.9)]/(CT)

where:
VHRCAP = Single vehicle sludge handling rate, gal/hr.
CAP = Vehicle tank capacity, gal.
0.9 = Efficiency factor.

Table 16-4 shows VHRCAP values for typical size vehicles.

Table 16-4. Vehicle Sludge Handling Capacity

Vehicle Capacity (CAP) (gal)	VHRCAP[a] (gal/hr)
1,600	3,456
2,200	4,243
3,200	5,574
4,000	6,545

[a] VHRCAP = Single vehicle sludge handling rate.

(5) Total land area required.

For virtually all sludge-to-cropland applications, a larger land area is required than that needed only for sludge application (SDAR). The additional area may be required for changes in cropping patterns, buffer zones, onsite storage, wasted land due to unsuitable soil or terrain, and/or land available in the event of unforeseen future circumstances. The additional land area required is site-specific and varies significantly (e.g., from 10 to 100 percent of the SDAR).

TLAR = (1 + FWWAB)(SDAR)

where:
TLAR = Total land area required for agricultural land application site, ac.
FWWAB = Fraction of farmland area needed in addition to actual sludge application area, e.g., buffer zones, unsuitable soil or terrain, changes in cropping patterns, etc. Default value = 0.4.
SDAR = Farm area required for sludge application, ac (see Calculation #2.)

(6) Lime addition required for soil pH adjustment to a value of at least 6.5.

TLAPH = (FRPH)(SDAR)

where:

TLAPH = Total land area requiring lime addition, ac.
FRPH = Fraction of crop growing area requiring lime addition to raise pH to 6.5. Depending on the natural

pH of local soils, this fraction can vary from 0 to 1. Default value = 0.5.

SDAR = Farm area required for sludge application, ac (see Calculation #2.)

(7) Total land area requiring light grading.

Typical agricultural land used for growing crops is usually already graded to even slopes. However, when sewage sludge is added to the soil, additional light grading may be necessary to improve drainage control and minimize runoff of sludge solids. This need is site-specific.

TLARLG = (FRLG)(SDAR)

where:
TLARLG = Total land area requiring light grading, ac.
FRLG = Fraction of crop-growing area requiring light grading for drainage control. Depending on local conditions at the sludge application sites this fraction can vary from 0 to 1. Default value = 0.3.
SDAR = Farm area required for sludge application, ac (see Calculation #2.)

(8) Annual operation labor requirement.

L = 8 (NOV)(DPY)/0.7

where:
L = Annual operation labor requirement, hr/yr.
NOV = Number of onsite sludge application vehicles (see Calculation #4).
DPY = Annual sludge application period, days/yr (see Calculation #3).
8 = Hr/day assumed.
0.7 = Efficiency factor.

(9) Annual diesel fuel requirement for onsite mobile sludge application vehicles.

FU = (HSV)(HPD)(DPY)(DFRCAP)/(VHRCAP)

where:
FU = Annual diesel fuel usage, gal/yr.
HSV = Hourly sludge application rate, gal/hr (see Calculation #3).
HPD = Daily sludge application period, hr/day (see Calculation #3).
DPY = Annual sludge application period, days/yr (see Calculation #3).
DFRCAP = Diesel fuel consumption rate (gal/hr); for specific capacity vehicle, see Table 16-5.
VHRCAP = Vehicle sludge handling rate (see Calculation #4).

Table 16-5. Gallons of Fuel Per Hour for Various Capacity Sludge Application Vehicles

Vehicle Capacity (CAP) (gal)	DFRCAP[a] (gal/hr)
1,600	3.5
2,200	4
3,200	5
4,000	6

[a] DFRCAP = Diesel fuel consumption rate.

(10) Cost of land.

COSTLAND = (TLAR)(LANDCST)

where:
COSTLAND= Cost of land, $.
TLAR = Total land area required for agricultural land application site, ac (see Calculation #5).
LANDCST = Cost of land, $/ac. Default value = 0. It is assumed that application of sludge is to privately owned farm land.

(11) Cost of lime addition to adjust pH of soil.

COSTPHT = (TLAPH)(PHCST)

where:
COSTPHT = Cost of lime addition, $.
TLAPH = Total land area requiring lime addition, ac (see Calculation #6)
PHCST = Cost of lime addition, $/ac. Default value = $82/acre (ENRCCI/5,445.83); assumes 2 Tons of lime/ac requirement.

(12) Cost of light grading earthwork.

COSTEW = (TLARLG)(LGEWCST)

where:
COSTEW = Cost of earthwork grading, $.
TLARLG = Total land area requiring light grading, ac (see Calculation #7)
LGEWCST = Cost of light grading earthwork, $/ac. Default value = $1,359/ac. (ENRCCI/5,445.83).

(13) Cost of onsite mobile sludge application vehicles.

Note: If same vehicle is used both to transport sludge to the site and to apply sludge to the land, then COSTMAV = 0.

$$\text{COSTMAV} = (\text{NOV})(\text{COSTPV})\,\frac{\text{MSECI}}{990.8}$$

where:
COSTMAV = Cost of onsite mobile sludge application vehicles, $.

NOV = Number of onsite sludge application vehicles (see Calculation #4).
COSTPV = Cost of onsite mobile sludge application vehicle, obtained from Table 16-6.
MSECI = Current Marshall and Swift Equipment Cost Index at time analysis is made.

Table 16-6. Cost of Onsite Mobile Sludge Application Vehicles

Vehicle Capacity (CAP) (gal)	Cost Per Vehicle (COSTPV) (1994 $)[a]
1,600	112,000
2,200	125,000
3,200	158,000
4,000	185,000

[a] Costs were taken from EPA's 1985 Cost Estimation Handbook (U.S. EPA, 1985) and inflated to 1994 price levels using the MSECI.

(14) Annual cost of operation labor.

COSTLB = (L)(COSTL)

where:
COSTLB = Annual cost of operation labor, $/yr.
L = Annual operation labor required, hr/yr.
COSTL = Cost of operation labor, $/hr. Default value = $22.97/hr. (ENRCCI/5,445.83).

(15) Annual cost of diesel fuel.

COSTDSL = (FU)(COSTDF)

where:
COSTDSL = Annual cost of diesel fuel, $/yr.
FU = Annual diesel fuel usage, gal/yr.
COSTDF = Cost of diesel fuel, $/gal. Default value = $1.09/gal. (ENRCCI/5,445.83).

(16) Annual cost of maintenance for onsite mobile sludge application vehicles.

$$VMC = [(HSV)(HPD)(DPY)(MCSTCAP)/(VHRCAP)] \frac{MSECI}{990.8}$$

where:

VMC = Annual cost of vehicle maintenance, $/yr.
HSV = Hourly sludge application rate, gal/hr (see Calculation #3).
HPD = Daily sludge application period, hr/day (see Calculation #3).
DPY = Annual sludge application period, days/yr (see Calculation #3).
MCSTCAP = Maintenance cost, $/hr of operation; for specific capacity of vehicle, see Table 16-7.
VHRCAP = Vehicle sludge handling rate (see Calculation #4).
MSECI = Current Marshall and Swift Equipment Cost Index at time analysis is made.

Table 16-7. Hourly Maintenance Cost for Various Capacities of Sludge Application Vehicles

Vehicle Capacity (CAP) (gal)	Maintenance Cost (MCSTCAP) ($/hr, 1994 $)[a]
1,600	6.40
2,200	7.01
3,200	7.86
4,000	9.45

[a] Costs were taken from EPA's 1985 Cost Estimation Handbook (U.S. EPA, 1985) and inflated to 1994 price levels using the MSECI.

(17) Annual cost of maintenance for land application site (other than vehicles) including monitoring, recordkeeping, etc.

$$SMC = [(TLAR)(16)] \frac{ENRCCI}{5,445.83}$$

where:
SMC = Annual cost of maintenance (other than vehicles), $/yr.
TLAR = Total land area required for land application site, ac (see Calculation #5).
16 = Annual maintenance cost, $/ac.
ENRCCI = Current Engineering News Record Construction Cost Index at time analysis is made.

(18) Total base capital cost.

TBCC = COSTLAND + COSTPHT + COSTEW + COSTMAV

where:
TBCC = Total base capital cost of agricultural land application program using onsite mobile sludge application vehicles, $.
COSTLAND = Cost of land for sludge application site, $ (see Calculation #10).
COSTPHT = Cost of lime addition, $ (see Calculation #11).
COSTEW = Cost of light grading earthwork, $ (see Calculation #12) .
COSTMAV = Cost of onsite mobile sludge application vehicles, $ (see Calculation #13).

(19) Total annual operation and maintenance cost.

COSTOM = COSTLB + COSTDSL + VMC + SMC

where:

COSTOM	=	Total annual operation and maintenance cost for agricultural land application program using onsite mobile sludge application vehicles, $/yr.
COSTLB	=	Annual cost of operation labor, $/yr (see Calculation #14).
COSTDSL	=	Annual cost of diesel fuel, $/yr (see Calculation #15).
VMC	=	Annual cost of vehicle maintenance, $/yr (see Calculation #16).
SMC	=	Annual cost of site maintenance, $/yr (see Calculation #17).

16.3 Application to Forest Lands

16.3.1 General Information and Assumptions Made

The cost algorithms presented below for forest land application estimate only the cost of sewage sludge application at the forest site using specially designed onsite liquid sludge application vehicles. It is assumed that the sludge is transported to the site by one of the transportation processes discussed in Section 16.5. Typically, the onsite liquid sludge application vehicles will obtain sludge from a large "nurse" truck, or an on-site sludge storage facility. These cost algorithms assume that liquid sludge is applied by means of *specially designed tanker trucks equipped with a spray "cannon" having a range of approximately 100 ft.*

Unlike agricultural land application which usually involves *annual* sewage sludge application, forest land application to a specific site is often done at *multi-year intervals*, e.g., every 5 years, which will influence costs. In addition, forest land sites are usually less accessible to sludge application vehicles than cropland, and on-site clearing and grading of access roads is often an initial capital cost. Provisions for estimating the cost of clearing brush and trees and grading rough access roads, which are often paid by the land owner, are included in these cost algorithms.

While provision is made in the cost algorithms for including land costs, the municipality generally will *not* purchase or lease the application site, and land cost will be zero.

Base capital costs include (where appropriate) the cost of land, clearing brush and trees, grading, and mobile sludge application vehicles. Base annual O&M costs include labor, diesel fuel for vehicles, vehicle maintenance, and site maintenance.

16.3.2 Process Design and Cost Calculations

(1) Calculate dry solids applied to land per year.

TDSS = [(SV)(8.34)(SS)(SSG)(365)]/(2,000)(100)

Same as Calculation #1 for agricultural land application (see Section 16.2 above).

(2) Sludge application area required.

SDAR = (TDSS)(FR)/(DSAR)

where:

SDAR	=	Site area required for sludge application, ac.
TDSS	=	Dry solids applied to land, Tons/yr (from Calculation #1).
FR	=	Frequency of sludge application to forest land at dry solids application rate (DSAR) (i.e., period between application of sludge to some forest land area), yr. This value varies depending on tree species, tree maturity, whether trees are grown for commercial purposes, and other factors. Default value = 5 yr.
DSAR	=	Average dry solids application rate, Tons of dry solids/ac. This value normally ranges from 20 to 40 for typical forest land sites depending on tree species, tree maturity, soil conditions, and other factors. Default value = 20 Tons/ac/yr. (See Chapter 8.)

(3) Hourly sludge volume which must be applied.

HSV = (SV)(365)/(DPY)(HPD)

where:

HSV	=	Hourly sludge volume during application period, gal/hr.
SV	=	Daily sludge volume, gpd. (See Calculation #1.)
DPY	=	Annual sludge application period, days/yr. This value normally ranges from 130 to 180 days/yr for forest land sites depending on climate, soil conditions, and other factors. Default value = 150 days/yr.
HPD	=	Daily sludge application period, hr/day. This value normally ranges from 5 to 8 hr/day depending on equipment used, site size, and other factors. Default value = 7 hr/day.

(4) Capacity of onsite mobile sludge application vehicles.

It is assumed that the sludge has already been transported to the forest land application site by a transport process such as truck hauling. The onsite mobile application vehicles accept the sludge from a large nurse truck, on-site storage facility, etc., and proceed to the sludge application area to apply the sludge. Typical onsite mobile sludge application vehicles at forest land sites are specially modified tank trucks equipped with a sludge cannon to spray the sludge at least 100 ft through a 240-degree horizontal arc. The application vehicle is modified to handle steep slopes, sharp turn radius, and doze through small trees and brush. Such vehicles can negotiate much rougher terrain, e.g., logging roads, than conventional road tanker trucks. Because of the special conditions encountered in forest land sludge application, it is assumed that the largest onsite sludge application vehicle feasible has a capacity of 2,200 gal of sludge. Only two capacity increments are included in this program, i.e., 1,000 gal and 2,200 gal.

(4a) Capacity and number of onsite mobile sludge application vehicles.

The capacity and number of onsite mobile sludge application vehicles required is determined by comparing the hourly sludge volume, HSV, with the vehicle sludge handling rate, VHRCAP, as shown in Table 16-8.

Above 7,584 gal/hr, the number of 2,200-gal capacity vehicles required is calculated by:

NOV = HSV/2,528 (round to the next highest integer)

where:

NOV	=	Number of onsite mobile sludge application vehicles.
HSV	=	Hourly sludge volume during application period, gal/hr (see Calculation #3).

Table 16-8. Capacity and Number of Onsite Mobile Sludge Application Vehicles Required

	Vehicle Number of Each Capacity (NOV) Capacity (CAP) (gal)	
HSV[a] (gal/hr)	1,000	2,200
0 - 1,317	1	-
1,317 - 2,528	-	1
2,528 - 5,056	-	2
5,056 - 7,584	-	3

[a] Hourly sludge volume during application period.

(4b) Average round trip on-site cycle time for mobile sludge application vehicles.

CT = [(LT) + (ULT) + (TT)]/0.75

where:

CT	=	Average round trip on-site cycle time for mobile sludge application vehicle, min.
LT	=	Load time, min, varies with vehicle size (see Table 16-9).
ULT	=	Unload time, min, varies with vehicle size (see Table 16-9).
TT	=	On-site travel time to and from sludge loading facility to sludge application area, min (assumed values are shown in Table 16-9).
0.75	=	An efficiency factor.

(4c) Single vehicle sludge handling rate.

Table 16-9. Vehicle Load, Unload, and Onsite Travel Time[a]

Vehicle Capacity, CAP (gal)	LT (min)	ULT (min)	TT (min)	CT (min)
1,000	6	8	10	32
2,200	7	9	10	35

[a] LT = Loading time.
ULT = Unloading time.
TT = Onsite travel time.
CT = Average round-trip onsite cycle time.

The actual hourly sludge throughput rates for an onsite mobile sludge application vehicle is dependent on the vehicle tank capacity, the cycle time, and an efficiency factor.

VHRCAP = [(CAP)(60)(0.9)]/(CT)

where:

VHRCAP	=	Single vehicle sludge handling rate, gal/hr.
CAP	=	Capacity of onsite mobile sludge application vehicle, gal.
0.9	=	Efficiency factor.

Table 16-10 shows VHRCAP values for typical size vehicles.

Table 16-10. Vehicle Sludge Handling Capacity

Vehicle Capacity, (CAP) (gal)	VHRCAP[a] (gal/hr)
1,000	1,317
2,200	2,528

[a] VHRCAP = Single vehicle sludge handling rate.

(5) Total land area required.

For virtually all forest land sites, a larger land area is required than that needed only for sludge application (SDAR). The additional area may be required for buffer zones, on-site roads, on-site storage, wasted land due to unsuitable soil or terrain, etc. The additional land area required is site-specific and varies significantly, e.g., from 10 to 50 percent of the SDAR.

TLAR = (1 + FWWAB)(SDAR)

where:

TLAR	=	Total land area required for forest land site, ac.
FWWAB	=	Fraction of forest land site area used for purposes other than sludge application, e.g., buffer zone, internal roads, sludge storage, waste land, etc. Varies significantly depending on site-specific conditions. Default value = 0.2 for forest land sites.
SDAR	=	Site area required for sludge application, ac (see Calculation #2).

(6) Clearing of brush and trees required.

Often a forest land site will require clearing brush and trees in access road areas to allow access by the sludge application vehicle.

TLAWB = (FWB)(TLAR)

where:

TLAWB	=	Total land area with brush and trees to be cleared, ac.
FWB	=	Fraction of forest land site area requiring clearing of brush and trees to allow access by application vehicle. Varies significantly depending on site-specific conditions. Default value = 0.05 for forest land sites.
TLAR	=	Total land area required for forest land site, ac (see Calculation #5).

(7) Earthwork required.

Often a forest land application site will require grading of access roads for the sludge application vehicles, to provide drainage control, etc. The extent of grading required is site-specific.

TLARG = (FRG)(TLAR)

where:

TLARG	=	Total land area requiring grading, ac.
FRG	=	Fraction of land area requiring grading of access roads to allow travel by sludge application vehicle, etc. Varies significantly depending on site-specific conditions. Default value = 0.05 for forest land sites.
TLAR	=	Total land area required for forest land site, ac (see Calculation #5).

(8) Annual operation labor requirement.

L = 8 (NOV)(DPY)/0.7

where:

L	=	Annual operation labor requirement, hr/yr.
8	=	Hr/day assumed.
NOV	=	Number of onsite sludge application vehicles (see Calculation #4).
DPY	=	Annual sludge application period, days/yr (see Calculation #3).
0.7	=	Efficiency factor.

(9) Annual diesel fuel requirement for onsite mobile sludge application vehicles.

FU = (HSV)(HPD)(DPY)(DFRCAP)/(VHRCAP)

where:

FU	=	Annual diesel fuel usage, gal/yr.
HSV	=	Hourly sludge application rate, gal/hr (see Calculation #3).
HPD	=	Daily sludge application period, hr/day (see Calculation #3).
DPY	=	Annual sludge application period, days/yr (see Calculation #3 above).
DFRCAP	=	Diesel fuel consumption rate (gal/hr); for specific capacity vehicle (see Table 16-11).
VHRCAP	=	Vehicle sludge handling rate (see Calculation #4).

Table 16-11. Gallons of Fuel Per Hour for Various Capacity Sludge Application Vehicles

Vehicle Capacity, (CAP) (gal)	DFRCAP[a] (gal/hr)
1,000	3
2,200	4

[a] DFRCAP = Diesel fuel consumption rate.

(10) Cost of land for forest land application site.

COSTLAND = (TLAR)(LANDCST)

where:

COSTLAND	=	Cost of land for forest land site, $.
TLAR	=	Total land area required for forest land site, ac. (see Calculation #5)
LANDCST	=	Cost of land, $/ac. Usually the forest land is not purchased by the municipality. Default value = 0.

(11) Cost of clearing brush and trees.

COSTCBT = (TLAWB)(BCLRCST)

where:

COSTCBT	=	Cost of clearing brush and trees, $.
TLAWB	=	Total land area with brush and trees to be cleared, ac (see Calculation #6).
BCLRCST	=	Cost of clearing brush and trees, $/ac. Default value = $1,359/acre (ENRCCI/5,445.83).

(12) Cost of grading earthwork.

COSTEW = (TLARG)(GEWCST)

where:

COSTEW	=	Cost of earthwork grading, $.
TLARG	=	Total land area requiring grading, ac (see Calculation #7).
GEWCST	=	Cost of grading earthwork, $/ac. Default value = $2,039/acre (ENRCCI/5,445.83).

(13) Cost of onsite mobile sludge application vehicles.

$$COSTMAV = [(NOV)(COSTPV)]\ \frac{MSECI}{990.8}$$

where:

COSTMAV	=	Cost of onsite mobile sludge application vehicles, $.
NOV	=	Number of onsite sludge application vehicles (see Calculation #4).
COSTPV	=	Cost/vehicle, obtained from Table 16-12.
MSECI	=	Current Marshall and Swift Equipment Cost Index at time analysis is made.

Table 16-12. Cost of On-Site Mobile Sludge Application Vehicles (1994)

Vehicle Capacity, (CAP) (gal)	COSTPV (1994 $)[a]
1,000	158,000
2,200	198,000

[a] Costs were taken from EPA's 1985 Cost Estimation Handbook (U.S. EPA, 1985) and inflated to 1994 price levels using the MSECI.

(14) Annual cost of operation labor.

COSTLB = (L)(COSTL)

where:

COSTLB	=	Annual cost of operation labor, $/yr.
L	=	Annual operation labor requirement, hr/yr (see Calculation #8).
COSTL	=	Cost of operational labor, $/hr. Default value = $22.97/hr (ENRCCI/5,445.83).

(15) Annual cost of diesel fuel.

COSTDSL = (FU)(COSTDF)

where:

COSTDSL	=	Annual cost of diesel fuel, $/yr.
FU	=	Annual diesel fuel usage, gal/yr (see Calculation #9).
COSTDF	=	Cost of diesel fuel, $/gal. Default value = $1.09/gal (ENRCCI/5,445.83).

(16) Annual cost of maintenance of onsite mobile sludge application vehicles.

$$VMC = [(HSV)(HPD)(DPY)(MCSTCAP)/(VHRCAP)]\ \frac{MSECI}{990.8}$$

where:

VMC	=	Annual cost of vehicle maintenance, $/yr.
HSV	=	Hourly sludge application rate, gal/hr (see Calculation #3).
HPD	=	Daily sludge application period, hr/day (see Calculation #3).
DPY	=	Annual sludge application period, days/yr (see Calculation #3).
MCSTCAP	=	Maintenance cost, $/hr of operation for specific capacity of vehicle; see Table 16-13.
MSECI	=	Current Marshall and Swift Equipment Cost Index at time analysis is made.

Table 16-13. Hourly Maintenance Cost for Various Capacities of Forest Land Sludge Application Vehicles

Vehicle Capacity, (CAP) (gal)	MSCTCAP[a] ($/hr, 1994)[b]
1,000	8.05
2,200	9.63

[a] MSCTCAP = Maintenance cost.
[b] Costs were taken from EPA's 1985 Cost Estimation Handbook (U.S. EPA, 1985) and inflated to 1994 price levels using the MSECI.

(17) Annual cost of maintenance for forest land site (other than vehicles) including monitoring, recordkeeping, etc.

$$SMC = [(TLAR)(16)]\ \frac{ENRCCI}{5{,}445.83}$$

where:
SMC = Annual cost of forest land site maintenance (other than vehicles), $/yr.
TLAR = Total land area required for forest land site, ac (see Calculation #5).
16 = Annual maintenance cost, $/ac.
ENRCCI = Current Engineering News Record Construction Cost Index at time analysis is made.

(18) Total base capital cost.

TBCC = COSTLAND + COSTCBT + COSTEW + COSTMAV

where:
TBCC = Total base capital cost of forest land application site using onsite mobile sludge application vehicles, $.
COSTLAND = Cost of land for forest land site, $ (see Calculation #10).
COSTCBT = Cost of clearing brush and trees, $ (see Calculation #11).
COSTEW = Cost of earthwork grading, $ (see Calculation #12).
COSTMAV = Cost of onsite mobile sludge application vehicles, $ (see Calculation #13).

(19) Total annual operation and maintenance cost.

COSTOM = COSTLB + COSTDSL + VMC + SMC

where:
COSTOM = Total annual operation and maintenance cost for forest land application site using onsite mobile sludge application vehicles, $/yr.
COSTLB = Annual cost of operation labor, $/yr (see Calculation #14).
COSTDSL = Annual cost of diesel fuel, $/yr (see Calculation #15).
VMC = Annual cost of vehicle maintenance, $/yr (see Calculation #16).
SMC = Annual cost of forest land site maintenance (other than vehicles), $/yr (see Calculation #17).

16.4 Land Application at Reclamation Sites

16.4.1 General Information and Assumptions Made

The cost algorithms for land application of sewage sludge at reclamation sites presented below *do not generate the* total *land area required, as do the other land application cost algorithms in this chapter, but instead generate the* annual *land area required*. This is because sewage sludge application for land reclamation is usually a one-time application (i.e., sewage sludge is not applied again to the same land area at periodic intervals in the future), and the project must therefore have a continuous supply of new disturbed land on which to apply sewage sludge in future years throughout the life of the sludge application project.

The cost algorithms presented for land application at reclamation sites estimate only the cost of sewage sludge application at the site using onsite sludge application vehicles. It is assumed that the sewage sludge is transported to the site by one of the transportation processes discussed in Section 16.5. Typically, the onsite sludge application vehicles will obtain sludge from a large "nurse" truck, or an interim on-site sludge storage facility. *However, if the same truck is used to both haul and apply the sludge, do not add the cost of onsite application trucks* (i.e., COSTMAV in the algorithms would equal zero).

Disturbed or marginal lands often require extensive grading, soil pH adjustment by lime addition, scarifying, and vegetation seeding. Usually, the landowner pays for the cost of these operations. However, there are provisions for including these costs in the cost algorithms, if desired.

16.4.2 Process Design and Cost Calculations

(1) Calculate dry solids applied to land per year.

TDSS = [(SV)(8.34)(SS)(SSG)(365)]/(2,000)(100)

Same as Calculation #1 for agricultural land application (see Section 16.2).

(2) Sludge application area required.

SDAR = (TDSS)/(DSAR)

where:
SDAR = Land area required for sludge application, ac/yr. Since sludge is typically applied only once to reclamation

sites, the sludge application area required represents the annual new land area which must be located each year.

TDSS	=	Dry solids applied to land, Tons/yr (see Calculation #1).
DSAR	=	Average dry solids application rate, Tons of dry solids/ac/yr. This value normally ranges from 10 to 100 for typical land reclamation sites depending on sludge quality, soil conditions, and other factors. Default value = 25 Tons/ac. (See Chapter 9.)

(3) Hourly sludge application rate.

HSV = (SV)(365)/(DPY)(HPD)

where:

HSV	=	Hourly sludge application rate, gal/hr.
SV	=	Daily sludge volume, gpd. (See Calculation #1.)
DPY	=	Annual sludge application period, days/yr. This value normally ranges from 100 to 180 days/yr for land reclamation sites depending on climate, soil conditions, planting seasons, and other factors. Default value = 140 days/yr.
HPD	=	Daily sludge application period, hr/day. This value normally ranges from 5 to 8 hr/day depending on equipment used, site size, and other factors. Default value = 8 hr/day.

(4) Capacity of onsite mobile sludge application vehicles.

Same as Calculations #4a, b, and c in Section 16.2.2 for agricultural land application sites.

(5) Total land area required per year.

For virtually all land reclamation sites, a larger land area is required than that needed only for sludge application (SDAR). The additional area may be required for buffer zones, on-site roads, on-site storage, wasted land due to unsuitable terrain, etc. The additional land area required for land reclamation sites is usually not significant, since these sites are typically located far from population centers.

TLAR = (1 + FWWAB)(SDAR)

where:

TLAR	=	Total land area required for land reclamation sites, ac/yr.
FWWAB	=	Fraction of land reclamation site area used for purposes other than sludge application, e.g., buffer zone, internal roads, sludge storage, waste land, etc. Varies significantly depending on site-specific conditions. Default value = 0.3 for land reclamation sites.
SDAR	=	Site area required for sludge application, ac/yr (see Calculation #2).

(6) Lime addition required for soil pH adjustment to a value of pH = 6.5.

TLAPH = (FRPH)(SDAR)

where:

TLAPH	=	Total land area which must have lime applied for pH control, ac/yr.
FRPH	=	Fraction of land reclamation site area requiring addition of lime for adjustment of soil pH to a value of 6.5. Typically, strip mining spoils have a low soil pH, and substantial lime addition may be required. Default value = 1.0 for land reclamation sites.
SDAR	=	Site area required for sludge application, ac/yr (see Calculation #2).

(7) Earthwork required.

Usually a potential land reclamation site will require extensive grading to smooth out contours, provide drainage control, etc. The extent of grading required is very site-specific, and can represent a significant portion of the total site preparation cost when the terrain is rough.

TLARLG = (FRLG)(TLAR)
TLARMG = (FRMG)(TLAR)
TLAREG = (FREG)(TLAR)

where:

TLARLG	=	Total land area requiring light grading, ac/yr.
TLARMG	=	Total land area requiring medium grading, ac/yr.
TLAREG	=	Total land area requiring extensive grading, ac/yr.
FRLG	=	Fraction of land area requiring light grading. Varies significantly depending on site-specific conditions. Default value = 0.1.
FRMG	=	Fraction of land area requiring medium grading. Varies significantly depending on site-specific conditions. Default value = 0.3.
FREG	=	Fraction of land area requiring extensive grading. Varies significantly depending on site-specific conditions. Typically, a land reclamation site requires significant heavy grading. Default value = 0.6.

TLAR = Total land area required per year (TLAR) (see Calculation #5).

(8) Possible number of monitoring wells needed.

Many state regulatory agencies require that ground-water quality monitoring wells be installed as a condition of land reclamation site permitting. The permitting authority may also require ground-water monitoring if he or she has approved land application in excess of agronomic rates at a reclamation site, as allowed by the federal Part 503 regulation. The number and depth of monitoring wells required varies as a function of site size, ground-water conditions, and regulatory agency requirements. In this algorithm, it is assumed that even the smallest land reclamation site must have one downgradient ground-water quality monitoring well, and one additional monitoring well for each 200 ac/yr of total site area (TLAR) above 50 ac/yr. In some cases, at least one upgradient well is also required.

NOMWR = 1 + [(TLAR) - 50]/200 (increase to next highest integer)

where:

NOMWR = Number of monitoring wells required/yr.
TLAR = Total land area required per year (see Calculation #5).

(9) Operation labor requirement.

L = 8 (NOV)(DPY)/0.7

where:

L = Operation labor requirement, hr/yr.
8 = Hr/day assumed, hr.
NOV = Number of onsite sludge application vehicles (see Calculation #4).
DPY = Annual sludge application period, days/yr (see Calculation #3).
0.7 = Efficiency factor.

(10) Diesel fuel requirements for onsite mobile sludge application vehicles.

FU = (HSV)(HPD)(DPY)(DFRCAP)/(VHRCAP)

where:

FU = Diesel fuel usage, gal/yr.
HSV = Hourly sludge application rate, gal/hr (see Calculation #3).
HPD = Daily sludge application period, hr/day (see Calculation #3).
DPY = Annual sludge application period, days/yr (see Calculation #3).
DFRCAP = Diesel fuel consumption rate for certain capacity vehicle, gal/hr, see Table 16-5.
VHRCAP = Vehicle sludge handling rate (see Calculation #4).

(11) Annual cost of land.

COSTLAND = (TLAR)(LANDCST)

where:

COSTLAND = Annual cost of land for land reclamation site, $/yr.
TLAR = Total land area required for land reclamation sites, ac/yr (see Calculation #5).
LANDCST = Cost of land, $/ac. Typically, the land used for reclamation is *not* purchased by the municipality. Default value = 0.

(12) Annual cost of lime addition to adjust pH of the soil.

COSTPHT = (TLAPH)(PHCST)

where:

COSTPHT = Annual cost of lime addition for pH adjustment, $/yr.
TLAPH = Total land area which must have lime applied for pH control, ac/yr (see Calculation #6).
PHCST = Cost of lime addition, $/ac. Default value = $163/ac. (ENRCCI/5,445.83), based on 4 Tons of lime/ac (in some cases up to 10 Tons/ac may be required for extreme pH conditions).

(13) Annual cost of grading earthwork.

COSTEW = (TLARLG)(LGEWCST) + (TLARMG)(MGEWCST) + (TLAREG)(EGEWCST)

where:

COSTEW = Cost of earthwork grading, $/yr.
TLARLG = Total land area requiring light grading, ac/yr (see Calculation #7).
LGEWCST = Cost of light grading earthwork, $/ac. Default value = $1,359/ac. (ENRCCI/5,445.83).
TLARMG = Total land area requiring medium grading, ac/yr (see Calculation #7).
MGEWCST = Cost of medium grading earthwork, $/ac. Default value = $2,719/ac. (ENRCCI/5,445.83).
TLAREG = Total land area requiring extensive grading, ac/yr (see Calculation #7).
EGEWCST = Cost of extensive grading earthwork, $/ac. Default value = $6,797/ac. (ENRCCI/5,445.83).

(14) Annual cost of monitoring wells.

COSTMW = (NOMWR)(MWCST)

where:

COSTMW = Cost of monitoring wells, \$/yr.
NOMWR = Number of monitoring wells required/yr (see Calculation #8).
MWCST = Cost of monitoring well, \$/well. Default value = \$6,797/well (ENRCCI/5,445.83).

(15) Cost of onsite mobile sludge application vehicles.

$$COSTMAV = [(NOV)(COSTPV)] \frac{MSECI}{990.8}$$

where:

COSTMAV = Cost of onsite mobile sludge application vehicles, \$.
NOV = Number of onsite sludge application vehicles (see Calculation #4).
COSTPV = Cost/vehicle, \$, obtained from Table 16-6.
MSECI = Current Marshall and Swift Equipment Cost Index at time analysis is made.

(16) Annual cost of operation labor.

COSTLB = (L)(COSTL)

where:

COSTLB = Annual cost of operation labor, \$/yr.
L = Annual operation labor required, hr/yr.
COSTL = Cost of operational labor, \$/hr. Default value = \$22.97/hr. (ENRCCI/5,445.83).

(17) Annual cost of diesel fuel.

COSTDSL = (FU)(COSTDF)
where:

COSTDSL = Annual cost of diesel fuel, \$/yr.
FU = Annual diesel fuel usage, gal/yr.
COSTDF = Cost of diesel fuel, \$/gal. Default value = \$1.09/gal (ENRCCI/5,445.83).

(18) Annual cost of maintenance of onsite mobile sludge application vehicles.

$$VMC = [(HSV)(HPD)(DPY)(MCSTCAP)/(VHRCAP)] \frac{MSECI}{990.8}$$

where:

VMC = Annual cost of vehicle maintenance, \$/yr.
HSV = Hourly sludge application rate, gal/hr (see Calculation #3).
HPD = Daily sludge application period, hr/day (see Calculation #3).
DPY = Annual sludge application period, days/yr (see Calculation #3).
MCSTCAP = Maintenance cost, \$/hr of operation; for specific capacity of vehicle see Table 16-7.
VHRCAP = Vehicle sludge handling rate (see Calculation #4)
MSECI = Current Marshall and Swift Equipment Cost Index at time analysis is made.

(19) Annual cost of maintenance of land reclamation site (other than vehicles) for monitoring, recordkeeping, etc.

$$SMC = [(TLAR)(16)] \frac{ENRCCI}{5,445.83}$$

where:

SMC = Annual cost of land reclamation site maintenance (other than vehicles), \$/yr.
TLAR = Total land area required, ac (see Calculation #5).
16 = Annual maintenance cost, \$/ac.
ENRCCI = Current Engineering News Record Construction Cost Index at time analysis is made.

(20) Total base capital cost.

TBCC = COSTMAV

where:

TBCC = Total base capital cost of land reclamation site using onsite mobile sludge application vehicles, \$.
COSTMAV = Cost of onsite mobile sludge application vehicles, \$ (see Calculation #15).

(21) Total annual operation, maintenance, land, and earthwork cost.

COSTOM = COSTLB + COSTDSL + VMC + SMC + COSTLAND + COSTPHT + COSTEW + COSTMW

where:

COSTOM = Total annual operation, maintenance, land, and earthwork cost for land reclamation site using onsite mobile sludge application vehicles, \$/yr.
COSTLB = Annual cost of operation labor, \$/yr (see Calculation #16).
COSTDSL = Annual cost of diesel fuel, \$/yr (see Calculation #17).
VMC = Annual cost of vehicle maintenance, \$/yr (see Calculation #18).

SMC	=	Annual cost of site maintenance, \$/yr (see Calculation #19).
COSTLAND	=	Annual cost of land for reclamation site, \$/yr (see Calculation #11).
COSTPHT	=	Annual cost of lime addition for pH adjustment,\$/yr (see Calculation #12).
COSTEW	=	Annual cost of grading earthwork, \$/yr (see Calculation #13).
COSTMW	=	Annual cost of monitoring wells, \$/yr (see Calculation #14).

16.5 Transportation of Sewage Sludge

This section covers the two primary modes of sewage sludge transport, truck hauling (for both liquid and dewatered sludge) and pipeline transport of liquid sludge. For cost estimate information regarding rail or barge transport of sewage sludge, see EPA's *Handbook: Estimating Sludge Management Costs* (U.S. EPA, 1985).

Generally, truck hauling is more economical than railroad or pipeline when transporting sewage sludge less than 150 miles. Diesel-equipped vehicles are an economic choice for larger trucks and trucks with high annual mileage operation. Pipelines have been successfully used for transporting liquid sludge (i.e., usually less than 10 percent solids by weight) from very short distances up to distances of 10 miles or more. Liquid sludge pumping through pipelines is generally best accomplished with sludge containing 3 percent solids or less.

16.5.1 Truck Hauling of Liquid Sewage Sludge

16.5.1.1 General Information and Assumptions Made

For the cost algorithms presented below for truck hauling of liquid sewage sludge, capital costs include purchase of specially designed tank trucks, as well as construction of sludge loading facilities at the treatment plant. The loading facility consists of a concrete slab and appropriate piping and valving set at a height of 12 ft to load the tanker from the top. Base annual O&M costs include driver labor, operational labor, fuel, vehicle maintenance, and loading facility maintenance.

16.5.1.2 Process Design and Cost Calculations

(1) Number and capacity of sludge haul trucks.

Liquid sludge is hauled in tanker trucks with capacities between 1,600 and 6,000 gal. The capacity of the tank trucks utilized is a function of the volume of sludge to be hauled per day and the round trip haul time. Special tanker capacities available are 1,600, 2,000, 2,500, 3,000, 4,000, and 6,000 gal.

(1a) Total volume hauled per trip.

FACTOR = [SV (LT + ULT + RTHT)(365)]/(HPD)(DPY)

where:

FACTOR	=	Gallons hauled per trip if only one truck were utilized.
SV	=	Daily sludge volume, gpd.
LT	=	Truck loading time at treatment plant, hr. Default value = 0.4 hr.
ULT	=	Truck unloading time at application site, hr. Default value = 1.0 hr. See Table 16-14 for guidance.
RTHT	=	Round trip haul time from treatment plant to application site, hr. If a value is not available, this value can be estimated using an average mph for truck hauling, as follows:

Urban travel:

$$RTHT = \frac{RTHD}{25 \text{ miles/hr average speed}}$$

Rural travel:

$$RTHT = \frac{RTHD}{35 \text{ miles/hr average speed}}$$

Highway travel:

$$RTHT = \frac{RTHD}{45 \text{ miles/hr average speed}}$$

where:

RTHD	=	Round trip haul distance from treatment plant to application site, miles. If several sludge application sites are planned (e.g., private farm agricultural utilization), use average distance to sites.
HPD	=	Work schedule for hauling, hr/day. Default value = 7 hr/day.
DPY	=	Number of days/yr sludge is hauled, days/yr. Default value = 120 days/yr. See Table 16-15 for guidance.

Table 16-14. Typical Truck Unloading Time as a Function of Type of Land Application Used

Type of Land Application	Typical Unloading Time (Hr)
Agricultural	1.0
Forest land	1.5
Land reclamation	1.0

Table 16-15. **Typical Days Per Year of Sludge Hauling as a Function of Types of Application Used and Geographical Region**

Type of Application	Geographical Region	Typical Days/Yr of Sludge Hauling
Agricultural or land reclamation utilization	Northern U.S.	100
	Central U.S.	120
	Sunbelt States	140
Forest land utilization	Northern U.S.	160
	Central U.S.	180
	Sunbelt States	200

(1b) Number of vehicles and capacity of each truck.

The number of vehicles is calculated using FACTOR and Table 16-16.

If FACTOR exceeds 12,000, NTR = Factor/6,000 (Round to next highest integer.)

where:
NTR = Number of trucks required, from Table 16-16.

Table 16-16. Number of Vehicles and Capacity of Each Truck

FACTOR, (gal)	Number (NTR) and Capacity (CAP) of Tanker Trucks, (gal)[a]
<1,600	1 at 1,600
>1,600 but <2,500	1 at 2,500
>2,500 but <4,000	1 at 4,000
>4,000 but <8,000	2 at 4,000
>8,000 but <12,000	2 at 6,000
>12,000	All 6,000

[a] FACTOR = Gallons hauled per trip if only one truck is used.
CAP = Capacity of tanker trucks required, gal.
NTR = Number of trucks required.

(2) Number of round trips/yr.

NRT = SV (365)/CAP

where:
NRT = Number of round trips/yr.
SV = Daily sludge volume, gpd (see Calculation #1).
CAP = Capacity of tanker trucks required, gal (see Table 16-16).

(3) Driver labor requirement.

DT = (LT + ULT + RTHT) NRT

where:
DT = Driver labor requirement, hr/yr.
LT = Truck loading time at treatment plant, hr (see Calculation #1).
ULT = Truck unloading time at application site, hr (see Calculation #1).
RTHT = Round trip haul time from treatment plant to application site, hr (see Calculation #1).
NRT = Number of round trips/yr (see Calculation #2).

(4) Annual fuel requirement.

Vehicle fuel usage is a function of truck size. Table 16-17 lists typical fuel usage values for different capacity trucks.

FU = (RTHD)(NRT)/FC

where:
FU = Annual fuel requirement, gal/yr.
RTHD = Round trip haul distance from treatment plant to application site, miles (see Calculation #1).
NRT = Number of round trips/yr (see Calculation #2).
FC = Fuel consumption rate, mpg, see Table 16-17.

Table 16-17. Fuel Use Capacities for Different Sized Trucks

Truck Capacity (CAP) (gal)	Fuel Consumption (FC) (mpg)
1,600	8
2,500	7
4,000	6
6,000	5

(5) Cost of sludge tanker trucks.

$$TTCOST = (NTR)(COSTSTT)\ \frac{MSECI}{990.8}$$

where:
TTCOST = Total cost of all sludge tanker trucks, $.
NRT = Number of round trips/yr (see Calculation #2).
COSTSTT = Cost per sludge tanker truck, obtained from Table 16-18.
MSECI = Current Marshall and Swift Equipment Cost Index at time cost analysis is made.

Table 16-18. Cost of Tanker Truck

Tanker Capacity (CAP) (gal)	Cost of Truck (COSTSTT) (1994 $)
1,600	79,000
2,500	106,000
4,000	132,000
6,000	158,000

(6) Cost of vehicle loading area facilities.

The tanker truck loading facilities are assumed to consist of a concrete slab, appropriate piping and valving to a height of 12 ft to load the tanker from the top. Cost of the loading area facilities are assumed to be a function of sludge volume, (SV in Calculation #1), in gal/yr. The relationship of SV to loading area facilities cost is graduated in a stepped manner.

$$\text{COSTLA} = (\text{COSTLAB}) \frac{\text{ENRCCI}}{5{,}445.83}$$

where:

COSTLA	=	Total capital cost of loading area facilities, $.
COSTLAB	=	Base cost of loading area facilities, $. This is a function of the annual volume of sludge hauled, SV, in gal/yr, and can be obtained from Table 16-19.
ENRCCI	=	Current Engineering News Record Construction Cost Index at time cost analysis is made.

Table 16-19. Loading Area Costs Based on Sludge Volume

Annual Volume of Sludge Hauled (SV x 365) (gal/yr)	Base Cost of Loading Area Facilities (COSTLAB) (1994 $)
100,000 to 500,000	27,000
500,000 to 1,000,000	41,000
1,000,000 to 2,000,000	54,000
2,000,000 to 4,000,000	68,000
4,000,000 to 8,000,000	82,000
8,000,000 to 12,000,000	95,000
12,000,000 to 16,000,000	109,000
16,000,000 to 20,000,000	122,000
20,000,000 and over	136,000

(7) Annual vehicle maintenance cost.

Maintenance cost per vehicle mile traveled is a function of truck capacity and initial cost of truck. The factors listed in Table 16-20 are used to calculate vehicle maintenance costs.

$$\text{VMC} = (\text{RTHD})(\text{NRT})(\text{MCM}) \frac{\text{MSECI}}{990.8}$$

where:

VMC	=	Annual vehicle maintenance cost, $.
RTHD	=	Round trip haul distance from treatment plant to application site, miles (see Calculation #1).
NRT	=	Number of round trips/yr (see Calculation #2).
MCM	=	Maintenance cost per mile traveled, $/mile from Table 16-20.
MSECI	=	Current Marshall and Swift Equipment Cost Index at time cost analysis is made.

Table 16-20. Vehicle Maintenance Cost Factors

Truck Capacity (CAP) (gal)	Maintenance Cost (MCM) $/mile Traveled, (1994 $)
1,600	0.37
2,500	0.42
4,000	0.47
6,000	0.53

(8) Loading area facility annual maintenance cost.

For the purposes of this program, it is assumed that loading area facilities annual maintenance cost is a function of loading area facility capital cost.

$$\text{MCOSTLA} = (\text{COSTLA})(0.05)$$

where:

MCOSTLA	=	Annual maintenance cost for loading facilities, $/yr.
COSTLA	=	Total capital cost of loading area facilities, $ (see Calculation #6).
0.05	=	Assumed annual maintenance cost factor as a function of total loading area facility capital cost.

(9) Annual cost of operation labor.

$$\text{COSTLB} = (\text{DT})(\text{COSTL})(1.2)$$

where:

COSTLB	=	Annual cost of operation labor, $/yr.
DT	=	Driver labor requirement, hr/yr (see Calculation #3).
COSTL	=	Cost of labor, COSTL, $/hr. Default value = $22.97/hr. (ENRCCI/5,445.83).
1.2	=	A factor to account for additional labor required at the loading facility.

(10) Annual cost of diesel fuel.

$$\text{COSTDSL} = (\text{FU})(\text{COSTDF})$$

where:

COSTDSL	=	Annual cost of diesel fuel, $/yr.
FU	=	Annual fuel requirement, gal/yr (see Calculation #4).
COSTDF	=	Cost of diesel fuel, $/gal. Default value = $1.09. (ENRCCI/5,445.83).

(11) Total base capital cost.

TBCC = TTCOST + COSTLA

where:

TBCC	=	Total base capital cost, $.
TTCOST	=	Total cost of all sludge tanker trucks, $ (see Calculation #5).
COSTLA	=	Total capital cost of loading area facilities, $ (see Calculation #6).

(12) Annual operation and maintenance cost.

COSTOM = (VMC) + (MCOSTLA) + (COSTLB) + (COSTDSL)

where:

COSTOM	=	Total annual operation and maintenance cost, $/yr.
VMC	=	Annual vehicle maintenance cost, $ (see Calculation #7).
MCOSTLA	=	Annual maintenance cost for loading facilities, $/yr (see Calculation #8).
COSTLB	=	Annual cost of operation labor, $/yr (see Calculation #9).
COSTDSL	=	Annual cost of diesel fuel, $/yr (see Calculation #10).

16.5.2 Truck Hauling of Dewatered Sewage Sludge

16.5.2.1 General Information and Assumptions Made

Capital costs in the cost algorithms presented below for dewatered sewage sludge transport include construction of a truck loading facility designed to accommodate the sludge volume within the operating schedule. Costs include construction of a concrete loading slab, and purchase of skip loaders and trucks. Annual O&M costs include vehicle and loading facility maintenance, driver and operational labor, and diesel fuel for vehicles.

16.5.2.2 Process Design and Cost Calculations

Same as Calculation #1 for truck hauling of liquid sewage sludge, shown in Section 16.5.1 above.

(1) Annual sludge volume hauled, cu yd/yr.

Trucks which haul dewatered sludge are sized in terms of yd^3 of capacity. Therefore, it is necessary to convert gal of dewatered sludge to yd^3 of dewatered sludge.

SVCY = (SV)(365)/202

where:

SVCY	=	Sludge volume hauled, cu yd/yr.
SV	=	Daily sludge volume, gpd.
202	=	Conversion factor, gal/cu yd.

(2) Number and capacity of sludge haul trucks.

Dewatered sludge is hauled in trucks with capacities between 7 and 36 cu yd. The capacity of the trucks utilized is a function of the volume of sludge to be hauled per day and the round trip hauling time. Typical capacities available are 7, 10, 15, 25, and 36 cu yd.

(2a) Total sludge volume hauled per day.

FACTOR = SVCY(LT + ULT + RTHT)/(HPD)(DPY)

where:

FACTOR	=	Cu yd which would have to be hauled per trip if only one truck were utilized.
SVCY	=	Sludge volume hauled, cu yd/yr (see Calculation #1).
LT	=	Truck loading time at treatment plant, hr (see Calculation #1 for liquid sludge, section 16.5.1.2).
ULT	=	Truck unloading time at application site, hr (see Calculation #1 for liquid sludge, Section 16.5.1.2).
RTHT	=	Round trip haul time from treatment plant to application site, hr (see Calculation #1 for liquid sludge, Section 16.5.1.2).

(2b) Capacity and number of haul vehicles.

Capacity and number of haul vehicles are calculated using FACTOR and Table 16-21.

Table 16-21. Capacity and Number of Haul Vehicles

FACTOR (cu yd)	Number (NTR) and Capacity[a] of Trucks (CAP) (cu yd)
<7	1 at 7
7 to 10	1 at 10
10 to 15	1 at 15
15 to 25	1 at 25
25 to 36	1 at 36
36 to 50	2 at 25
50 to 72	2 at 36

[a] NTR = Number of trucks required.

If FACTOR exceeds 72, use:

$$NTR = \frac{FACTOR}{36} \text{ (Round to next highest integer).}$$

CAP = 36 cu yd.

where:

NTR	=	Number of trucks required. Calculated from Table 16-21.
CAP	=	Capacity of truck required, cu yd.

(3) Number of round trips/yr.

NRT = (SVCY)/(CAP)

where:

NRT	=	Number of round trips/yr (round to next highest integer).
SVCY	=	Annual sludge volume hauled, cu yd/yr (see Calculation #1).
CAP	=	Capacity of truck, cu yd (see Calculation #2).

(4) Driver time.

Same as Calculation #3 for truck hauling of liquid sewage sludge in Section 16.5.1.2.

(5) Annual fuel requirement.

Vehicle fuel usage is a function of truck size. Table 16-22 lists typical fuel usage values for different capacity trucks.

FU = (RTHD)(NRT)/(FC)

where:

FU	=	Annual fuel requirement, gal/yr.
RTHD	=	Round trip haul distance from treatment plant to application site, miles (see Calculation #1 for liquid sludge in Section 16.5.1.2).
NRT	=	Number of round trips/yr (see Calculation #3).
FC	=	Fuel consumption rate, miles/gal, see Table 16-22.

Table 16-22. Fuel Usage Values for Different Sized Trucks

Truck Capacity (CAP) (cu yd)	Fuel Consumption (FC) (miles/gal)
7	9
10	8
15	7
25	6
36	5

(6) Cost of sludge haul trucks.

$$TCOSTTRK = (NTR)(COSTTRK) \frac{MSECI}{990.8}$$

where:

TCOSTTRK	=	Total cost of dewatered sludge haul trucks, $.
NTR	=	Number of trucks required (see Calculation #2).
COSTTRK	=	Cost per truck, obtained from Table 16-23.
MSECI	=	Current Marshall and Swift Equipment Cost Index at time cost analysis is made.

Table 16-23. Costs for Different Sized Trucks

Truck Capacity (CAP) yd^3	Cost of Truck (COSTTRK) (1994 $)
7	86,000
10	129,000
15	172,000
25	226,000
36	282,000

(7) Cost of vehicle loading facilities.

Truck loading facilities are assumed to consist of a concrete slab, one or more skip loaders to load the trucks, and miscellaneous improvements such as drainage, lighting, etc. Cost of the truck loading facilities are assumed to be a function of sludge volume in yd^3/yr (SVCY in Calculation #1). The relationship of SVCY to loading area facilities cost is graduated in a stepped manner and depends on the number of loading vehicles required.

$$COSTLA = (COSTLAB) \frac{ENRCCI}{5{,}445.83}$$

where:

COSTLA	=	Total capital cost of loading area facilities, $.
COSTLAB	=	Base cost of loading area facilities, $. This is a function of the annual volume of sludge hauled (SVCY in Calculation #1) and can be obtained from Table 16-24.
ENRCCI	=	Current Engineering News Record Construction Cost Index at time cost analysis is made.

Table 16-24. Loading Area Costs

Annual Volume of Sludge Hauled (SVCY) (yd^3)	Base Cost of Loading Area Facilities (COSTLAB) (1994 $)
500 to 2,500	54,000
2,500 to 5,000	61,000
5,000 to 10,000	68,000
10,000 to 20,000	109,000
20,000 to 40,000	122,000
40,000 to 60,000	136,000
60,000 to 80,000	204,000
80,000 to 100,000	251,000
100,000 and over	299,000

(8) Annual vehicle maintenance cost.

Maintenance cost per vehicle mile traveled is a function of truck capacity and initial cost of the truck.The factors outlined in Table 16-25 are used to calculate vehicle maintenance costs.

$$VMC = (RTHD)(NRT)(MCM) \frac{MSECI}{990.8}$$

where:
VMC = Annual maintenance cost, $/yr.
RTHD = Round trip haul distance from treatment plant to application site, miles (see Calculation #1 for truck hauling of liquid sewage sludge).
NRT = Number of round trips/yr (see Calculation #3).
MCM = Maintenance cost/mile travelled, $/mile from Table 16-25.
MSECI = Current Marshall and Swift Equipment Cost Index at time cost analysis is made.

Table 16-25. Vehicle Maintenance Cost Factors

Truck Capacity (CAP) yd^3	Maintenance Cost (MCM) $/mile Traveled (1994 $)
7	0.34
10	0.42
15	0.49
25	0.59
36	0.70

(9) Annual maintenance cost for loading area facilities.

For the purposes of this program, it is assumed that loading area facilities annual maintenance cost is a function of loading area facilities capital cost.

$$MCOSTLA = (COSTLA)(0.05)$$

where:
MCOSTLA = Annual maintenance cost for loading area facilities, $/yr.
COSTLA = Total capital cost of loading area facilities, $ (see Calculation #7).
0.05 = Assumed annual maintenance cost factor as a function of total loading area facilities capital cost.

(10) Annual cost of operational labor.

$$COSTLB = (DT)(COSTL)(1.2)$$

where:
COSTLB = Annual cost of operational labor, $/yr.
DT = Driver labor requirement, hr/yr (see Calculation #3 for truck hauling of liquid sludge, Section 16.5.1.2).
COSTL = Cost of labor, $/hr. Default value = $22.97/hr. (ENRCCI/5,445.83).
1.2 = A factor to account for additional labor required at loading facility.

(11) Annual cost of diesel fuel.

$$COSTDSL = (FU)(COSTDF)$$

where:
COSTDSL = Annual cost of diesel fuel, $/yr.
FU = Annual fuel requirement, gal/yr (see Calculation #5).
COSTDF = Cost of diesel fuel, $/gal. Default value = $1.09/gal. (ENRCCI/5,445.83).

(12) Total base capital cost.

$$TBCC = TCOSTTRK + COSTLA$$

where:
TBCC = Total base capital cost, $.
TCOSTTRK = Total cost of dewatered sludge haul trucks, $ (see Calculation #6).
COSTLA = Total capital cost of loading area facilities, $.

(13) Annual operation and maintenance cost.

$$COSTOM = (VMC) + (MCOSTLA) + (COSTLB) + (COSTDSL)$$

where:
COSTOM = Total annual operation and maintenance cost, $/yr.
VMC = Annual vehicle maintenance cost, $/yr (see Calculation #8).
MCOSTLA = Annual loading facility maintenance cost, $/yr (see Calculation #9).
COSTLB = Annual cost of operation labor, $/yr (see Calculation #10).

COSTDSL = Annual cost of diesel fuel, $/yr (see Calculation #11).

16.5.3 Long-Distance Pipeline Transport of Liquid Sewage Sludge

16.5.3.1 General Information and Assumptions Made

Friction losses associated with sludge pipelines have been taken into account in the cost algorithms presented below by applying a "K" factor to an otherwise unmodified Hazen-Williams formula. This "K" factor, which is a function of both sludge solids content and sludge type, is discussed in more detail in Calculation #2 below. Pipelines with coated interiors (e.g., glass or cement mortar linings) are often used as a means of reducing friction loss. Because dried sludge can "cake" on interior pipe walls, flushing pipelines with clean water or treated effluent is also commonly practiced as a means of reducing friction loss due to such "caking." In addition, flushing has been used as a means for preventing sludge solids from settling and hardening in dormant pipelines.

Cost considerations for these algorithms include: pipeline and pumping station construction costs and O&M labor, materials, and energy requirements. Large variations in construction costs are associated with certain route-specific variables, such as the number of river crossings or the fraction of pipeline length requiring excavation of rock. To obtain the best results, the user is encouraged to obtain or plot a viable pipeline route on a suitable scale map and input the most accurate design parameter values possible. Cost of right-of-way acquisition is not included in these algorithms.

16.5.3.2 Process Design and Cost Calculations

(1) Pipeline diameter.

$$PD = 12\,[SV/(63{,}448)(HPD)]^{0.5}$$

(Round to next highest even integer.)

where:
PD = Pipeline diameter, inches.
SV = Daily sludge volume, gpd.
63,488 = Conversion factor = (3.1416/4)[(3 ft/sec)(7.48 gal/cu ft)(86,400 sec/day)/(24 hr/day)]
HPD = Hours per day of pumping, HPD, hr.

Note: Pipeline is assumed to be flowing full.

(2) Head loss due to pipeline friction.

$$PFL = K\,[(SV)/(HPD)(PD)^{2.63}(C)(16.892)]^{1.852}$$

where:
PFL = Head loss due to pipe friction, ft/ft. Is function of pipe diameter, velocity, and "C" value selected.
K = Coefficient to adjust for increased head loss due to sludge solids content. No default value. Pipeline friction losses may be much higher for transporting sewage sludge than for transporting water, depending on such factors as the sludge concentration (percent solids by weight) and the type of sludge (raw primary, digested, etc.). The user is cautioned that the K factors provided in Table 16-26 are highly simplified and may give inaccurate results for pipeline friction loss. An elaborate method for design engineering calculations is provided in U.S. EPA, 1979.
2.63 = Hazen-Williams constant.
C = Hazen-Williams friction coefficient. Default value = 90.
16.892 = $(646{,}000\ \text{gpd/cfs})/(24)(2.31)(12)^{2.63}$

Table 16-26. Factors for Various Sludge Concentrations and Two Types of Sludge

Solids Concentration Percent by Weight	K Factor	
	Digested Sludge	Untreated Primary Sludge
1.0	1.05	1.20
2.0	1.10	1.60
3.0	1.25	2.10
4.0	1.45	2.70
5.0	1.65	3.40
6.0	1.85	4.30
7.0	2.10	5.70
8.0	2.60	7.20

(3) Head required due to elevation difference.

$$HELEV = ELEVMX - PSELEV$$

where:
HELEV = Head required due to elevation difference, ft.
ELEVMX = Maximum elevation in the pipeline, ft.
PSELEV = Elevation at the start of the pipeline, ft.

(4) Total pumping head required.

H = [(PL)(PFL) + HELEV]

where:

H	=	Total pumping head required, ft.
PL	=	Pipeline length, ft.
PFL	=	Head loss due to pipe friction, ft/ft (see Calculation #2).
HELEV	=	Head required due to elevation difference, ft (see Calculation #3).

(5) Number of pumping stations.

NOPS = H/HAVAIL

If the decimal ending for the MOPS resultant is greater than or equal to 0.25, then round up to the next higher integer. If it is less than 0.25, round down. Thus, if MOPS is 2.35, use 3 pump stations. If MOPS = 2.10, use 2 pump stations.

where:

NOPS	=	Number of pumping stations.
H	=	Total pumping head required, ft.
HAVAIL	=	Head available from each pumping station, ft. This is a function of the type of pump, sludge flow rate, and whether or not pumps are placed in series. Obtain this value from Table 16-27.

Table 16-27. Head Available from Each Pumping Station

Pipe Diameter (PD) (inches)	Head Available (HAVAIL) (ft)
4 & 6	450
8	260
10 & 12	230
14 & 16	210
18 & 20	200

(6) Total horsepower required for pump stations.

HP = (H)(SV)(8.34)/(HPD)(60)(0.50)(33,000)

where:

HP	=	Total pumping horsepower required, hp.
H	=	Total pumping head required, ft (see Calculation #5).
SV	=	Daily sludge volume, gpd (see Calculation #1).
HPD	=	Hours per day of pumping, HPD, hr (see Calculation #1).
33,000	=	Conversion factor, hp to ft-lb/min.
60	=	Conversion factor, min/hr.
0.50	=	Assumed pump efficiency.
8.34	=	Density of water, lb/gal.

(7) Horsepower required per pump station.

HPS = HP/NOPS

where:

HPS	=	Horsepower required per pump station, hp.
HP	=	Total pumping horsepower required, hp (see Calculation #6).
NOPS	=	Number of pumping stations (see Calculation #5).

(8) Electrical energy requirement.

E = [(0.0003766)(1.2)(H)/(0.5)(0.9)](SV)(365)(8.34)/1,000

where:

E	=	Electrical energy, kWhr/yr.
0.0003766	=	Conversion factor, kWhr/1,000 ft-lb.
8.34	=	Density of water, lb/gal.
1.2	=	Assumed specific gravity of sludge.
0.5	=	Assumed pump efficiency.
0.9	=	Assumed motor efficiency.

(9) Operation and maintenance labor requirement.

L = (NOPS)(LPS) + (PL)(0.02)

where:

L	=	Annual operation and maintenance labor, hr/yr.
NOPS	=	Number of pumping stations (see Calculation #5).
LPS	=	Annual labor per pump station, hr/yr. This is a function of pump station horse power, HPS, as shown in Table 16-28.
PL	=	Pipeline length, ft (see Calculation #4).
0.02	=	Assumed maintenance hr/yr per ft of pipeline, hr/ft.

Table 16-28. Annual Labor Per Pump Station

Pump Station Horsepower (HPS)	Annual O&M Labor (LPS) (hr)
25	700
50	720
75	780
100	820
150	840
200	870
250	910
300	940
350	980

(10) Cost of installed pipeline.

$$COSTPL = (1 + 0.7\ ROCK)(1 + 0.15\ DEPTH)\ PL\ (COSTP)\ \frac{ENRCCI}{5445.83}$$

where:

COSTPL	=	Cost of installed pipeline, $.
0.7	=	Assumed fraction of pipeline length that requires rock excavation.
ROCK	=	Fraction of pipeline length that requires rock excavation.
0.15	=	Assumed fraction of pipeline length that does not require rock excavation, but is greater than 6 ft deep.
DEPTH	=	Fraction of pipeline length that does not involve rock excavation, but is greater than 6 ft deep.
PL	=	Pipeline length, ft (see Calculation #4).
COSTP	=	Pipeline cost per unit length, $/ft. This cost is obtained from Table 16-29.
ENRCCI	=	Current Engineering News Record Construction Cost Index at time analysis is made.

Table 16-29. Pipeline Cost

Pipeline Diameter (PD) (inches)	Installed Cost (COSTP) ($/ft, 1994 $)[a]
4	28.68
6	30.99
8	34.39
10	37.93
12	41.33
14	48.26
16	52.88
18	58.59
20	68.92

[a] Costs were taken from EPA's 1985 Cost Estimation Handbook (U.S. EPA, 1985) and inflated to 1994 price levels using the MSECI.

(11) Cost of pipeline crossings.

$$COSTPC = [NOH(\$26,000) + NODH(\$52,000) + NRC(\$19,000) + NOSR(\$116,000) + NOLR(\$462,000)]\ \frac{ENRCCI}{5445.83}$$

where:

COSTPC	=	Cost of pipe crossings, $.
NOH	=	Number of 2- or 4-lane highway crossings. Default value = 1.
NODH	=	Number of divided highway crossings, NODH. Default value = 0.
NRC	=	Number of railroad tracks (2 rails/track) crossed. Default value = 2.
NOSR	=	Number of small rivers crossed. Default value = 0.
NOLR	=	Number of large rivers crossed. Default value = 0.
ENRCCI	=	Current Engineering News Record Construction Cost Index at time analysis is made.

(12) Cost of pump stations.

$$COSTPS = NOPS\ [\$218,000 + \$3,600\ (HPS-25)]\ \frac{MSECI}{990.8}$$

where:

COSTPS	=	Construction cost of all pump stations.
NOPS	=	Number of pumping stations (see Calculation #5).
HPS	=	Horsepower required per pump station, hp (see Calculation #7).
MSECI	=	Current Marshall and Swift Equipment Cost Index at time analysis is made.

Note: If HPS is less than 25 hp, then, for this calculation, let HPS = 25 hp.

(13) Annual cost of electrical energy.

$$COSTEL = (E)(COSTE)$$

where:

COSTEL	=	Total annual cost of electricity, $/yr.
E	=	Electrical energy requirement, kWhr/yr.
COSTE	=	Unit cost of electricity, $/kWhr. Default value = $0.121/kWhr (ENRCCI/5445.83).

(14) Annual cost of operation and maintenance labor.

$$COSTLB = (L)(COSTL)$$

where:

COSTLB	=	Annual cost of operation and maintenance labor, $/yr.
L	=	Operation and maintenance labor requirement, hr/yr.
COSTL	=	Unit cost of labor, $/hr. Default value = $22.97/hr (ENRCCI/5445.83).

(15) Cost of pumping station replacement parts and materials.

$$COSTPM = NOPS\ (PS)\ \frac{MSECI}{990.8}$$

where:
COSTPM = Annual cost of pumping station replacement parts and materials, $/yr.
PS = Annual cost of parts and supplies for a single pumping station, $/yr. This cost is a function of pumping station horse power as shown in Table 16-30.
MSECI = Current Marshall and Swift Equipment Cost Index at time analysis is made.

Table 16-30. Annual Cost of Pumping Station Parts and Supplies

Pump Station Horsepower (HPS)	Annual Parts and Supplies[a] Cost (PS) ($/Yr, 1994 $)
25	1,420
50	1,490
75	1,680
100	1,820
150	1,980
200	2,100
250	3,750
300	3,910
350	4,100

[a] Costs were taken from EPA's 1985 Cost Estimation Handbook (U.S. EPA, 1985) and inflated to 1994 price levels using the MSECI.

(16) Total base capital cost.

TBCC = COSTPL + COSTPC + COSTPS

where:
TBCC = Total base capital cost, $.
COSTPL = Cost of installed pipeline, $.
COSTPC = Cost of pipeline crossings, $.
COSTPS = Cost of pump stations, $.

(17) Total annual operation and maintenance cost.

COSTOM = COSTEL + COSTLB + COSTPM

where:
COSTOM = Total annual operation and maintenance cost, $/yr.
COSTEL = Annual cost of electrical energy, $/yr.
COSTLB = Annual cost of operation and maintenance labor, $/yr.
COSTPM = Cost of pumping station replacement parts and materials, $/yr.

16.6 Example of Preliminary Cost Estimation for Agricultural Land Application to Cropland

The following preliminary cost estimation for land application of sewage sludge to cropland is for a midwestern city generating a daily sludge volume of 131,894 gpd (20 dry t/day, 22 T/day).[1] The sludge has a suspended solids concentration of 4 percent and the appropriate application rate for growing corn at this site was determined to be 4 T/ac/yr (9 t/ha/yr).

16.6.1 Process Design and Cost Calculations

(1) Calculate dry solids applied to land per year.

TDSS = [(SV)(8.34)(SS)(SSG)(365)]/(2,000)(100)

where:
TDSS = Dry solids applied to land, Tons/yr.
SV = 131,894 gpd.
SS = 4 percent.
SSG = Calculate using the following equations:

SSG = 1/[(100 - SS)/100) + (SS)/(1.42)(100)]

SSG = 1/[(100 - 4)/100) + (4)/(1.42)(100)]

SSG = 1.01

TDSS = [(131,894)(8.34)(4)(1.01)(365)]/(2,000)(100)

TDSS = 8,126 Tons/year

(2) Sludge application area required.

SDAR = (TDSS)/(DSAR)

where:
SDAR = Farm area required for sludge application, ac.
TDSS = 8,126 Tons/yr.
DSAR = 4 Tons/ac/yr.

SDAR = (8,126)/(4)

SDAR = 2,302 ac.

(3) Hourly sludge application rate.

HSV = (SV)(365)/(DPY)(HPD)

where:
HSV = Hourly sludge application rate, gal/hr.
SV = 131,894 gpd.
DPY = 120 days/yr from Table 16-1.
HPD = 8 hr/day.

HSV = (131,894)(365)/(120)(8)

HSV = 50,147 gal/hr.

[1] See Appendix D for equations for converting sludge volume to dry metric tons.

(4) Capacity of onsite mobile sludge application vehicles.

It is assumed that the sludge has already been transported to the private farm land application site by a large-haul vehicle. The onsite mobile application vehicles accept the sludge from the transport vehicle and proceed to the sludge application area to apply the sludge.

(4a) Capacity and number of onsite mobile sludge application vehicles.

The capacity and number of onsite mobile sludge application vehicles required is determined by comparing the hourly sludge volume, (HSV), with the vehicle sludge handling rate, (VHRCAP), as shown in Table 16-2.

Since the HSV is 50,147 gal/hr, the number of 4,000-gal capacity vehicles required is calculated by:

NOV = HSV/6,545 (round to the next highest integer)

where:

NOV	=	Number of onsite sludge application vehicles.
HSV	=	50,147 gal/hr.

NOV = 50,147/6,545

NOV = 8

(4b) The average round trip onsite cycle time (CT) for mobile sludge application vehicles with a capacity of 4,000 gal. is 33 from Table 16-3.

(4c) The VHRCAP for a single vehicle is 6,545 from Table 16-4.

(5) Total land area required.

TLAR = (1 + FWWAB)(SDAR)

where:

TLAR	=	Total land area required for agricultural land application site, ac.
FWWAB	=	0.4.
SDAR	=	2,032 ac.

TLAR = (1 + 0.4)(2,032)

TLAR = 2,845 ac.

(6) Lime addition required for soil pH adjustment to a value of at least 6.5.

TLAPH = (FRPH)(SDAR)

where:

TLAPH	=	Total land area requiring lime addition, ac.
FRPH	=	0.5.
SDAR	=	2,032 ac.

TLAPH = (0.5)(2,032)

TLAPH = 1,016 ac.

(7) Total land area requiring light grading.

TLARLG = (FRLG)(SDAR)

where:

TLARLG	=	Total land area requiring light grading, ac.
FRLG	=	0.3.
SDAR	=	2,032 ac.

TLARLG = (0.3)(2,032)

TLARLG = 610 ac.

(8) Annual operation labor requirement.

L = 8 (NOV)(DPY)/0.7

where:

L	=	Annual operation labor requirement, hr/yr.
NOV	=	8
DPY	=	120 days/yr.
8	=	Hr/day assumed.
0.7	=	Efficiency factor.

L = 8 (8)(120)/0.7

L = 10,971 hr/yr.

(9) Annual diesel fuel requirement for onsite mobile sludge application vehicles.

FU = (HSV)(HPD)(DPY)(DFRCAP)/(VHRCAP)

where:

FU	=	Annual diesel fuel usage, gal/yr.
HSV	=	50,147 gal/hr.
HPD	=	8 hr/day.
DPY	=	120 days/yr.
DFRCAP	=	6 gal/hr from Table 16-5.
VHRCAP	=	6,545 gal/hr.

FU = (50,147)(8)(120)(6)/(6,545)

FU = 44,132 gal/yr.

(10) Cost of land (COSTLAND) is zero because it is assumed that the application of sewage sludge is on privately owned farm land.

(11) Cost of lime addition to adjust pH of soil.

COSTPHT = (TLAPH)(COSTPHT)

where:
COSTPHT = Cost of lime addition, $.
TLAPH = 1,016 ac.
PHCST = $82/ac., this value assumes 2 Tons of lime/ac requirement.

COSTPHT = (1,016)($82)

COSTPHT = $83,312

(12) Cost of light grading earthwork.

COSTEW = (TLARLG)(LGEWCST)

where:
COSTEW = Cost of earthwork grading, $.
TLARLG = 610 ac.
LGEWCST = $1,359/ac.

COSTEW = (610)($1,359)

COSTEW = $828,990

(13) Cost of onsite mobile sludge application vehicles.

$$\text{COSTMAV} = (\text{NOV})(\text{COSTPV})\,\frac{\text{MSECI}}{990.8}$$

where:
COSTMAV = Cost of onsite mobile sludge application vehicles, $.
NOV = 8.
COSTPV = $185,000 from Table 16-6.
MSECI = Current Marshall and Swift Equipment Cost Index at time of analysis is 990.8.

$$\text{COSTMAV} = (8)(\$185{,}000)\,\frac{990.8}{990.8}$$

COSTMAV = $1,480,000

(14) Annual cost of operation labor.

COSTLB = (L)(COSTL)

where:
COSTLB = Annual cost of operation labor, $/yr.
L = 10,971 hr/yr.
COSTL = Cost of operation labor, $22.97/hr.

COSTLB = (10,971)($22.97)

COSTLB = $252,004

(15) Annual cost of diesel fuel.

COSTDSL = (FU)(COSTDF)
where:
COSTDSL = Annual cost of diesel fuel, $/yr.
FU = 44,132 gal/yr.
COSTDF = Cost of diesel fuel, $1.09/gal.

COSTDSL = (44,132)($1.09)

COSTDSL = $48,104

(16) Annual cost of maintenance for onsite mobile sludge application vehicles.

$$\text{VMC} = [(\text{HSV})(\text{HPD})(\text{DPY})(\text{MCSTCAP})/(\text{VHRCAP})]\,\frac{\text{MSECI}}{990.8}$$

where:
VMC = Annual cost of vehicle maintenance, $/yr.
HSV = 50,147 gal/hr.
HPD = 8 hr/day.
DPY = 120 days/yr.
MCSTCAP = $9.45/hr from Table 16-7.
VHRCAP = 6,545 gal/hr.
MSECI = Current Marshall and Swift Equipment Cost Index at time of analysis is 990.8.

$$\text{VMC} = [(50{,}147)(8)(120)(\$9.45)/(6{,}545)]\,\frac{990.8}{990.8}$$

VMC = $69,509

(17) Annual cost of maintenance for land application site (other than vehicles) including monitoring, recordkeeping, etc.

$$\text{SMC} = [(\text{TLAR})(16)]\,\frac{\text{ENRCCI}}{5{,}445.83}$$

where:
SMC = Annual cost of maintenance (other than vehicles), $/yr.
TLAR = 2,845 ac.
16 = Annual maintenance cost, $/ac.
ENRCCI = Current Engineering News Record Construction Cost Index at time of analysis is 5445.83.

$$\text{SMC} = [(2{,}845)(16)]\,\frac{5{,}445.83}{5{,}445.83}$$

SMC = $45,520

(18) Total base capital cost.

TBCC = COSTLAND + COSTPHT + COSTEW + COSTMAV

where:

TBCC	=	Total base capital cost of agricultural land application program using onsite mobile sludge application vehicles, $.
COSTLAND	=	$0.
COSTPHT	=	$83,312.
COSTEW	=	$828,990.
COSTMAV	=	$1,480,000.

TBCC = $0 + $83,312 + $828,990 + $1,480,000

TBCC = $2,392,302

(19) Total annual operation and maintenance cost.

COSTOM = COSTLB + COSTDSL + VMC + SMC

where:

COSTOM	=	Total annual operation and maintenance cost for agricultural land application program using onsite mobile sludge application vehicles, $/yr.
COSTLB	=	$252,004/yr.
COSTDSL	=	$48,104/yr.
VMC	=	$69,509/yr.
SMC	=	$45,520/yr.

COSTOM = $252,004 + $48,104 + $69,509 + $45,520

COSTOM = $415,137/yr.

16.7 References

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Appendix A
Case Studies

This appendix presents four cases studies illustrating land application at agricultural, forest, and reclamation sites. The case studies include:

- Madison Metropolitan Sewerage District (MMSD), Madison, Wisconsin. The MMSD applies approximately 20 dry tons of sewage sludge per day to private farmland. Reprinted from *Document Long-Term Experience of Biosolids Land Application Programs*, Water Environment Research Foundation, 1993.
- Metro Wastewater Reclamation District (MWRD), Denver, Colorado. The MWRD produces 70 dry tons of sewage sludge per day, which are either applied to agricultural land or composted and sold to the public. Reprinted from *Document Long-Term Experience of Biosolids Land Application Programs*, Water Environment Research Foundation, 1993.
- The Municipality of Metropolitan Seattle (Metro), Seattle, Washington. Metro has applied sewage sludge to private forest land, with 19,000 dry tons applied to date. Reprinted from *The Future Direction of Municipal Sludge (Biosolids) Management: Where We Are and Where We're Going*, Proceedings, Volume 1, Water Environment Research Foundation, 1992.
- Venango County, Pennsylvania, Abandoned Mine Land Reclamation. Sewage sludge was applied in a single application at a rate of 184 mg/ha.

These case studies provide valuable insights into design, operation, monitoring, public relations, and other aspects of programs representing a range of sizes and geographical locations. It should be noted that, in some cases, these programs will need to make minor operational changes to achieve compliance with the Part 503 regulation.

MADISON METROPOLITAN SEWERAGE DISTRICT, MADISON, WI

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Average flow:	37 mgd
Design capacity of WWTP:	50 mgd
Dry tons of biosolids/day:	20
Type of biosolids:	anaerobically digested
Biosolids management options:	land application
Application method:	injection
Started application:	1974

5.1 Program Overview

Wastewater treatment at the Nine Springs WWTP started in 1933. Until 1942, anaerobically digested biosolids was air dried and applied to farmland as a fertilizer/soil conditioner. Because of the manpower shortage during World War II, the system was abandoned in favor of a lagoon storage system. In 1974, after evaluating several alternatives, the Madison Metropolitan Sewerage District (MMSD) decided to begin land applying the biosolids to private farmland.

Currently all biosolids produced at the Nine Springs Wastewater Treatment Plant (WWTP) are land applied. The design capacity of this activated biosolids treatment plant is 50 mgd. Current flow is around 37 mgd. About 15% of the wastewater comes from industrial sources. The raw sludge is stabilized by anaerobic digestion, and the resulting biosolids are marketed to farmers through the Metrogro™ Program. Current biosolids production is approximately 20 dry tons per day. The MMSD is also removing biosolids from the lagoons, resulting in a 50 percent increase in the quantity of biosolids land applied.

Biosolids are thickened by gravity belt thickeners to approximately 6% total solids. The thickened solids are transported directly to land application, to off-site storage lagoons, or to storage lagoons located adjacent to the treatment plant. Prior to off-site transport, the thickened or dredged biosolids are pumped to a 100,000 gallon holding basin at the truck loading station. The biosolids dredged from the lagoons have a total solids concentration between 4 and 5 percent. From the holding basin the biosolids are pumped to a 50,000-gallon elevated loading well from which biosolids can be pumped to the transport trucks. After a truck is loaded any spilt biosolids are washed off using the on-site washing facilities that are available at the loading site. The MMSD owns six transport trucks, three mobile storage tanks, and four application vehicles.

Liquid biosolids are transported to the land application site using 5,500-gallon vacuum trucks that are compatible with the weight limits on the local roads. The trucks discharge the biosolids into a 12,000-gallon mobile storage tank located at the application site. A 3,500-gallon application vehicle withdraws biosolids from the storage tank, and injects them 6 to 8 inches beneath the soil surface. Figure 5-1 shows a typical storage tank and application vehicle.

Two trucks normally supply one storage tank and application vehicle. The use of the storage tank has resulted in a 25% increase in productivity. Usually the storage tank stays in one place during the application to minimize the size of the staging area. After the application is complete, the staging area is tilled to counteract the compaction caused by the truck traffic. One application vehicle is capable of spreading biosolids over 8 to 10 acres during a 10-hour operating period. The biosolids injection vehicles have been modified by increasing the number of injection shanks to 6 per vehicle, and by adding a drag behind the injectors to smooth the disturbed soil as shown in Figure 5-2. During the application season the vehicles return to the treatment plant only for major repairs.

Figure 5-1. Storage tank and application vehicle.

Figure 5-2. Application vehicle.

The MMSD has permits for 250 to 300 farms to apply biosolids or approximately 30,000 acres of permitted land with 3,000 to 4,000 acres used annually. Biosolids are applied at agronomic rates ranging from 3 to 5 dry tons per acre per year depending on the crop. The biosolids cumulative loading on the field included in this study (site 22, Field 2) is approximately 80 dry tons per acre. Field corn is the primary crop, but other crops include sweet corn, soybeans, and alfalfa (at seedbed preparation). No minimum size has been established for fields; however the MMSD prefers to use large fields to help reduce operating costs. The average transport distance is about 13 miles, while the maximum distance is 22 miles.

During peak application periods, i.e. spring and fall, biosolids are applied 10 to 12 hours per day, 6 days per week. Contract operators, under MMSD supervision, are employed to assist the MMSD, and truck traffic becomes heavy with as many as 100 truckloads hauled every day. This truck traffic can generate numerous complaints from the public. Participating farmers have expressed concern over the use of contractors during the peak application season. Most contractors use five-wheeled application vehicles, which the farmers feel cause more soil compaction than the MMSD's four-wheeled application vehicles.

The MMSD is closing both the on-site and off-site storage lagoons, except for a portion of the on-site lagoons which will be retained for emergency storage. Concurrently with the lagoon closure plan, the MMSD is constructing tank storage facilities for 18 million gallons of biosolids or for 180 days at maximum monthly design flow.

The MMSD uses a computerized recordkeeping and tracking system for all aspects of its Metrogro Program. The MMSD works closely with the Wisconsin Department of Natural Resources (WDNR) to ensure that reports are formatted to ensure a fast and efficient transfer of information to the regulating agency.

5.2 Monitoring

As shown in Table 5–1, the monitoring program includes sampling and analyses of biosolids, soil, crop/tissue/grain, and groundwater. Samples of biosolids are collected from each truck and combined into a daily composite sample. The daily composite is analyzed for total solids, total kjeldahl nitrogen and ammonia nitrogen. Weekly and monthly composite samples are made from the daily composites. The monthly samples are analyzed for the parameters in Table 5–1. A full priority pollutant analysis is conducted once each year.

Surface soil samples (0 to 6 inch depth) are collected from each field when the site is initially permitted with the WDNR. Active application sites are resampled every three years. The surface soil samples are used to determine crop nutrient requirements, as well as the soil cation exchange capacity (CEC) and soil pH. Where necessary, the MMSD requires that farmers lime fields to meet the minimum soil pH requirement of 6.5 that is specified by the WDNR.

Deep core (4 feet) soil samples and plant tissue samples are collected from representative soil types encountered in the Metrogro program. These samples are analyzed for the parameters listed in Table 5–1. Deep core samples are collected from these soil types prior to the initial biosolids application, and every three years thereafter. These samples are used to evaluate whether metals are moving from the zone of incorporation. Plant tissue samples are collected from these sites every three years, and the metal concentrations are compared to available risk–based criteria.

Groundwater samples are collected from private wells located near land application sites. Approximately 750 private wells are sampled each year. The samples are analyzed for nitrate, chloride, sulfate, coliform bacteria, and zinc. Results of the groundwater analyses are provided to the well owner.

Table 5-1
Parameters Monitored by Madison Metropolitan Sewerage District

Parameter	Biosolids	Soil	Crops	Groundwater
Total Solids	x			
Total Volatile Solids	x			
pH	x	x		
Cation Exchange Capacity (CEC)		x		
Total Kjeldahl Nitrogen (TKN)	x			
Ammonium-Nitrogen	x			
Nitrate-Nitrogen	x			x
Phosphorus	x	x		
Potassium	x	x		
Cadmium	x	x	x	
Chloride				x
Chromium		x	x	x
Copper	x	x	x	
Nickel	x	x	x	
Lead	x	x	x	
Zinc	x	x	x	x
PCB (lagoon)	x			
Arsenic	x			
Molybdenum (lagoon)	x			
Selenium (lagoon)	x			
Pesticides	x			
Phenol	x			
Tetrachloroethylene	x			
Trichloroethylene	x			
Vinyl Chloride		x		
Ascaris			x	
Coliform		x		x
Salmonella	x			

Table 5-2
Average Concentrations in MMSD Digested Biosolids

Parameter	1989	1990	1991	1992
pH	7.4	7.5	7.5	7.6
		- - - - - - - - - - % - - - - - - - - - -		
Total Solids	2.2	4.8	5.5	5.7
TKN	10.6	8.2	7.5	7.4
Ammonium-Nitrogen	5.5	3.2	2.1	2.0
Phosphorus	2.8	2.5	2.6	2.6
Potassium	1.0	0.7	0.6	0.7
		- - - - - - - - - mg/kg - - - - - - - - -		
Arsenic	4.1	6.9	4.7	3.7
Cadmium	15.0	13.1	11.2	13.7
Chromium	96.6	107	71.5	81.6
Copper	683	671	634	609
Lead	145	152	133	134
Mercury	6.7	8.1	5.9	4.8
Molybdenum	18.4	18.9	15.3	12.2
Nickel	46.2	46.7	45.4	42.9
Selenium	2.9	5.3	8.2	6.3
Zinc	1,200	1,250	1,060	1,040

The deep core soil, plant tissue, and groundwater monitoring programs are not required by the WDNR. They are conducted on a voluntary basis by the MMSD in an effort to increase both farmer and the general public's confidence in the Metrogro program. Soil and plant samples have also been collected from a number of test sites, with controlled, replicated biosolids applications.

5.3 Results

Table 5-2 lists the average digested biosolids quality. The values for the lagooned biosolids are similar. Of the organics tested, only bis-(2-ethylhexyl) phthalate was above the detection limit and measured 6.3 mg/kg. Although bis-(2-ethylhexyl) phthalate is a common laboratory contaminant and was found in some of the blanks, it is commonly found in biosolids. Parameter concentrations in biosolids are currently below the Pollutant Concentration limits of 40 CFR Part 503.

Figures 5–3 through 5–5 show the soil concentrations for cadmium, nickel, and lead, at different soil depths on site 22, Field 2. The metal concentrations in the soil do not appear to be well correlated with the loading. Nickel concentrations in the soil are declining; cadmium concentrations stay fairly constant in the surface soil, but are declining in the subsoil; and lead concentrations in the surface soil increased much faster than would be expected from the loading but show little change in the lower soil layers.

The plant uptake of metals was investigated by the MMSD through a field experiment with three replications. Fertilizer, biosolids at agronomic rates, and biosolids at twice the agronomic rates were applied to the field. Table 5–3 shows the cumulative metals loadings for the three test fields and the soil concentrations at the conclusion of the study in 1987. Corn was grown, and samples were taken from ear leaf and grain tissues. Results from the ear leaf analyses are shown in Table 5–4. Significant increases in the zinc and cadmium and decreases in the copper concentrations could be detected in the ear leaf tissues. Grain tissue concentrations were always significantly lower than ear leaf concentrations.

The groundwater monitoring results have shown a trend for increasing nitrate and chloride concentrations over time. The lack of background data for coliform bacteria in many wells made it difficult to evaluate changes in water quality relative to this parameter. A long–term groundwater monitoring study was initiated by the MMSD in 1982 to compare groundwater quality trends at Metrogro application sites to sites where commercial fertilizers and animal manures were used. The study found no significant difference in groundwater quality trends between sites where Metrogro was used and sites where commercial fertilizers/animal manures were used. Thus, while the farming practices seem to impact the groundwater, the impact from Metrogro applications seems to be no different than the impact of traditional farming practices.

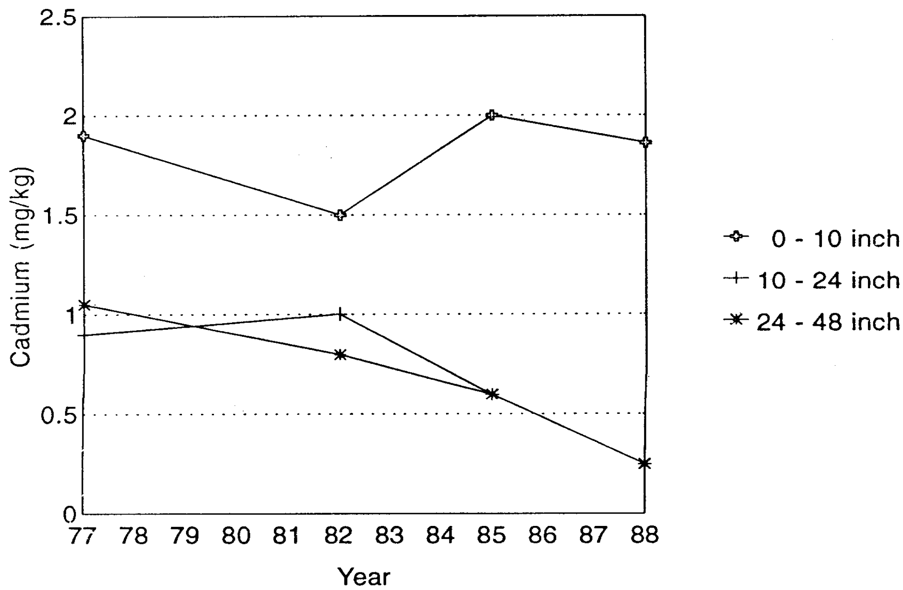

Figure 5-3. Cadmium concentrations in the soil on site 22, Field 2.

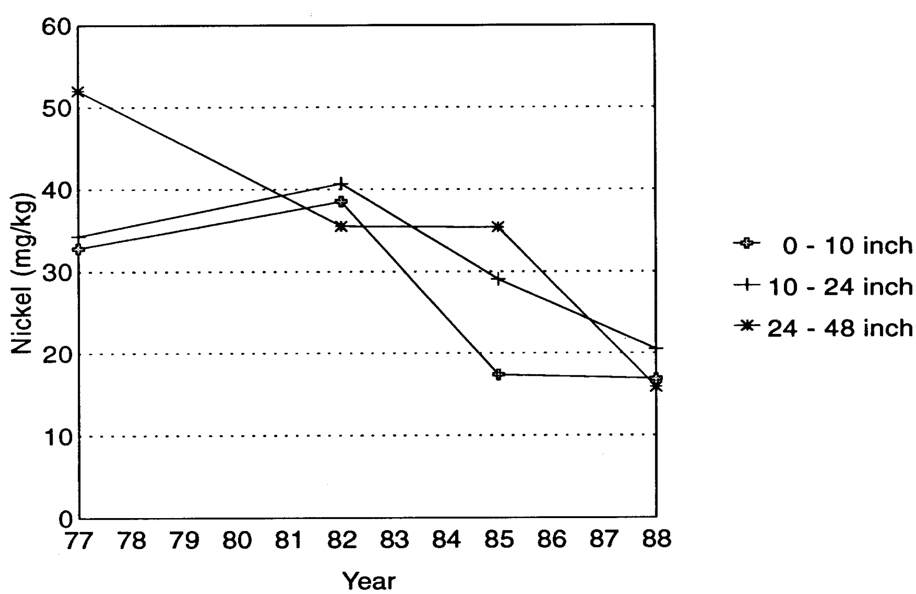

Figure 5-4. Nickel concentrations in the soil on site 22, Field 2.

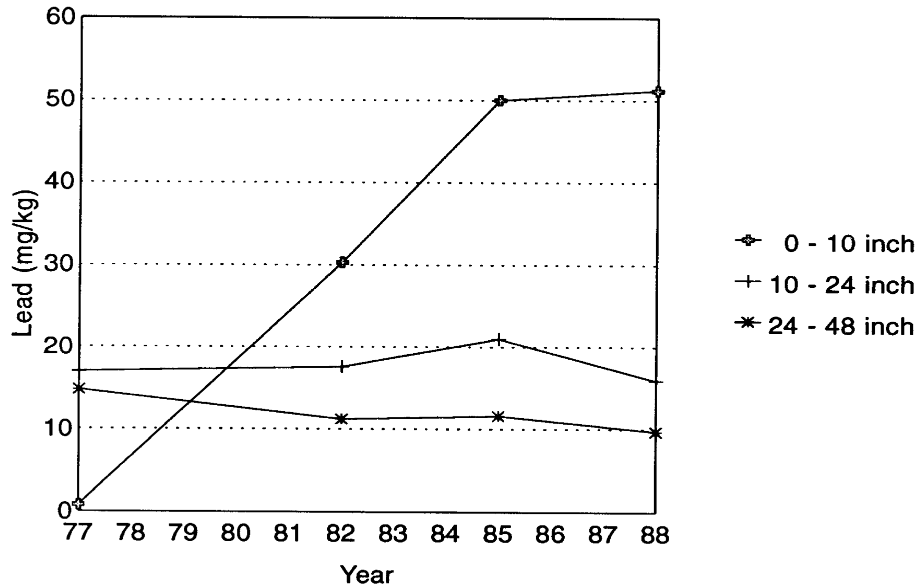

Figure 5-5. Lead concentrations in the soil on site 22, Field 2.

Table 5-3
Cumulative Metals Loadings and Soil Test Levels for Plant Uptake Study

Treatment	Cd	Cr	Cu	Ni	Pb	Zn
			Cumulative Loading (lb/acre)			
Fertilizer	0	N/A[+]	0	0	0	0
Biosolids	1.31	N/A	30.6	3.0	12.5	97.1
Biosolids 2X	2.62	N/A	61.2	6.0	23.9	194
			1987 Soil Test (mg/kg)			
Fertilizer	0.27	17.2	16.8	13.8	23.7	95
Biosolids	0.63	19.2	23.9	14.2	25.9	113
Biosolids 2X	0.81	24.1	29.4	15.7	28.1	134

[+] Data not available.

Table 5-4
Metal Concentrations in Corn Ear Leaf Tissue

Year	Cd	Cr	Cu	Ni	Pb	Zn
			mg/kg (dry weight)			
			Fertilizer			
78	0.13	0.51	13.8	0.87	0.86	67.5
79	0.22	0.63	12.4	1.00	0.93	79.5
80	0.14	0.39	14.7	0.75	0.63	80.0
81	0.15	0.44	13.0	1.08	0.82	88.8
82	0.22	0.51	16.8	1.31	1.74	125.5
83	0.18	6.48	10.2	5.27	0.78	66.0
84	0.18	3.60	12.4	3.24	0.66	50.0
85	0.10	2.03	10.8	1.75	0.53	54.0
86	0.19	1.72	11.0	1.13	0.20	47.0
87	0.06	1.02	7.6	0.93	0.24	39.8
			Biosolids			
78	0.17	0.62	13.1	0.64	0.94	68.7
79	0.28	0.68	11.8	0.85	1.06	79.0
80	0.41	0.41	14.0	0.67	0.76	79.5
81	0.31	0.56	12.3	0.97	0.79	132.
82	0.43	0.67	14.2	1.35	1.98	152
83	0.27	6.41	10.0	5.76	0.69	57.5
84	0.30	3.91	11.4	3.45	0.57	49.0
85	0.17	2.00	9.6	1.69	0.69	59.5
86	0.27	1.81	11.2	1.18	0.20	46.5
87	0.09	1.42	8.0	1.05	0.20	47.8
			Biosolids 2x			
78	0.20	0.54	13.8	0.57	0.91	65.5
79	0.48	0.51	12.5	0.72	0.91	91.0
80	0.70	0.44	14.7	0.68	0.62	105.5
81	0.41	0.52	12.3	0.88	0.77	172.5
82	0.52	0.66	14.6	1.36	1.94	167.0
83	0.36	4.78	9.3	4.45	0.50	66.0
84	0.33	6.33	11.5	5.27	0.50	47.5
85	0.23	2.00	10.2	1.68	0.59	65.8
86	0.31	1.86	11.8	1.27	0.22	57.5
87	0.14	2.13	8.2	1.55	0.23	60.3

5.4 Public Relations

Public relations and education are critical to the success of the MMSD's Metrogro program. The MMSD has sought to include the public in the planning and design of the Metrogro system. Questionnaires were distributed to farmers to determine their interests, concerns, and farming practices. Equipment demonstrations were held, and feedback was sought from farmers, local officials, and the public. Farmers were interested in having equipment that would incorporate residuals into the soil, and they preferred high flotation tires that would help reduce soil compaction. Local officials were concerned about road damage from heavy truck traffic. The cleanliness of the applications was of concern to both homeowners and farmers.

One of the first steps taken in the Metrogro public education effort was to avoid the use of the term "sewage sludge" because of its negative connotations. A contest was held to select an alternative term. The reus ogram became known as the "Metrogro Program" and the biosolids were referred to as "Metrogro". A logo was developed to help identify the "Metrogro Program".

The MMSD attends town meetings and sponsors farmer meetings to explain the benefits and limitations of the environmental monitoring program, the wastewater treatment processes, and the land application program. Tours of the treatment plant are given to interested parties. Public demonstration plots comparing Metrogro and commercial fertilizer treatments were established and maintained.

The local news media are kept informed about the project and its activities. The relationship with the media continues to be favorable. Articles in local newspapers and farm publications generally promote the Metrogro program.

The perception that Metrogro is a resource rather than a waste product was fostered by establishing a fee for the biosolids application. Over the years increases in the fees have been made. The fee is currently $7.50 per acre. The fertilizer $N-P_2O_5-K_2O$ value of the biosolids is around \$35 in fertilizer savings. This value was calculated for 64, 120, and 14 pounds of N, P_2O_5, and K_2O/ton using \$0.20, \$0.23, and \$0.12 for N, P_2O_5, and K_2O respectively.

Other activities and publications the MMSD has developed to educate the public and farm community include the following:

- Informational brochures.
- Letters to farmers once or twice a year.
- A slide show for public meetings and school demonstrations.
- Periodic farmer meetings.

The private groundwater testing program has also become a part of the outreach program. A representative of the treatment plant contacts the landowners on a regular basis. Complaints and concerns about the program are likely to be discussed with the representative and can be dealt with in a constructive manner.

Farmer acceptance of the Metrogro program seems to rest on the following factors:

- Keeping the application equipment clean and neat to project a professional image.
- Trying to minimize the compaction of soil by keeping the staging area in the field as small as possible.
- Using a storage tank in the field to provide a buffer between the trucking and application of biosolids, increasing the efficiency of the operation.
- Employing experienced operators, who can minimize mistakes during the land application.
- Being willing to do a little extra work to leave the field in a condition that helps the farmer with his operation.
- Maintaining a constant presence in the community, so that the program is associated with the activities of the city, like garbage pickup or street cleaning.

5.5 Summary

The MMSD has been applying biosolids from its Nine Springs WWTP on privately owned farmland since 1974. The Nine Springs WWTP produces approximately 20 dry tons of biosolids per day. An existing lagoon storage system allows the MMSD to store biosolids during periods when inclement weather and agricultural practices prevent land application. New storage tanks are being constructed, and a portion of the existing lagoons is being closed. The new tank facilities should provide storage capacity for 180 days of biosolids production at maximum monthly flows.

Anaerobically digested biosolids are thickened to approximately 6 percent prior to land application. The MMSD uses its own equipment to transport and apply biosolids on a regular basis; however, contractors are used to supplement the MMSD's operations during peak periods. Biosolids are injected at agronomic rates that typically range from 3 to 5 dry tons per acre per year. Total cumulative biosolids loading on the site evaluated is approximately 80 dry tons per acre, equivalent to 16 to 27 years of consecutive agronomic applications.

One of the unique aspects of this program is the use of a storage tank in the field to decouple the transport and application of biosolids. Using storage tanks in the field has increased the MMSD's productivity by about 25%.

A comparison of soil metal loadings and soil metal test values show that the two parameters are not well correlated. For example, lead concentrations in the surface soil increased faster than would be expected from the loading.

Field experiments were conducted by the MMSD to evaluate plant uptake of metals. Under the controlled conditions, significant increases in zinc and cadmium concentrations could be detected in corn ear leaf tissue.

The MMSD's groundwater monitoring program has shown a trend for increasing nitrate and chloride concentrations over time. However, a study comparing the groundwater quality at Metrogro sites to sites where commercial fertilizers and animal manures are used showed that the impacts from Metrogro applications appear to be no different than the impacts from traditional farming practices.

The MMSD credits its extensive public relations efforts and willingness to work with farmers for the success of the program. The public is not only regularly informed about the program's status through the news media and public meetings, but the MMSD also involves the public in the planning and design of the program. For example, the public was actively involved in the selection of equipment and the Metrogro logo. The perception that biosolids are a resource rather than a waste is fostered by charging a fee for the biosolids application.

METRO WASTEWATER RECLAMATION DISTRICT, DENVER CO

Contact Person:	William J. Martin Metropolitan Denver Sewage Disposal Dist. No. 1 6450 York Street Denver, CO 80229
Phone Number:	(303) 289-5941

Average flow	150 mgd
Design capacity	185 mgd
Dry tons of biosolids/day	70
Type of biosolids	anaerobically digested
Biosolids management options	land application and composting
Application method	injection/surface application followed by incorporation
Started application	1979

6.1 Program Overview

The Metro Wastewater Reclamation District (MWRD) began processing wastewater at the Central Plant in 1966. The agricultural land application program was established in 1979. The MWRD currently processes 150 mgd at its Central Plant, which has a design capacity of 185 mgd. The plant provides primary and secondary treatment using the activated sludge process to provide nitrification-denitrification. Primary and secondary sludges are combined and stabilized by anaerobic digestion. The treatment plant produces about 70 dry tons per day of digested biosolids. The digested biosolids are thickened or dewatered using centrifuges. The dewatered biosolids are either applied to agricultural land or composted and sold to the public under the name METROGRO™. The charges for the METROGRO™ products at the time of this study are:

- $1.75 per 1.25 cubic foot bag of fine-screened compost.
- $19.00 per ton for fine-screened compost.
- $13.00 per ton for coarse-screened compost.
- $3.00 per acre for thickened or dewatered biosolids.

About 10% of the biosolids produced is currently composted, and the remaining 90% is applied to land. While composting is more expensive than land application, the MWRD maintains the composting facilities to enhance the flexibility and reliability of the program. During the preparation of this report, the MWRD purchased approximately 10,000 acres of land. Use of this site will reduce the need to obtain permits from local jurisdictions for privately-owned farmland and allow MWRD to manage the entire agricultural program.

The MWRD began applying biosolids to privately-owned farmland in 1979. The biosolids are thickened to approximately 8 to 9 percent total solids prior to being transported to the application site in 7,000-gallon tank trucks. The MWRD owns eight tank trucks like the one shown in Figure 6-1. The biosolids are injected 6 to 12 inches beneath the soil surface by one of three injection vehicles. Two of the injection units have a capacity of 7,200 gallons and the third one, 4,000 gallons.

Later, the MWRD began surface application of dewatered biosolids to improve the cost-effectiveness and flexibility of the program. Dewatered biosolids can be applied during the winter months when subsurface injection is impossible. The dewatered biosolids are transported to the application site in 45 cubic yard tractor/trailer trucks and discharged into a temporary holding area at the application site. The holding area is a three sided earthen pit (similar to a bunker silage pit), that will be restored when the application has been completed. A front-end-loader is used to load the biosolids into one of three 22-cubic yard, custom-built surface spreaders. The biosolids are usually not stockpiled overnight at the application site because of the odor potential. However, if they must remain in the loading pit overnight, soil is used to cover the biosolids.

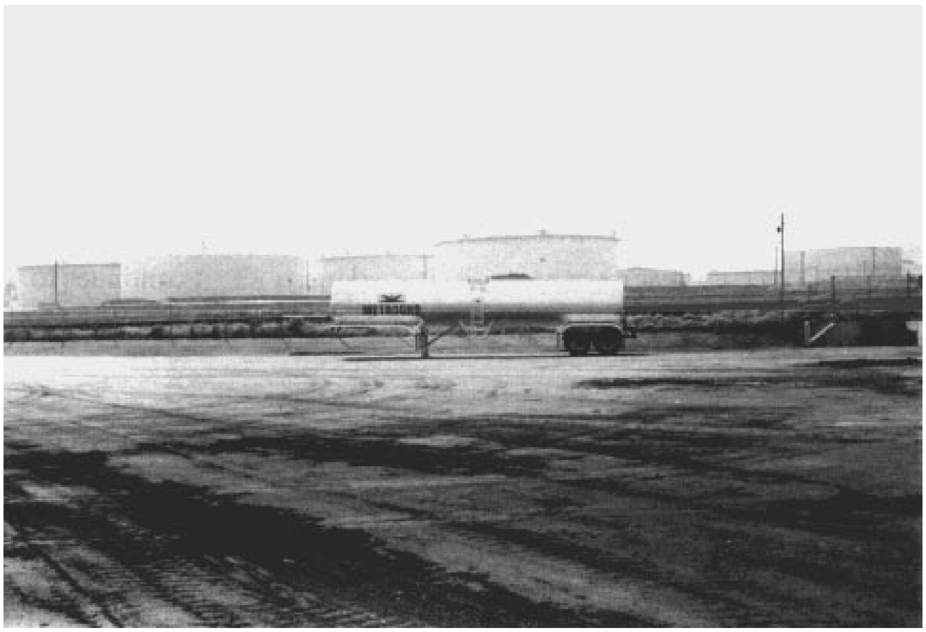

Figure 6-1. Biosolids tanker truck.

Spreaders were custom built to provide a more even application of biosolids than commercially available spreaders. The MWRD's spreaders have a metering screw and gauge that allow the operator to obtain a more even application than could be obtained with commercial equipment and the MWRD's biosolids. In addition, the MWRD installed a heating system on the spreader box, which allows for spreading of biosolids during the winter months.

Following surface application, the solids are incorporated into the soil by disking and plowing, as shown in Figure 6–2. The MWRD supplies the labor and tillage equipment. In some cases, minimum tillage (para–tilling) is required by the U.S. Department of Agriculture Soil Conservation Service (SCS) to minimize erosion potential. The Agriculture Stabilization and Conservation Service (ASCS) and SCS are also beginning, through contingencies on farm subsidies, to encourage certain tillage practices. To facilitate application during the winter, sufficient land is prepared to allow application of 90 days' biosolids production. Construction plows pulled by a tracked tractor are used to incorporate the biosolids during the winter. Although the MWRD prefers to surface apply dewatered biosolids, it continues to use subsurface injection on sites in developed areas to avoid odor complaints.

Biosolids application rates are based on the recommended nitrogen loadings for the intended crop, and the plant available metal concentration in the soil. The most common crops grown on biosolids–amended soils are dryland wheat and irrigated corn. In 1992, the MWRD had permits for approximately 18,000 acres of dryland wheat, and 5,000 acres of irrigated corn land. Average winter wheat yields have increased from 40 bushels per acre without biosolids to 65 bushels per acre after biosolids application. Corn is grown for both silage and grain. Annual application rates range from 1 to 3 dry tons per acre (50 to 75 pounds of nitrogen per acre) for dryland wheat, and from 5 to 10 dry tons per acre (about 300 pounds of nitrogen per acre) for corn. Based on these rates, biosolids are applied to 1,900 to 19,000 acres annually. The exact acreage depends on the mix between dryland and irrigated fields used. Other crops that have been grown on biosolids–amended soils include milo, oats and barley.

Figure 6-2. A field after biosolids application and incorporation.

The MWRD had approximately 150 permitted sites at the time of this study. Transport distances vary widely from approximately 30 miles to as much as 150 miles one-way. Of the 150 sites, 24 are at least 90 miles away. One of the primary reasons for the long transport distances is the difficulty in obtaining permits from local jurisdictions.

In selecting application sites, the MWRD follows the criteria established by the Colorado Department of Health. In addition to the state permits, the MWRD is required to obtain county permits for sites in Adams and Wells Counties. More than 50 percent of the MWRD's permitted sites are located within Adams County. Approval of a site in Adams County is contingent on SCS approval. A number of sites used in the past have been denied renewed permits because the SCS had concerns about the suitability of sandy soils for application. The primary concern is that sandy soils could pose an increased risk for leaching of nitrate and other constituents.

Permitting fees are charged by the state and the county. The state currently charges $2.40 per dry ton of biosolids applied, while the County fees are approximately $0.50 per dry ton. In addition to the permit fees, local jurisdictions often require a 24 to 48-hour notice before biosolids can be applied to specific sites.

6.2 Monitoring

Soil samples are taken from each site prior to the application of biosolids and tested for nutrients using Colorado State University tests. Both total and extractable metal concentrations are determined. DTPA extraction is used to measure available metals in the soil. Soil samples are stored for one year. Crop samples are collected at harvest. Biosolids are sampled from the loading area during the land application. The District works with the U.S. Geological Survey (USGS) to monitor the groundwater at a selected site, which is assumed to be representative of all of the application sites. The parameters monitored are summarized in Table 6-1.

Table 6–1
Parameters Monitored by Metro Wastewater Reclamation District

Parameter	Soil	Biosolids	Crops	Groundwater
pH	x	x		x
Electrical Conductivity (EC)				x
Cation Exchange Capacity (CEC)	x			
Organic Matter (OM)	x	x		
Total Volatile Solids		x	x	x
Total Kjeldahl Nitrogen (TKN)		x	x	
Nitrate–Nitrogen (NO_3–N)	x	x		x
Ammonium–Nitrogen	x	x		x
Phosphorus	x	x		x
Available Phosphorus	x			
Potassium		x		
Available Potassium	x			
Aluminum		x		
Antimony		x		
Arsenic		x		
Beryllium				
Cadmium	x	x	x	x
Chromium		x		x
Copper	x	x	x	x
Iron	x	x	x	x
Lead	x	x	x	x
Mercury		x		
Manganese				x
Molybdenum		x		
Nickel	x	x	x	x
Selenium		x		
Silver		x		
Zinc	x	x	x	x
Available Cadmium	x			
Available Copper	x			
Available Iron	x			
Available Lead	x			
Available Nickel	x			
Available Zinc	x			
Polychlorinated Biphenyls (PCB)		x		
Asbestos		x		
Fecal Coliforms				x

6.3 Results

Table 6–2 shows the composition of the thickened digested biosolids. The concentrations of most metals and nutrients have been fairly constant during the past 10 years. Lead concentrations show a downward trend over the last decade, while zinc, nickel, and cadmium remain unchanged as shown in Figure 6–3. The biosolids have concentrations less than the Pollutant Concentration limits of the 40 CFR Part 503 regulations for all elements except molybdenum; but the molybdenum concentration is well below the Ceiling Concentration of 75 mg/kg.

Table 6–3 and Table 6–4 show the soil analysis from two sandy loam fields. Field 88 had received 53 dry tons of biosolids per acre over an 8–year period, while Field 89 had received 42 dry tons per acre. Tables 6–5 and 6–6 show the amount of biosolids and the concurrent metal loadings applied to these two fields.

The usable site–life of these fields is going to be limited by zinc or copper. On the sites examined, the concentration of organic matter has doubled since the biosolids application began. This should enable farmers to reduce the application of water to amended fields, although no water use data are available to verify this. The increase in organic matter might account for the higher yields on the biosolids–amended soils.

The total and available phosphorus levels in the soils at Fields 88 and 89 increased significantly during the study period, as shown on Tables 6–3 and 6–4. For example, on Field 88 the total phosphorus level increased from 210 to 505 mg/kg, and the available phosphorus level increased from 19 to 100 mg/kg. This increase is in response to the application of about 2,900 pounds per acre phosphorus over a 10 year period. Only about one–fifth of the applied phosphorus can be detected in the soil, but a TKN digestion is used to determine total phosphorus content. This type of digestion does not solubilize all of the phosphorus in the system.

Table 6-2
Average Concentrations in the Metro Wastewater Reclamation District Digested Biosolids

Parameter	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
pH	7.4	7.3	7.7	8.0	7.8	7.4	7.8	7.8	7.8	7.9
EC (μmho/cm)	6,980	12,600	4,130	9,960	6,900	6,900	15,300	15,300	15,300	11,800
					%					
OM	N/A[†]	N/A	N/A	32	N/A	N/A	62.1	64.1	64.1	67.7
TKN	8.33	8.28	7.5	7.0	4.9	6.2	9.4	9.5	9.5	7.7
NH_4-N	2.83	4.48	2.24	3.00	1.08	2.38	2.87	2.87	2.87	3.13
NO_3-N	0.08	0.02	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
Phosphorus	2.35	3.13	2.7	2.12	3.4	2.35	2.23	2.23	2.23	2.32
Potassium	0.49	0.50	0.42	0.30	N/A	0.30	0.33	0.33	0.33	0.39
					mg/kg					
Aluminum	6,950	9,080	20,000	6,890	7,350	11,000	10,900	10,900	10,900	8,920
Arsenic	0.09	1.55	0.29	3.0	4.2	0.0	9.2	9.2	9.2	6.0
Cadmium	24.9	28.0	18.0	12.1	7.2	9.1	9.5	9.5	9.5	12.0
Chromium	276	N/A	212	123	86.9	137	165	165	165	114
Copper	675	826	670	535	1,130	566	829	829	829	622
Iron	30,400	18,000	19,900	14,900	18,200	18,200	31,000	31,000	31,000	26,600
Lead	344	445	270	203	189	180	210	210	210	165
Mercury	9.9	10.5	5.2	3.0	4.1	3.8	4.2	4.2	4.2	3.0
Molybdenum	18	67	36	8.5	10	19	28.3	28.3	28.3	30
Nickel	98	124	76	69	135	64	114	114	114	54
Selenium	<0.01	0.09	<0.08	3	5.1	10	3.3	3.3	3.3	7
Silver	110	N/A	92	53	57	115	86	86	86	95
Zinc	1,500	1,500	1,400	1,220	1,040	1,130	1,450	1,450	1,450	1,010
PCB	N/A	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

[†] Data not available.

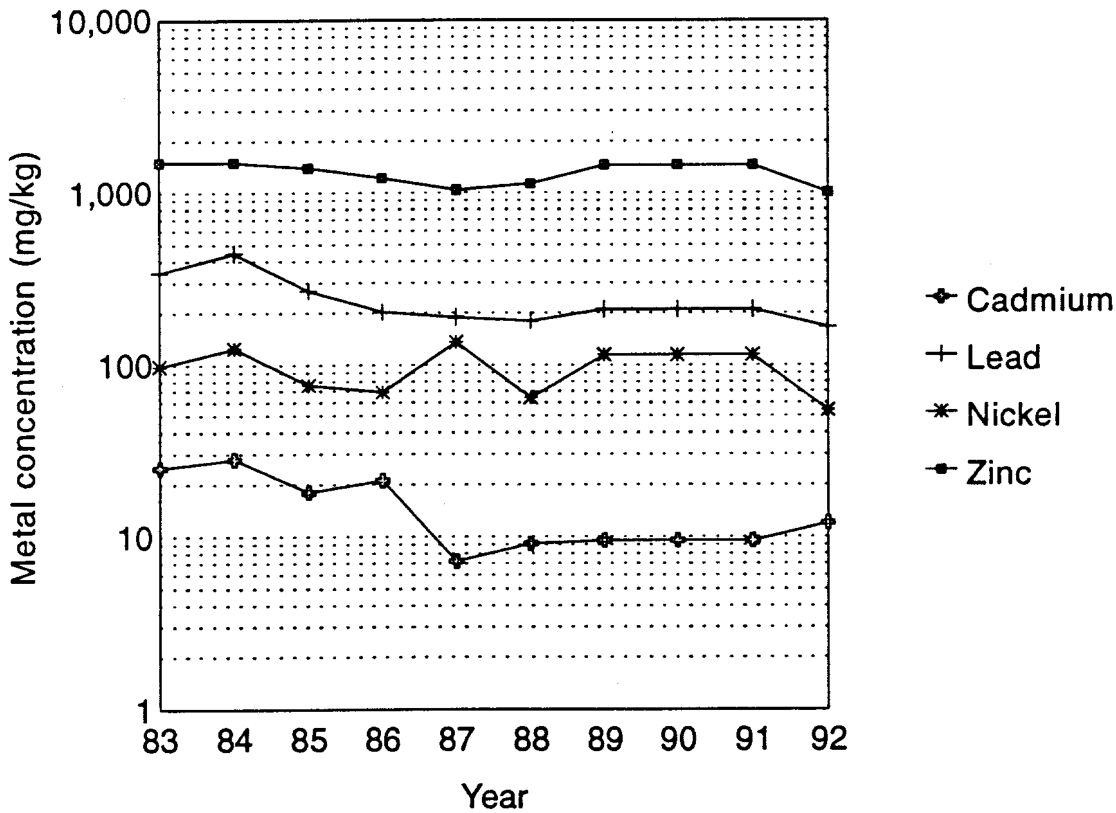

Figure 6-3. Pollutant concentration trends (1983-1992).

Table 6–3
Soil Analysis for Field 88

Parameter	1982	1983	1984	1985	1986	1987	1988	1989	1990	1992
pH	7.4	7.8	6.6	6.5	6.6	6.6	6.5	7.7	7.1	7.0
CEC (meq/100g)	6.5	6.1	8.7	9.4	7.0	7.0	6.0	14.6	12.9	13.8
OM (%)	0.60	0.60	0.80	0.83	0.80	1.01	0.62	1.28	1.60	1.24
EC (μmoh/cm)	380	329	420	295	368	568	426	520	468	516
				Total Concentrations (mg/kg)						
Phosphorus	210	210	290	325	446	490	610	560	580	505
Cadmium	N/A	0.08	0.20	1.32	1.40	0.80	0.30	0.20	0.20	0.49
Copper	5.0	3.5	8.5	4.8	9.4	9.0	6.7	9.0	10.0	7.0
Iron	N/A[†]	6,500	10,600	6,920	8,380		7,960	10,200	9,760	7,770
Lead	N/A	7.5	10.0	13.9	20.0	20.0	20.0	40.0	24.0	27.0
Nickel	N/A	4.0	8.0	4.4	6.8	5.9	5.3	7.8	6.1	4.2
Zinc	27	24	42	27	40	44	38	55	56	47
				Available Concentration (mg/kg)						
NO_3-N	7.4	14.2	8.9	4.0	3.8	23.0	6.3	19.5	20.0	9.6
NH_4-N	N/A	N/A	N/A	N/A	N/A	3.6	2.2	3.0	4.7	2.9
Phosphorus	19.0	28.2	57.2	50.8	59.8	81.0	67.0	108	101	52.4
Cadmium	0.05	0.08	0.12	0.15	0.16	0.17	0.74	N/A	N/A	N/A
Copper	0.52	0.86	2.78	2.77	3.49	4.92	4.02	N/A	N/A	N/A
Iron	N/A	16	24.8	30.6	30.2	35.8	37.2	N/A	N/A	N/A
Lead	0.94	0.94	1.6	1.18	1.32	1.31	1.4	N/A	N/A	N/A
Nickel	0.26	0.24	0.64	0.92	0.59	0.9	0.66	N/A	N/A	N/A
Zinc	1.2	1.5	3.98	4.34	5.39	6.91	5.18	N/A	N/A	N/A

[†] Data not available.

Table 6-4
Soil Analysis for Field 89

Parameter		1982	1983	1984	1986	1987	1988	1989	1990	1991
pH		6.5	7.4	7.0	6.5	6.9	6.5	7.4	7.4	6.5
CEC	meq/100g	12.6	8.3	7.4	6.7	6.3	5.0	14.3	6.1	10.1
O.M.	%	0.43	0.82	0.62	0.73	0.85	0.57	1.21	0.63	1.24
NO_3-N	mg/kg	10.4	1.2	11.6	4.6	11.6	2	10.6	2.4	7.4
NH_4-N	mg/kg	N/A*	N/A	N/A	N/A	28.6	2.2	1	1.38	2.10
EC	moh/cm	N/A	N/A	N/A	N/A	465	197	198	224	251
		Total Concentrations (mg/kg)								
P		230	330	310	567	400	620	490	340	486
Cd		N/A	0.2	0.2	1.93	0.5	0.6	1.5	0	0.5
Cu		7.6	6.5	12	6.7	7.0	6.2	12	3.0	15
Pb		N/A	6.2	12	20	20	17	27	10	22
Ni		N/A	5.8	6.5	5.8	5.3	4.8	9.3	2.0	4.7
Zn		42	34	42	33	31	31	56	20	47
Fe		N/A	8,000	9,250	6,970	6,320	6,790	10,915	7,030	8,760
		Available Concentrations (mg/kg)								
P		20	21	59	64	69	55	120	56	61
Cd		0.92	0.09	0.10	0.12	0.12	0.12	N/A	N/A	N/A
Cu		1.1	1.3	2.52	2.66	4.12	3.2	N/A	N/A	N/A
Pb		1.4	1.0	1.42	1.03	0.99	1.2	N/A	N/A	N/A
Ni		0.68	0.46	0.62	0.66	0.77	0.60	N/A	N/A	N/A
Zn		0.56	2.56	3.56	3.46	5.15	3.90	N/A	N/A	N/A
Fe		N/A	22	24	31	32	34	N/A	N/A	N/A

* Data not available.

Table 6–5
Annual Loading to Field 88

Year	Biosolids	Cd	Cu	Pb	Ni	Zn	P
	– dt/acre –	– – – – – – – – – – – lb/acre	– – – – – – – – – – –				
1983	9.0	0.38	13.7	5.94	1.88	25.6	421
1984	6.4	0.26	8.02	3.65	1.16	18.2	401
1985	6.0	0.21	7.07	3.24	0.69	15.6	323
1986	8.4	0.21	9.86	3.59	1.13	19.9	356
1987	7.3	0.13	2.66	0.96	0.44	6.9	496
1988	11.5	0.23	12.7	4.13	1.65	24.6	551
1989	5.2	0.08	5.61	1.63	0.74	10.8	195
1990	4.6	0.08	4.4	1.43	0.39	8.7	181
Total	58.4	1.5	64.0	24.6	8.08	130	2924

Table 6–6
Annual Loading to Field 89

Year	Biosolids	Cd	Cu	Pb	Ni	Zn	P
	– dt/acre –	– – – – – – – – – – – lb/acre	– – – – – – – – – – –				
1983	9	0.38	15.8	7.42	1.81	28	381
1984	5	0.24	5.32	2.56	0.85	11.7	275
1986	7	0.19	8.23	3.21	1.19	16.7	242
1988	18	0.43	17.3	6.05	2.27	36.5	201
1990	7	0.13	6.99	2.28	0.63	13.9	290
Total	46	1.37	53.6	21.5	6.75	107	1,389

With the exception of lead, only a relatively small portion of the added metals could be detected in the soil. For the two fields studied, an average of 25 percent of the cadmium, 8.7 percent of the copper, 81 percent of the lead, 2 percent of the nickel, and 11 percent of the zinc was found in the soil. Metal concentrations in the corn tissue on Field 88, as shown in Table 6-7, are variable. The concentrations are similar to those in diagnostic corn tissue grown on soils not treated with biosolids.

The MWRD, jointly with the USGS, recently completed a five year groundwater monitoring program. The site used in the study was selected because of its sandy soils and relatively shallow depth to groundwater. The program was to determine whether the land application practices resulted in contamination of the groundwater with nitrates. Elevated concentrations of nitrates and higher specific conductance were observed beneath the site; however, the source of the contamination could not be identified. The use of commercial fertilizers, animal manure, and biosolids were all considered to be potential sources. Because of the inconclusive results of the groundwater monitoring program, the MWRD is beginning a new groundwater monitoring program at a controlled site where the MWRD will control not only the application of biosolids, but also the agricultural management of the site.

Table 6-7

Metal Concentration in Corn Ear Leaf Tissue on Field 88

	Cu	Ni	Zn	Pb	Cd	TKN
Year				mg/kg		
1984	3.8	10.2	19	<0.2	< 0.1	13,000
1986	3.6	0.2	22	nd†	0.1	13,800
1987	nd	5.3	45	6.0	nd	16,300
1988	4	2	60	2	nd	13,000
1989	2.6	nd	31	nd	nd	12,000

† Parameter not detectable by the method of analysis.

6.4 Public Relations

The MWRD strives to maintain positive relationships not only with the farmers providing the land, but also with the general public. The MWRD works with the farmer to schedule biosolids application and tilling operations to meet the farmer's needs and to ensure that the tillage method complies with SCS requirements. Farmers are charged $3.00 per acre for the biosolids application. The MWRD has estimated that the total value of this service to the farmer, including the nutrients and tillage, is between $30 and $60 per acre. In addition, the MWRD maintains the roads during application at the farm site.

MWRD personnel participate in public hearings, respond to citizen complaints, and assist with the repair of roads damaged by the biosolids trucks. Some counties require a public hearing for each permitted site. MWRD personnel respond to odor complaints by going to the source of the complaint and taking scentometer readings. The readings are recorded, and any possible mitigation measures are implemented. The number of complaints in recent years has not exceeded four per year.

The METROGRO™ name was chosen for the biosolids and the composted biosolids to provide a name free of the negative connotations associated with "sludge".

6.5 Summary

The land application program, which has been in operation since 1979, is the primary method of biosolids utilization by the MWRD. While a portion of the biosolids produced are handled through a composting and distribution program, land application remains the primary method because of its cost-effectiveness. Recently, the MWRD has encountered difficulties in permitting sites in nearby townships and counties and has been forced to transport biosolids to sites as far as 150 miles away. The MWRD has recently purchased land for a biosolids application site because of these problems.

Biosolids are either injected or surface applied and incorporated in the soil. Typical application rates are between 3 and 8 dry tons per acre. Cumulative biosolids applications after eight years are currently between 30 and 60 dry tons per acre. Review of available biosolids quality data shows that most metal and nutrient concentrations over the last eight years have remained relatively constant. Cadmium, lead, and nickel concentrations have decreased, probably as a result of industrial pretreatment.

Concentrations of extractable metals in the soil remained constant through the last 10 years. One exception was lead, which showed a slightly increasing trend. Total and available phosphorus increased, and the organic matter content of the sandy loam soil doubled. The increase in organic matter could be expected to reduce the demand for irrigation water. Plant tissue data showed no increase in the plant uptake of metals.

The results of past groundwater monitoring at the District's test site were inconclusive because the District was unable to control the management of the privately-owned site. Although elevated nitrate levels were observed, commercial fertilizers, animal manures, and biosolids were all believed to have contributed to the contamination.

FERTILIZING FORESTS WITH BIOSOLIDS: HOW TO PLAN, OPERATE, AND MAINTAIN A LONG-TERM PROGRAM

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INTRODUCTION/PROGRAM HISTORY

The Municipality of Metropolitan Seattle (Metro) has a program of beneficial use of its biosolids in composting, agriculture and forest fertilization projects. Metro's land application program began in the early 1970s, with a proposal from the University of Washington to study the potential benefits of wastewater sludge as a fertilizer of commercial forests of the Puget Sound area. The first ten years of research by the University focused on application technology, environmental effects, and growth response. After determining that sludge greatly increased tree growth on nutrient-poor soils and could be applied safely with no detrimental public health or environmental effects, the University and Metro moved on to larger-scale demonstrations.

In 1985, Metro conducted operational-scale applications on some of its own forestland in the county. After that, two timber-growing companies and the state department of natural resources signed agreements with Metro for applications on their own lands. The most suitable sites for sludge application, both from a technical and public access standpoint, were found on one of the companies' lands. Metro staff concentrated their efforts on developing a project with that landowner, the Weyerhaeuser Company.

Metro is now in its sixth year of operations on Weyerhaeuser lands with over 19,000 dry tons of biosolids applied. The program has been successful for both biosolids generator and landowner, but, as with any ongoing program, has had its share of the unexpected. As Metro now begins working with farmers in agricultural uses of biosolids, we are using many of the "lessons learned" from forestry in how to work with the landowner and the public, and how to manage operations and maintain quality control.

In this paper, the authors will describe how Metro has developed its program with this landowner, how application sites are designed and operated, and the standards of performance that we feel are necessary for successful long-term operations.

WHY FOREST APPLICATION?

Technical Reasons

(1) The soils need nitrogen and organic matter.
The soils in the Puget Sound area are glacially derived, composed of deep layers of gravel and sand deposited by glaciers that moved into Washington from the north. They are young on a geological timescale, and so lack the reserves of organic matter and minerals found in older, more developed soils. Forest soils of the entire region are generally deficient in nitrogen.

(2) Forest fertilization with nitrogen is a well-known industrial practice.
Some of the large industrial landowners have established programs of fertilizing both natural stands and plantations with chemical nitrogen fertilizer in the form of urea. Thus, the concept of routine fertilizing to produce faster growth in trees is not new in the Northwest.

(3) The most important commercial tree species grows faster with biosolids.
Early research with a variety of Northwest tree species demonstrated that Douglas-fir trees had the best growth response to sludge. Douglas-fir is the most important commercial tree in the Pacific Northwest. Most private timberland owners in our region grow Douglas-fir on a cycle of 45 to 50 years, replanting and managing it in single-species plantations. Since the 1960s, Douglas-fir has been fertilized with nitrogen. But research showed that growth response to biosolids exceeded the response from urea.

(4) The climate and terrain near Seattle allow nearly year-round operations.
The maritime climate is characterized by mild, wet winters and cool, dry summers. In the lowland forests east of the city, precipitation averages about 60 inches per year, with average daily temperatures of 40 degrees in the winter and 60 degrees in the summer. Light snow may occur December through February, with accumulations averaging less than 6 inches. The gravelly forest soils are well-drained and can withstand the impact of ground equipment, even during the wet winters.

Location and Land Use/Ownership Patterns

Other cities may find, like Seattle, that if large tracts of forestland are close to the city, they are a logical and feasible choice for biosolids management.

The population centers of western Washington are located along Puget Sound. East of the cities is the broad, rolling to level plain occupied by commercial forests and rural communities, but with encroaching suburban development. Further east, about 75 miles from Seattle, are the foothills and mountains of the Cascade Range. Most of the state's agricultural areas (grains and fruit) are located over the mountain passes on the eastern side of the Cascades, where the climate is much drier.

Several forest products companies have large timber holdings in the glacial plains immediately east and within 30 miles of the Puget Sound cities (Seattle, Tacoma, Olympia). Although these forests are open to the public for hunting, they are "working" forests with a great deal of harvesting activity and log truck traffic. These large contiguous tracts have a well developed network of gravel roads and access that is controlled through a few main gates. These characteristics, plus the remoteness from residences, make these areas well suited for use of biosolids.

Transportation Cost

The close-in location reduces the cost of hauling biosolids from the treatment plants. Metro's hauling costs are from $9 to $10 per wet ton (23% solids) for forest sites, while agricultural sites are generally about 200 miles from the treatment plants and average $25 per ton for hauling. As seen in Figure 1, however, total haul and application costs for the two uses are comparable due to the ease of application in agricultural fields.

OPERATIONS ON THE SNOQUALMIE TREE FARM

In 1985, Metro and the Weyerhaeuser Company signed a 2-year agreement for the utilization of Metro's biosolids -- trademarked Silvigrow -- on the company's Snoqualmie Tree Farm, approximately 30 miles east of Seattle. The tree farm encompasses 170,000 acres, most of it in one large contiguous block. The application of Silvigrow to selected areas would supplement the company's urea fertilization program. The first Silvigrow project, 160 acres of 5-year-old trees, was begun and successfully completed in 1987. After two years of projects, the agreement was renewed for another two years and then in early 1991, a ten-year agreement was signed.

Metro has the responsibility for site selection, design, permitting, operation and monitoring. Site design and operating plans are subject to company approval, particularly with respect to haul and transfer routes within the private road system of the tree farm. Weyerhaeuser retains the responsibility for managing the timber to meet its corporate objectives. What follows is a discussion of how Metro plans and operates its fertilization projects on this tree farm.

<u>Site Selection</u>

Careful site selection is essential for producing the best growth response. Listed below are the most important factors that we consider when choosing candidate sites. Initial screening is done in Metro's office with topographic maps, soil maps, recent aerial photos and the landowner's inventory records. A careful walk-through of each potential site is necessary to confirm the suitability of the soils and terrain. See Figure 2 for the checklist that we develop for each site that is inspected in the field.

• Terrain - gentle

For ground application, equipment is limited to slopes of 30%, and ideally, slopes of 15% or less. Federal and state guidelines recommend rolling to level sites, with only short stretches of slopes at 30%. We've found that sites with a slight tilt or those with some variable topography are preferable to those "flat-as-a-pancake" sites, where drainage problems can develop.

Slope allowances for forestry sites are considerably higher than those allowed in agriculture. This is due to the excellent infiltration capacity of the forest floor and, in young stands, the amount of herbs and shrubs in the understory whose foliage intercepts the biosolids and aids in stabilizing and drying.

• Soils - well drained

We target soils that have a high content of gravel and sand and minimal amounts of clay. These soils work best for two reasons: (1) they can withstand the impact of the loaded applicator vehicles, even during wet winter weather. To apply a full prescription of biosolids usually requires many passes. If the soils are too fine-textured, the applicator vehicles can create deep ruts and mud. In our experience, trail rutting is one of the "hot buttons" for the timberland owner. The owner wishes to preserve and enhance the long-term productivity of his lands, and rutting destroys the fertile upper horizons of the soil. (2) coarse textured soils are low in nutrients and need extra nitrogen and organic matter. The best growth response to biosolids are on sites of this medium to poor quality.

• Vegetation - well stocked and the right height

Height of the trees is a critical factor. Early research by the University of Washington demonstrated that when biosolids is applied to very young plantations, there are several undesirable results: (1) if not controlled by herbicides, understory plants will respond rapidly and compete with the tree seedlings for water, nutrients, and light; (2) the heavy herbaceous growth leads to population growth of small rodents who will chew on and girdle the tree seedlings; (3) the amount of damage to the seedlings from browsing deer increases, as the deer will preferentially browse on fertilized seedlings that are at or below their "browse height" of 4 to 5 feet. To avoid these problems, we apply only to plantations that are at least five feet tall and that have a minimum of brushy, unstocked "holes" in the plantation.

• Surface waters - as few as possible
Sites with many draws, streams and wetlands may require a large proportion of the area in setbacks or buffers, thus reducing the net usable area for application. Generally, sites with well drained soils will have 30% or less of the area lost to buffers.

• Road system - suitable width and grade
Although the tree farm includes plateau, foothills, and mountainous areas from 700 to over 3500 feet in elevation, our operations are limited to the lower elevations by the inability of the biosolids delivery trucks to haul steep grades on gravel roads. Grades cannot exceed 10% for long distances and the roads must have frequent turnouts or be wide enough to allow two trucks to pass each other.

• Seasonal restrictions - no slurry on the foliage in dry season
Liquid or rewatered Silvigrow at 7 to 15% solids cannot be applied over the foliage of trees during the growing season, since the summers in the Pacific Northwest are relatively dry. There is no rain to wash the foliage, and the biosolids become cemented onto the foliage. (Metro is currently testing equipment that applies biosolids as dewatered cake. This type of application may minimize the amount of biosolids clinging to the foliage and so may be suitable for summer use. More on this later in the paper.)

• Project size
The minimum parcel size that allows continuous operations is dependent upon the time required for a layer or lift of Silvigrow to stabilize. A typical rate of 10 DT/ac is applied in three separate lifts with drying time after each application. During the wet season, a lift requires three to four weeks to stabilize. If Silvigrow can be applied at the rate of 40 acres per week, then 160 acres of working area is required to keep operations continuous for 4 weeks. By that time the first areas to be applied would be stabilized and ready for the second lift. The entire 160 acres would be completed in 12 weeks.

Design Factors

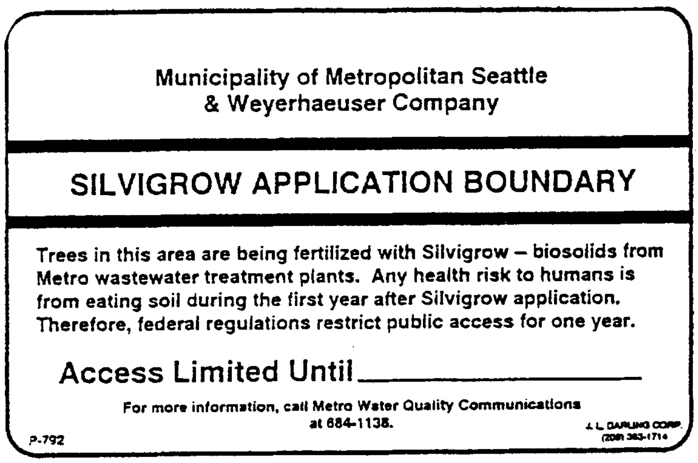
The first steps in confirming the initial assessment of a site are a soil evaluation and an assessment of the ground water conditions. These tasks are performed by University soil scientists and hydrogeology consultants, respectively. See Figure 3 for the sequence of steps in designing and permitting a site.

To design each project, Metro employs contract foresters who are knowledgeable in the best management practices of biosolids application. During a thorough examination of each proposed unit, they eliminate areas that are too steep, too wet or that might be pathways for water movement during rainstorms. Boundaries of the usable area are marked in the field with fluorescent pink flagging. Then they design a trail system of parallel, looping or dead ended trails which will allow the applicator vehicle to completely reach all the usable areas. We achieve slightly overlapping, even coverage by applying into a compartment from trails on either side. The spacing between trails varies from 185 to 200 feet, depending on the height and density of the trees. See Figure 4 for an example of a trail system that covers a 98-acre site.

Streams in or adjacent to the application area are buffered by non-application strips of varying widths. We use the following guidelines: 200 feet from large, continuously flowing streams, 100 feet from small tributary streams, and 50 feet from ephemeral drainage ways. The purpose of the buffer is to provide a safety margin if an operator were to overshoot the boundaries or if Silvigrow were to move during a rainstorm. The width of these buffers is far greater than actually needed. Since beginning operations on this tree farm, we have had no significant movement of Silvigrow away from an application area, primarily for two reasons: sites are heavily covered with vegetation, and the practice of applying in thin layers works well to stabilize the Silvigrow.

The development of an appropriate application rate is an essential part of the design process. Researchers from the University of Washington inspect all proposed forest sites and recommend an agronomic rate. The variables in this calculation are: estimated annual uptake of nitrogen for tree and understory species, mineralization rate for the organic nitrogen in the biosolids, soil storage capacity, and estimates for volatilization and denitrification. With the total nitrogen in our biosolids averaging about 5%, a typical application rate for a 10-year-old plantation is around 9 dry tons per acre. Our current plans are for a 4 to 5-year cycle of reapplication.

Because Metro's biosolids are treated by a PSRP (Process to Significantly Reduce Pathogens) rather than a PFRP (Process to Further Reduce Pathogens), site access is restricted for 12 months after application. Yellow plastic signs are posted around the site boundaries every 100 to 200 feet:



Permitting Process

In the state of Washington, the state Department of Ecology has delegated permitting authority for biosolids to local health districts. For this particular project, the Seattle-King County Department of Public Health is the regulator and permitting authority. We are fortunate to have local regulators who are knowledgeable about biosolids practices and research as well as the draft federal regulations. Permitting of new areas on the tree farm has gone smoothly because of the projects' remoteness, low public profile, and good monitoring results.

Following the submission of the permit application package (which includes description of soil profiles, analyses of soils for metals and nutrients, chemical analyses of biosolids, topographic maps of application areas, hydrogeology study, monitoring plan, calculation of application rates, and proposed trail layout), the regulator makes a field visit with the project manager and field designer for the project. Representatives from the state Department of Ecology attend whenever possible. The field inspection usually focuses on the buffering and protection of water bodies and other sensitive areas as well as any downstream water users. The entire permitting process can usually be completed in 45 days, the minimum review period required by county regulations.

Operations Tracking

Metro's current forest operations involve the addition of water to dewatered cake biosolids to produce a slurry of 7 to 15% solids which is then sprayed onto the trees. The mixing/delivery station at the tree farm is located in a large gravel pit. Here the haul trucks unload biosolids (at 18 to 27% solids) into an in-ground mixing tank to which dilution water is added. The diluted biosolids, called Silvigrow, are then pumped into adjacent storage tanks for the day's application. Usually 4 to 5 truckloads of 30 wet tons each can be processed and applied in a day.

The application units are usually located in a 3-mile radius from the mix station, so transfer tanker trucks are used to shuttle Silvigrow from the mix station out to the working applicator vehicles. The applicator vehicle is a rubber-tired, articulated, four-wheel drive chassis with a 2200-gallon tank mounted over the rear axle. The tanks contain an internal pumping system driven by the power take-off connected to a one-inch diameter nozzle mounted on top of the vehicle. The loaded applicator vehicles travel into the forest on the trail system; they are stationary as the operator applies the material, controlling the direction and trajectory of the spray from a joystick inside the vehicle cab.

Each operator has a clipboard with a map of the application unit and a logbook (see Figure 5). Each application unit is divided into compartments of 1 to 6 acres which are used to keep track of the actual amount of Silvigrow applied. For example the application rate for Unit 24-08-02 is 8.5 DT/acre. Compartment 22 in this unit is 1.1 acres, which would require 1.1 X 8.5 = 9.3 DT to complete. Each applicator applies 1 DT per load, so 9 loads total would be needed for this compartment. Applying this amount in three separate lifts means that 1 complete lift consists of 3 loads. The logbook is marked to show when each lift is completed.

At the end of each day, the site supervisor checks the condition of trails and the buffers for all the compartments that were applied that day. Records of these checks (see Figure 6) are kept at the field trailer at the mixing station for the Metro site manager's inspection.

Contingency Plans

Metro and the application contractor have developed a set of procedures for responding to any incidents on the site. An "incident" may be a spill, surface runoff, traffic accident, work site accident, misapplication of biosolids or any other site problem. The operations plan includes a contingency plan, which outlines the individuals to be contacted in case of a large-scale incident. The plan also includes a list of local contractors and their equipment (dump trucks, loaders, vacuum trucks, tow trucks, and cranes) that could be called for assistance. Small spills or misapplications are corrected immediately, and an Incident Report form (developed by Metro) is filed. We have had some trucking incidents but no large spills in the 6 years of operation.

Monitoring

Water Quality - To evaluate the water quality of streams near Silvigrow sites, Metro establishes *test* sampling stations downstream from project areas and *control* stations upstream. Two types of monitoring are conducted: (1) Routine or ambient - conducted on a quarterly basis before, during, and for three years following applications; and (2) Storm - occurs during two to three rainstorms in the wet season following application. Storm sampling is conducted to ensure that Silvigrow is not being carried offsite by surface runoff. All samples are grab samples, collected by water quality specialists with Metro's Environmental Laboratories. Samples are analyzed for ammonia nitrogen, nitrate-nitrite nitrogen, fecal coliforms, and enterococcus. Six years of sampling have shown little to no significant changes in the excellent water quality in these streams.

There are no drinking water wells within a mile of any site, and most of the sites do not overlie aquifers of any significant size. For these reasons, we do not use ground water wells in our monitoring program. Two of our sites, however, have installations of tube lysimeters. Nitrate data collected from the lysimeters is used by the University of Washington to fine-tune their model and assumptions of nitrogen uptake in Douglas-fir stands.

Tree Growth - Many of the application areas at the tree farm contain growth plots. To maintain consistency in data collection, all growth plots are installed and measured by field crews from the Stand Management Cooperative (SMC). (The SMC is a cooperative of universities and landowners that sponsors integrated research in forest nutrition, silviculture, and wood quality.) Not all areas have these plots; we install them whenever there is an opportunity to gather data from different soil types or age classes of timber. The standard installation consists of three tenth-acre square plots treated with biosolids and three control (no biosolids) plots in the same stand. All trees are numbered and tagged; height and diameter are measured annually. Results from the first three years of operations in young stands indicate increases in annual height increment can range from 20 to 75% over controls.

Partnership with the University

Metro has continued its contract relationship with the University of Washington College of Forest Resources since 1973, not only for research but for design assistance on operational sites. As described in previous sections of this paper, researchers from the U.W. are an essential part of site design. They make a field visit to each proposed application area to evaluate the suitability of the soil to receive biosolids and to sustain traffic. They estimate the nutrient needs of the site and prescribe the appropriate application rate. They propose research to fill in the knowledge gaps, monitor the growth response, and assist us when something goes wrong. We know that their role is one of the critical factors in the long term success of this project.

Other municipalities have developed this kind of partnership with research institutions. Some examples are Greater Vancouver Regional District with the University of British Columbia, City of Spokane with Washington State University, Massachusetts Water Resources Authority with the University of Massachusetts, and Vail, Colorado with Colorado State University.

Performance Standards

Many of the operating practices that have been developed over the past six years of operations at the Snoqualmie Tree Farm have been formalized and incorporated into a set of standards that is now applied to all other kinds of biosolids projects. In any given month, Metro may deliver biosolids to two or three kinds of projects. Each site may be operated by a different contractor, and even permitted by different counties. Last year when one of the contractor-managed soil improvement sites came under public scrutiny for failing to closely follow the operations plan, the sludge program staff developed common performance standards to which all projects would conform. These standards would ensure that all projects receiving Metro biosolids would operate with the same attention to detail, regardless of the local requirements. The new standards gave Metro a visible and active role during the permitting and operating of the project. Listed below are some of the key requirements that have worked well on forestry sites and are now required of all other projects as well:

- Operations plan with detailed site maps;
- Haul route approved by Metro;
- Agronomic application rates reviewed by university or other independent specialists;
- Buffers and boundaries clearly marked in the field;
- Good housekeeping measures at the site with daily inspections of boundaries and buffers;
- Pre- and post-application monitoring of soils, surface water, and, if appropriate, ground water and crops.
- Public information plan with early and ongoing public involvement opportunities;
- Contingency plan for any incidents;
- Quarterly and annual reports to be produced and available for any interested parties.

WHEN SOMETHING GOES WRONG

Despite careful planning and site management, Murphy sometimes visits our projects. For the first two years the Metro/Weyerhaeuser projects went smoothly; a total of 1200 acres had been permitted and completed. Then scattered trees began to yellow and droop on one of the fertilized areas. Scientists from the University of Washington College of Forest Resources began an investigation into the source of the problem, which was obviously related to the biosolids application as adjacent unfertilized areas were unaffected. Over the next few months, the clumps of dying trees totaled about 40 acres.

The research team concluded that the trees weakened because of inadequate soil aeration. This lack of oxygen was caused by a combination of site conditions and the slow drying characteristics of secondary biosolids under these conditions. The very flat terrain and shallow soils restricted winter drainage, while the dense tree canopy kept the ground cool and shaded so that the biosolids did not dry. Under these conditions, the biosolids sealed the soil surface, reducing the movement of oxygen into the soil.

Weyerhaeuser forest scientists were consulted and involved in the investigation at every step, so there was consensus among Metro, the University and the landowner that we had a developed a problem that could be easily avoided in the future by focusing on young, open stands. The affected areas were harvested prematurely and Metro paid Weyerhaeuser for the value of the lost growth. Applications resumed the next year and are continuing.

CRITERIA FOR SUCCESS

• <u>Find your niche in the landowner's overall management plan.</u>
Niche, from the science of plant ecology, is defined as "the ultimate unit of the habitat, i.e. the specific spot occupied by an individual; the more or less specialized relationship existing between an individual and its environment." Forest landowners in Washington state have a multitude of laws, restrictions and regulatory agencies to deal with. We want the use of biosolids to be an easy practice to implement on their tree farm and one that requires minimal investment of staff time for them. Metro staff handle all the site development and permitting for Silvigrow projects and work hard to minimize any "hassle factor" for the landowner.

We also have found a place in the landowner's current management regime. Weyerhaeuser presently begins urea fertilization around age 17 and continues on 7 year intervals through the entire rotation of 45 to 50 years. Silvigrow fertilization begins around age 5 and is reapplied on 5 year intervals. This provides a real boost to developing plantations and allows the trees on these poorer-quality sites to grow at a rate typical of much more productive sites.

• <u>Hold your projects to the highest standards.</u> There are many obvious reasons to run a clean, well-managed operation. But it's essential if you're counting on a long-term relationship with a particular land owner and his community.

• <u>Be actively involved and visible to the public and the landowner.</u> As the biosolids generator, you will find it to your benefit to be visible, accountable, and responsive to your "customers". It eliminates confusion about who is responsible for the quality of the application and any perceived liability. Other types of projects with Metro's biosolids have been permitted and managed by private vendors/contractors. Whenever issues or problems arise, the public usually looks beyond the vendor to the generator for explanations or satisfaction of their complaint.

• Make projects a team effort with the landowner, contractor, scientists and community. There is no substitute for the support of your local research institution and the local newspaper editor/writer. The researchers will provide a check and balance for your operation plans, keep your projects on sound technical footing, and help with the problems that **will** surface. We found that working with and establishing an open relationship with the local editor from the very outset of the Snoqualmie project ensured that we had more reasonable and informed coverage when problems did arise.

• Monitor and publish results, both water quality and crop response.
Let the world know what a good job you're doing -- talk, talk to community groups and professional organizations. Presentations to the local SAF (Society of American Foresters) chapter or other industry group will go a long way toward informing the forestry community in your locale about the opportunities with biosolids.

PLANNING FOR THE NEXT DECADE

New Products, New Equipment

1992 is a year of transition and testing for Metro's forestry program. In addition to the current rewatered applications, this year we will be testing the feasibility of dewatered cake applications. In April and May we pilot-tested a side-cast spreader unit that flings dewatered material 200 feet out into the plantation. This type of application could extend operations into the summer and allow us to access areas of the tree farm that are only operable during the dry season. Such an operation would also reduce costs by eliminating the need for dilution water and reducing crew size from five to two.

Later this year Metro's first dried biosolids product will become available through a contract for biosolids drying with PCL/SMI. Metro will be testing some of this material in its existing forestry and irrigated agriculture projects.

More Efficient Planning and Permitting

During the first two years of operations on the Snoqualmie Tree Farm, we concentrated on choosing suitable sites for the upcoming year, doing a good job with operations, and following up carefully and accurately with monitoring results and reports. Now with a new ten-year contract, plus two new forms of biosolids product becoming available to us this year, we face the challenge of a more long-term planning approach.

Our goals are to:
• predict number of acres and locations that will be available each year over the next decade;
• reduce amount and redundancy of staff and consultant work.

To accomplish the first goal, Metro staff are currently working on a screening process for the entire tree farm. We are making field visits to all areas that have the potential to use liquid, cake, or dried biosolids. Using the information gathered with the checklist in Figure 2, we will be developing a database of stands that can be sorted by a number of variables: location, tree age, soil type, season of application, and type of fertilizer product.

Permitting and environmental reviews to date have been somewhat piecemeal. Each project area of 160-200 acres has been evaluated and permitted separately, with separate operations plans and individual reports of soils and ground water. To bring some continuity to the program and to streamline our permitting efforts, this year we are developing two documents (in three-ring binders) that can be used for all projects: (1) an operations plan for the entire tree farm, with site maps and specific permit conditions located in appendices; and (2) a hydrogeology study for the tree farm, again with site-specific studies added as needed.

Research Needs

For the next couple of years, Metro and the University of Washington will be focusing on: further fine-tuning of application rates, including the effects of residual nitrogen and multiple applications; expansion of operations to other forest types such as hybrid cottonwood plantations and mixed conifers in eastern Washington; and research on the fate of nutrients other than nitrogen.

One of the most exciting developments of the 1990s is the startup of similar forestry programs in other parts of the US and the world. We're watching with great interest what's happening in Vancouver, British Columbia; Christchurch, New Zealand; eastern Massachusetts, eastern Australia and elsewhere.

For the biosolids generator, forest application can provide a type of reuse that has a reasonable cost, is non food-chain, remote from homes, and provides economic benefits for the user. For the land-owner, the use of biosolids can result in faster-growing trees, greater timber volumes, and long-term improvements in productivity. With the information and operational experience gained by Metro and other forest fertilization programs, more POTWs may find that forest fertilization is the right option for their biosolids.

Acknowledgements

Although there have been many people who have helped shape the Silvigrow program, the authors want to recognize three who "made it happen": Steve Anderson, area forester for theWeyerhaeuser Snoqualmie Tree Farm; Charles Nichols, who designed the Silvigrow application/transfer equipment and is now with the Sanitary District of Orange County, California; and Suzanne Schweitzer, who developed the framework for designing and managing these projects and is now with East Bay Municipal Utility District.

Any correspondence or questions can be addressed to: Peggy Leonard, Municipality of Metropolitan Seattle, 821 Second Avenue, Mail Stop 81, Seattle, WA 98104-1598.

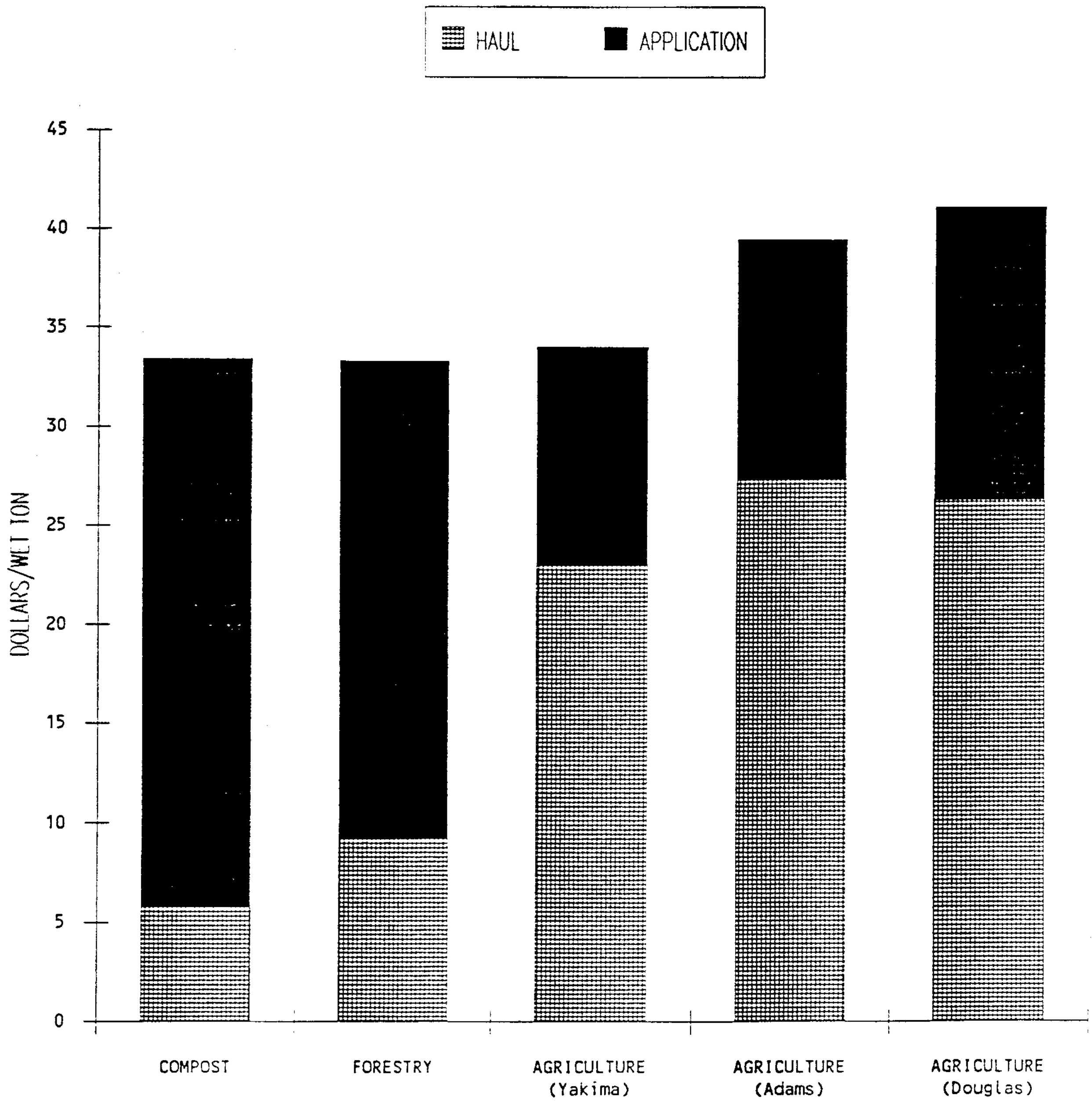


Figure 1. Approximate haul and application costs for compost, forest, and agriculture projects (by wet tons averaging 23% solids).

FIELD CHECKLIST

DATE OF FIELD CHECK: ____________________
FIELD EXAMINER: ____________________

LOCATION: (Section, Township, Range)
Attach map with boundaries marked.
____
____

PROPERTY OWNER: ____________________
ELEVATION: ____________________
NUMBER OF ACRES: ____________________
NEARBY SITES: ____________________

SOILS
Information Source: ____________________
Soil Series: ____________________
Parent Material: ____________________
Approx. Depth: ____________________ Does soil appear suitable? ____________________
____

TOPOGRAPHY
Slope: ____________________
Presence of draws (mark on map): ____________________
Areas where slope may be critical factor (mark on map): ____________________
____

SURFACE WATERS
Water body type and location (mark on map): ____________________
____
Areas of poor drainage (standing water, wet-site indicators): ____________________
____
Buffers required (mark on map): ____________________
____

VEGETATION
Tree species: ____________________
Stocking levels: ____________________ Average stand height: ____________________
Understory:

Species	Average Height	Average Cover (nearest 10%)

ACCESS
Main Roads: Grade: ____________________ Overall Condition: ____________________
Width: ____________________ ____________________
Any Limitations for Application Trails: ____________________
____

COMMENTS/RECOMMENDATIONS: ____________________
____
____

ESTIMATE OF USABLE ACRES: ____________________
RECOMMENDED SEASON OF APPLICATION: ____________________

Figure 2. Field checklist for evaluation of potential Silvigrow sites.

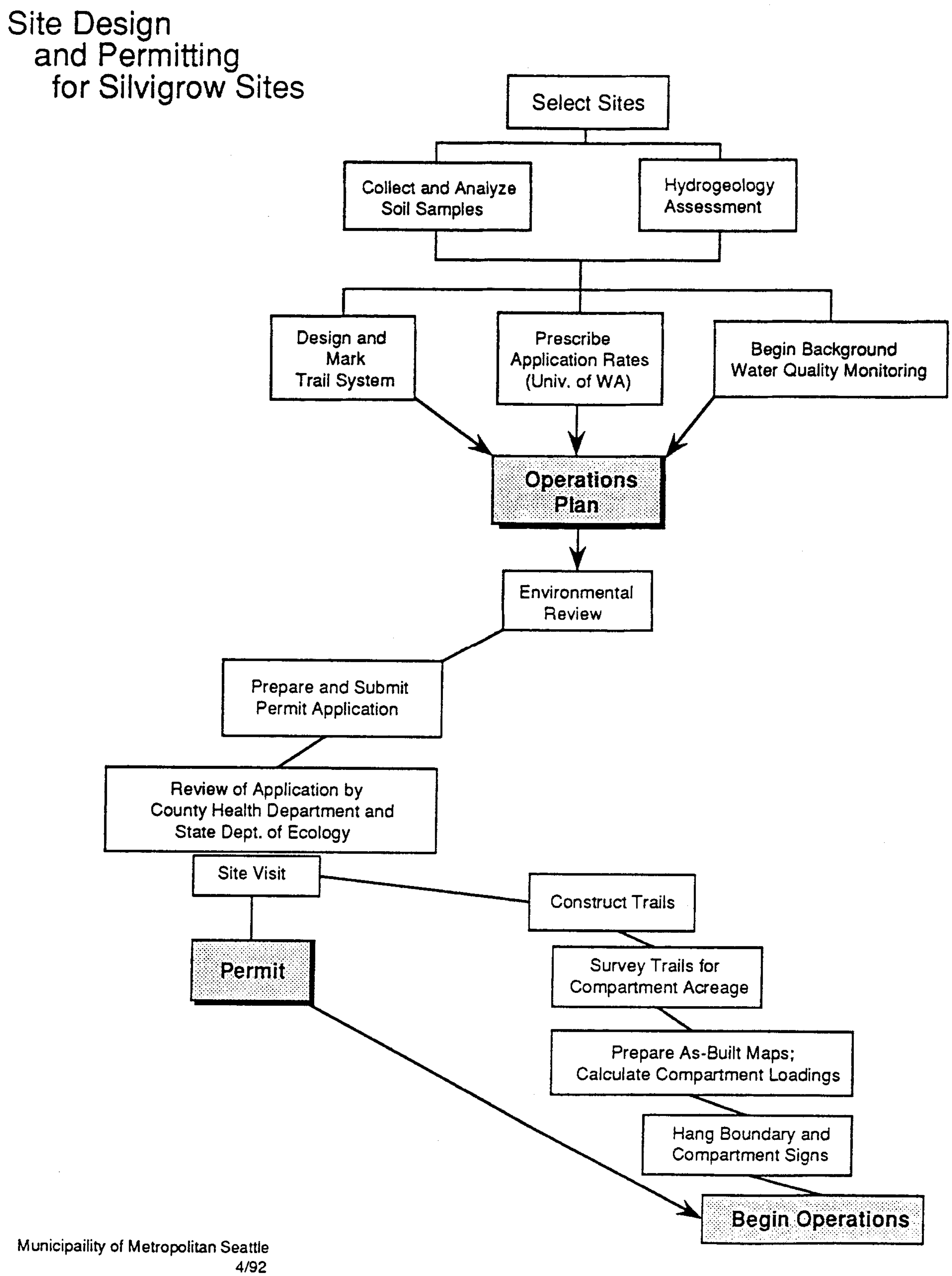


Figure 3. Steps in the design and permitting of forest application sites.

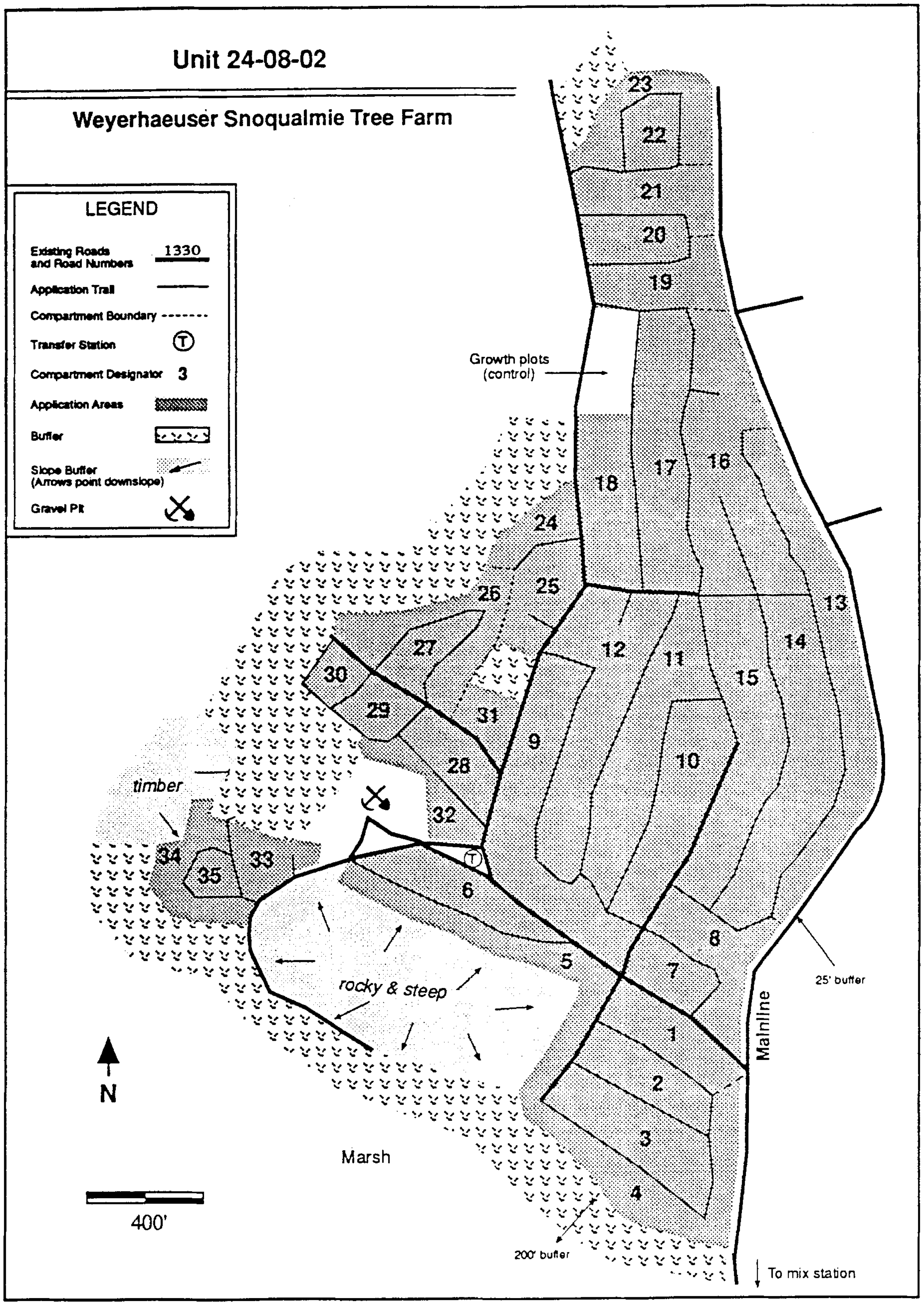


Figure 4. Trail map of typical Silvigrow unit. Units are named for the township, range, and section in which they are located—Unit 24-08-02 is located in T24N R8E, Section 2. This particular unit comprises 98 acres.

METRO

I = IME
A = Ag Chem
~~~ = End Lift

Application Log

Load	Date	Time	Applicator 1	Applicator 2	Load	Date	Time	Applicator 1	Applicator 2	Load	Date	Time	Applicator 1	Applicator 2
1	4/24	1:05	I		41					81				
2	4/26	11:45	I		42					82				
3	4/26	1:30	I	4/26 JS	43					83				
4					44					84				
5					45					85				
6					46					86				
7					47					87				
8					48					88				
9					49					89				
10	END				50					90				
11					51					91				
12					52					92				
13					53					93				
14					54					94				
15					55					95				
16					56					96				
17					57					97				
18					58					98				
19					59					99				
20					60					100				
21					61					101				
22					62					102				
23					63					103				
24					64					104				
25					65					105				
26					66					106				
27					67					107				
28					68					108				
29					69					109				
30					70					110				
31					71					111				
32					72					112				
33					73					113				
34					74					114				
35					75					115				
36					76					116				
37					77					117				
38					78					118				
39					79					119				
40					80					120				

Area Size 1.1 acre
Loads per lift 3
Page 1 of 1

Project SECTION 2
Unit 24-08-02
Compartment 22

1432 (Rev. 3/88)

Figure 5. Application log for tracking loadings to each compartment.
~~~

DAILY BOUNDARY AND BUFFER CHECK

Inspector ______________________ Date ______________

UNITS WORKED TODAY

Unit/ Compartment	# Passes per Day	Tire Depressions				Standing Water
		0-6"	6-12"	12-18"	Stuck	

	Trails (General conditions, incl. any Silvigrow on trails)
	Buffers (Note any oversprays, spills, etc.)
	Compartments (Application uniformity)

Figure 6. Field sheet for daily boundary and buffer checks by the site supervisor.

LONG-TERM EFFECTS OF A SINGLE APPLICATION OF MUNICIPAL SLUDGE ON ABANDONED MINE LAND[1]

BY

William E. Sopper and Eileen M. Seaker[2]

Abstract. In 1977, digested and dewatered municipal sludge was applied and incorporated in spoil material at a rate of 184 Mg/ha on a 0.4 ha experimental plot on an abandoned strip mine site in Pennsylvania. Data were collected for a five-year period (1977-1981) to determine the effects of the sludge application on the quality and growth of the herbaceous vegetation, the chemical properties of the soil, and the chemical quality of groundwater. In 1989, 12 years after sludge application, the site was again resampled to determine the long-term residual effects of the sludge application. Results of the re-evaluation indicated that the single high application of sludge facilitated the rapid development of a vegetative cover which has persisted over the 12 years with no apparent adverse effects on vegetation, soil, or groundwater.

Additional key words: Reclamation, trace metals, sludge utilization, revegetation, groundwater quality.

Introduction

It is estimated that more than 7.7 million dry metric tons of municipal sludge are currently produced each year by the 15,300 public-owned treatment works in the United States. Approximately 25% of this is being land-applied for its fertilizer and organic matter value (Federal Register 1989). One of the most efficient uses for sludge is the reclamation of disturbed lands, such as those abandoned after coal mining which are acidic, droughty, and devoid of organic matter. Sludge has been shown to improve spoil structure, water holding capacity, and bulk density in addition to adding N, P, K, and other plant nutrients (Sopper et al. 1982; Sopper and Seaker 1983).

Approximately 121,000 hectares of land in Pennsylvania, strip mined prior to the federal Surface Mining Control and Reclamation Act of 1977, were abandoned after the coal was removed, leaving vast areas of barren spoil (USDA 1980). These sites have remained barren for years due to the difficulty of establishing and maintaining vegetation on the highly acidic material.

In 1977, a project was initiated in Pennsylvania that introduced the concept of using municipal sludge for revegetation of mined land to the general public in order to gain public acceptance and support. The specific objective of the project was to demonstrate that municipal sludge could be used to reclaim strip mined land and return it to potential agricultural use or to a wildlife habitat in an environmentally acceptable manner, without adverse effects on the quality of the vegetation, soil, or water. Vegetation, soil, and groundwater samples were collected over a five-year period (1977-1981) and results of these studies have been reported by Seaker and Sopper (1984).

[1]Paper presented at the 1990 Mining and Reclamation Conference and Exhibition, Charleston, West Virginia, April 23-26, 1990. The research described in this article has been partially funded by the U.S. Environmental Protection Agency through Grant No. S-804511-020 and CR807408010.

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The issue of the long-term effect of applying single, large amounts of sludge in order to revegetate mine land often arises. What happens after all the sludge has been mineralized and all the nutrients and trace metals have been released to the soil and are potentially available for plant uptake and leaching? Will the vegetative cover persist or deteriorate?

One of the sites used in the 1977 project was an abandoned strip mine bank located in Venango County that had been backfilled and recontoured after mining without top soil replacement. Several revegetation attempts were unsuccessful. Dewatered digested sludge was applied in May 1977 to a 0.2-ha plot. In August, 1989, 12 years after sludge application, the site was revisited and samples of vegetation, soils, and groundwater were collected to evaluate the long-term effects. The project was originally designed as a demonstration to the public, rather than an experiment. Subsampling was employed, but statistical analyses could not be performed on the data. Instead, general trends are discussed.

Materials and Methods

Sludge Application

The surface soil was compacted, stony, and extremely acid (pH 3.8). The 0.2 ha plot was scarified with a chisel plow to loosen the surface spoil material and agricultural lime was applied at 12.3 Mg/ha to raise the spoil pH to 7.0. Sludge for the project was obtained from three local wastewater treatment plants. The sludge was applied at 184 Mg/ha with a manure spreader. The average concentrations of nutrients and trace metals and amounts applied in the sludge are given in Table 1. The amounts of nutrients applied were equivalent to applying an 11 (N) -9 (P_2O_5) -0 (K_2O) chemical fertilizer at 22,400 kg/ha.

Table 1. Chemical analysis of dewatered sludge applied and amounts of elements applied at 184 Mg/ha rate (Dwt Basis)

Constituent	Average Concentration	Amount Applied
	mg/kg	kg/ha
Total P	4624	918
Total N	12188	2388
K	93	18
Ca	9970	1834
Mg	2082	383
Zn	811	147
Cu	661	129
Pb	349	55
Ni	69	12
Cd	3.2	0.6
pH	7.9	

The amounts of trace metals applied are given in Table 2 along with the U.S. Environmental Protection Agency (EPA) and Pennsylvania Department of Environmental Resources (PDER) interim guideline recommendations (United States Environmental Protection Agency 1977; Pennsylvania Department of Environmental Resources 1977). It is quite obvious that the amounts of trace metals applied were well below the recommended lifetime limits except for copper, which slightly exceeded the Pennsylvania guidelines.

Immediately after sludge application and incorporation, the site was broadcast seeded with a mixture of two grasses (Kentucky-31 tall fescue, *Festuca arundinacea* Schreb., 22 kg/ha, Pennlate orchardgrass, *Dactylis glomerata* L., 22 kg/ha) and two legumes (Penngift crownvetch, *Coronilla varia* L., 11 kg/ha, and Empire birdsfoot trefoil, *Lotus corniculatus* L., 11 kg/ha). Then the site was mulched with straw and hay at the rate of 3.8 Mg/ha.

Sampling and Analyses

A complete monitoring system was installed on the plot to evaluate the effects of the sludge applications on water quality, vegetation, and soil. Two groundwater wells were drilled (up-gradient and down-gradient) to sample the effects of the sludge application on groundwater quality. After sludge application, groundwater samples were collected bi-weekly for the first two months and monthly thereafter. Samples were analyzed for pH, nitrate-N by ion-selective electrode (Ellis 1976), dissolved Cu, Zn, Cr, Pb, Co, Cd, and Ni by atomic absorption spectrophotometry (EPA Methods of Chemical Analysis 1974).

Minesoil samples were collected at the 0 to 15, and 15 to 30 cm depth, passed through a 2 mm sieve, and analyzed for pH, Kjeldahl-N, Bray-P, exchangeable K, Ca, and Mg by ammonium acetate extraction, and dilute hydrochloric acid extractable Cu, Zn, Cr, Pb, Cd, and Ni (Jackson, 1958). Exchangeable cation and extractable metal concentrations were determined by atomic absorption.

At the end of each growing season vegetation growth responses were determined by measurements of percentage areal cover, and dry matter production. No crops were harvested over the 12-year period. Individual samples of tall fescue, orchardgrass, crownvetch, and birdsfoot trefoil from each plot were collected for foliar analyses. Plant samples were analyzed for Kjeldahl-N; P, K, Ca, Mg, by plasma emission spectrometry (Baker et al. 1964), and Cu, Zn, Cr, Pb, Co, Cd, and Ni by atomic absorption (Jackson 1958), after dry ashing and digestion.

Results and Discussion

Vegetation

The site was completely vegetated by August 1977, three months after sludge application, which has persisted throughout the 12-year period. Average annual dry matter production for the first five years and in 1989 was as follows:

Year	Yield
	Mg/ha
1977	6.0
1978	9.3
1979	11.3
1980	31.2
1981	22.6
1989	15.5
AHY	4.0

Table 2. Trace metal loadings of the sludge application and lifetime loadings recommended by the EPA and PDER.

Constituent	Sludge Application 184 Mg/ha	EPA[1] (CEC 5-15)	PDER
	kg/ha		
Cu	129	280	112
Zn	147	560	224
Cr	74	NR[2]	112
Pb	55	800	112
Ni	12	280	22
Cd	0.6	11	3
Hg	0.09	NR[2]	0.6

[1] Average CEC of site ranged from 11.6 to 15.2 meq/100g

[2] No recommendation given by EPA

Dry matter production increased during the first four years, leveling off in 1981. In 1989 it was slightly lower but still well above the average hay yield (AHY) for undisturbed farmland soils in the county. During the first two years the two grass species dominated the site, but by the third growing season, the two legume species predominated and persisted through the fifth year (1981). However, by 1989 the birdsfoot trefoil had almost disappeared and now the dominating vegetative cover consists mostly of crownvetch and orchardgrass.

For brevity, only the foliar analyses for crownvetch and orchardgrass will be discussed. Foliar concentrations of macronutrients are given in Table 3. Nutrients (N and P) were all generally higher in the sludge-grown plants. Potassium and Ca were higher in the sludge-grown orchardgrass than in control plants. Potassium and Ca were only slightly lower in the sludge-grown birdsfoot trefoil plants than in the control plants. Foliar Mg concentrations were similar in both sludge-grown and control plants. Nutrient levels in the sludge-grown plants in 1989 were about the same level as the first year when sludge was applied. There appears to be little depletion of nutrients from the site over the 12-year period. Birdsfoot trefoil data are given in Table 3 because no crownvetch plants were present on the control plot for comparison. Macronutrient concentrations in crownvetch on the sludge-amended plot are given in Table 4. Concentrations were quite similar to those of birdsfoot trefoil.

Foliar concentrations of Zn, Cu, Pb, Ni, and Cd in orchardgrass and crownvetch are shown in Figures 1 to 5. Concentrations of Zn (Fig. 1), and Ni (Fig. 4) tended to be higher in crownvetch than in orchardgrass; whereas, concentrations of Cu (Fig. 2) tended to be higher in orchardgrass. Concentration of Pb (Fig. 3) and Cd (Fig. 5) were variable and showed no distinct trends. In general, trace metal foliar concentrations tended to be highest the first year and then decrease over time. Except for Ni, foliar concentrations of trace metals in the sludge-grown orchardgrass plants were higher than in control plants. The 1989 values for Cu (Fig. 2) and Cd (Fig. 5) were quite similar to those of 1981. Foliar concentrations of Zn, Ni, and Pb showed a slight increase from 1981 to 1989. Although sludge application appeared to increase some trace metal concentrations in the foliage, these increases were minimal and well below the suggested tolerance levels for agronomic crops (Melsted 1973). No phytotoxicity symptoms were observed during the study. The suggested tolerance levels are not phytotoxic levels but suggest foliar concentration levels at which decreases in growth may be expected.

Spoil Chemical Status

Changes in spoil pH over time are shown in Table 5. Spoil pH tended to increase from 1977 to 1979 and declined thereafter. This may explain why some of the foliar trace metal concentrations showed an increase in 1989. The nutrient status of the spoil seemed to show a general increase in concentrations of Kjeldahl-N up to 1981 and up to 1984 for Bray-phosphorus, K and Ca (Table 6). The application of lime and sludge initially resulted in a decrease in the concentration of Mg; however, since 1978 there has been a steady increase. The 1989 values are lower but still quite adequate to support plant growth.

Concentrations of extractable trace metals in the 0 to 15 cm spoil depth are given in Table 7 and for the 15 to 30 cm spoil depth in Table 8. Concentrations of Cu, Zn, Cr, Pb, Cd, and Ni all show a steady increase for the first five years (1977-81). By this time, most of the sludge organic matter was probably mineralized and most of the trace metals released to the surface spoil. Results of spoil analyses in 1984 and 1989 showed a gradual decrease in concentrations of all trace metals. Although the sludge application seemed to increase the concentrations of extractable trace metals in the 0 to 15 cm spoil depth, these higher concentrations are still within the normal ranges for these elements in U. S. soils (Allaway 1968).

It appears that there is some leaching of trace metals through the spoil profile. Concentrations of trace metals in the 15 to 30 cm spoil depth show a general increasing trend from 1977 to 1989.

Groundwater Quality

Results of the analyses of groundwater well samples are given in Table 9. The values for Well

Table 3. Mean foliar concentrations of macronutrient elements in orchardgrass and birdsfoot trefoil collected from the control and sludge-amended plots.

Sludge application	Year	Orchardgrass					Birdsfoot trefoil				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
Mg/ha		----------%----------					----------%----------				
0	1977	1					1				
	1978	0.92	0.18	1.51	0.36	0.23	1.03	0.24	1.93	0.61	0.26
	1979	1.17	0.22	2.41	0.30	0.22	2.59	0.14	1.74	1.82	0.40
	1980	1.11	0.24	1.86	0.32	0.20	2.11	0.17	1.92	1.02	0.23
	1981	1.22	0.18	1.62	0.68	0.22	3.32	0.17	1.89	1.52	0.29
	1989	1.67	0.17	1.82	0.42	0.30	2.31	0.17	1.71	0.92	0.22
184	1977	2.62	0.40	2.84	0.84	0.31	3.64	0.27	1.46	1.99	0.28
	1978	1.26	0.37	2.01	0.49	0.28	1.27	0.36	2.30	0.59	0.25
	1979	1.33	0.51	2.53	0.47	0.23	3.57	0.25	1.56	0.54	0.20
	1980	1.70	0.42	2.65	0.45	0.23	2.93	0.25	1.62	1.27	0.18
	1981	2.57	0.37	2.38	0.53	0.26	4.03	0.26	1.69	1.14	0.23
	1989	2.36	0.37	2.24	0.45	0.22	2.38	0.16	1.01	0.65	0.23

[1]No plants available for sampling

Table 4. Mean foliar concentrations of macronutrient elements in crownvetch on the sludge-amended plot.

Year	Crownvetch				
	N	P	K	Ca	Mg
	----------%----------				
1977	3.36	0.34	1.64	2.63	0.42
1978	2.35	0.37	3.14	0.96	0.45
1979	3.35	0.22	1.29	1.68	0.25
1980	3.00	0.27	1.89	1.72	0.29
1981	3.78	0.31	1.89	1.25	0.23
1989	2.62	0.21	2.20	0.91	0.26

Table 5. Changes in Spoil pH over the thirteen year period

Depth	Soil pH					
	May 1977[1]	Sept 1977	Nov 1978	Oct 1979	May 1981	Aug 1989
cm						
0-15	3.8	6.2	6.7	7.3	5.8	5.4
15-30	3.8	4.2	4.6	5.1	3.4	5.6

[1]Pre-treatment samples

1 (control) reflect quality of groundwater for the disturbed mine site. Well 2 reflects the effects of the sludge application on water quality. Depth to the water table was 4.9 m in Well 1 and 3.0 in Well 2 in 1989. During the first five years (1977 to 1981) the water table fluctuated between 4.4 to 5.3 m in Well 1 and between 2.5 and 3.4 m in Well 2. Results indicate that the sludge application did not appear to have any significant effect on groundwater concentrations of nitrate-N. Average monthly concentrations of NO_3-N were below 10 mg/l (maximum concentration for potable water) for all months sampled during the five-year period (1977-81). The highest monthly values were 3.0 mg/l for the control well and 2.4 mg/l for Well 2.

Application of lime and sludge and subsequent revegetation appears to have had a positive effect on groundwater pH (Table 9). Groundwater pH increased from 4.6 (1977) to 6.0 by 1981. Results of the 1989 sampling indicated a pH of 6.6. There has also been a gradual increase in pH in the

Table 6. Changes in concentrations of Kjeldahl-nitrogen, Bray-phosphorus and exchangeable cations in the spoil collected at the 0-15 cm depth

Year	Kjeldahl Nitrogen	Bray Phosphorus	K	Ca	Mg
	%	----------	mg/kg	----------	
May 1977[1]	0.04	2	12	541	452
Sept 1977	0.05	11	19	1222	32
1978	0.09	9	23	2600	40
1979	0.16	38	46	3873	53
1981	0.34	79	45	1298	99
1984	---	91	74	1440	108
1989	0.12	83	30	733	84

[1] Pre-sludge samples

Table 7. Changes in concentrations of extractable trace metals from spoil collected at the 0-15 cm depth following sludge application.

Sampling Date	Cu	Zn	Cr[2]	Pb	Cd	Ni
	----------	----------	----------	mg/kg	----------	----------
May 1977[1]	2.5	2.9	0.2	0.5	0.02	1.1
Sept 1977	10.8	7.7	0.4	3.5	0.04	0.9
1978	8.8	7.7	0.2	2.3	0.02	1.2
1979	58.7	56.9	1.7	13.0	0.27	1.5
1981	87.3	74.6	3.5	22.7	0.95	2.8
1984	57.6	59.6	---	14.8	0.56	2.8
1989	51.9	37.8	---	13.5	0.42	2.0
Normal Range for U.S. Soils	2-100	10-300	5-3000	2-200	0.01 7.00	5-500

[1] May 1977 values represent pretreatment conditions
[2] Values for Cr are total concentrations.

control well from pH 4.4 to pH 5.8. Since 1980, attempts have been made to reclaim the control area by conventional methods using lime and fertilizer. The amounts of lime and fertilizer applied and frequency of application are not known as the coal company is no longer in business. However, these applications and vegetation growth probably contributed to the increase in groundwater pH in the control well.

There appears to be no significant increase in any of the trace metal concentrations over the initial five-year period (1977-1981) in the groundwater samples from Well 2 compared to the control well (Table 9). From 1977 to 1981 most of the monthly concentrations were within the U.S. Environmental Protection Agency drinking water standards. The only exception was Pb which exceeded the limit of 0.05 mg/l for both the control well and Well 2, probably resulting from solubilization upon weathering after mining. The highest monthly Pb values were 0.28 mg/l in the control well and 0.33 mg/l in Well 2 in 1978, and the mean annual Pb concentrations were 0.19 and 0.20 mg/l for control well and Well 2, respectively. By 1981, however, the mean annual Pb concentrations had decreased to 0.04 and 0.05 mg/l for the two wells. Results of analyses of the groundwater samples collected in 1989 had extremely low concentrations of all trace metals in both wells in comparison to values for the initial five years (1977-81).

Conclusions

Re-evaluation of an abandoned strip mine spoil bank 12 years after being amended with 184 Mg/ha of

Table 8. Changes in concentrations of extractable trace metals from spoil collected at the 15-30 cm depth following sludge application.

Sampling Date	Cu	Zn	Cr	Pb	Cd	Ni
	mg/kg					
May 1977[1]	3.0	2.4	0.10	0.6	0.020	1.0
Sept 1977	4.0	2.0	0.10	1.3	0.010	0.4
1978	2.5	1.7	<0.01	1.3	0.007	0.7
1979	9.2	8.7	0.28	2.4	0.026	0.2
1981	2.4	2.8	0.05	0.5	0.014	0.4
1989	13.8	10.2	0.43	3.8	0.122	1.9

[1]May 1977 values represent pretreatment conditions
[2]Values for Cr are total concentrations

Table 9. Mean annual concentrations of nitrate - N and trace metals in groundwater

Site	Year[1]	pH	NO_3-N	Cu	Zn	Cr	Pb	Cd	Ni
			mg/l						
Well 1	1977	4.4	1.4	0.22	4.13	0.02	0.14	0.006	3.67
(control)	1978	4.3	<0.5	0.23	2.02	0.01	0.19	0.002	0.98
	1979	4.6	<0.5	0.17	1.48	0.03	0.13	0.001	0.50
	1980	5.5	0.6	0.05	0.89	0.05	0.09	0.001	0.50
	1981	5.7	0.7	0.06	0.83	0.03	0.04	0.003	0.31
	1989[2]	5.8	0.02	0.01	0.09	<0.001	0.01	0.001	0.06
Well 2	1977	4.6	1.1	0.10	3.39	0.03	0.09	0.001	2.67
(sludge)	1978	4.5	<0.5	0.14	3.29	0.01	0.20	0.002	1.26
	1979	4.4	<0.5	0.18	1.49	0.03	0.13	0.001	0.97
	1980	5.7	0.6	0.05	1.05	0.04	0.11	0.001	0.76
	1981	6.0	0.6	0.05	0.57	0.02	0.05	0.001	0.31
	1989[2]	6.6	0.06	0.01	0.07	<0.001	0.01	0.001	0.04
EPA drinking water standard			10	1	5	0.05	0.05	0.010	---

[1]Values are annual means of monthly samples.

[2]Average of three samples collected in August 1989.

municipal sludge indicates that a single large application of sludge can be used successfully to revegetate mine lands with no apparent adverse effects on vegetation, spoil, or groundwater quality.

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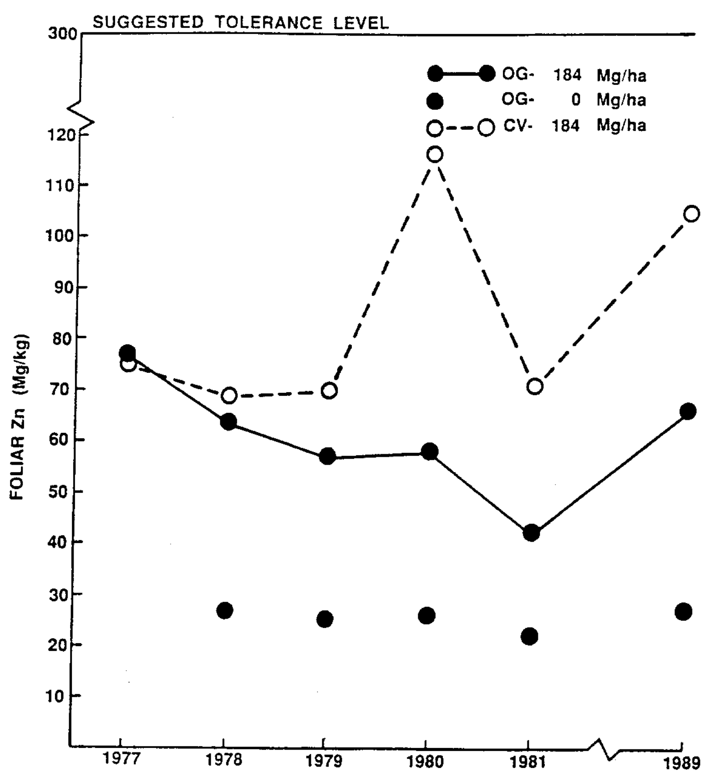


Figure 1. Mean foliar concentration of Zn in orchardgrass and crownvetch collected from the control and sludge-amended plots.

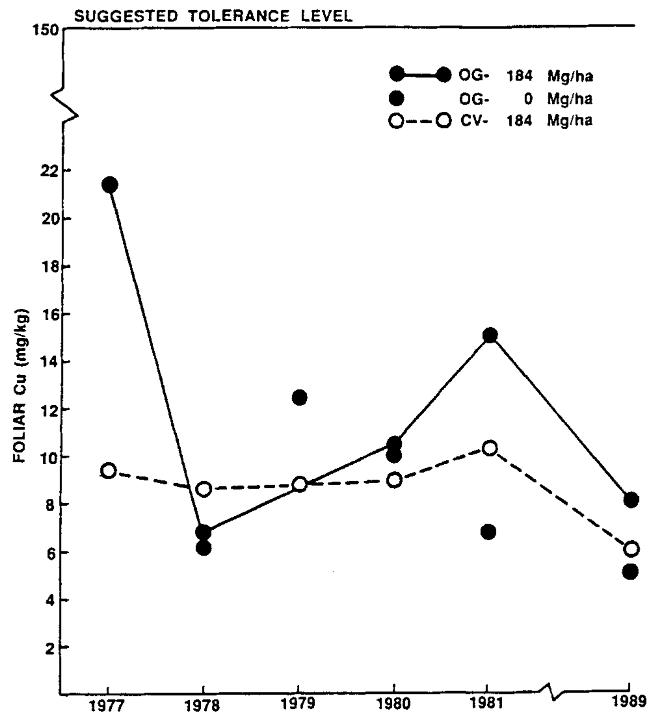


Figure 2. Mean foliar concentration of Cu in orchardgrass and crownvetch collected from the control and sludge-amended plots.

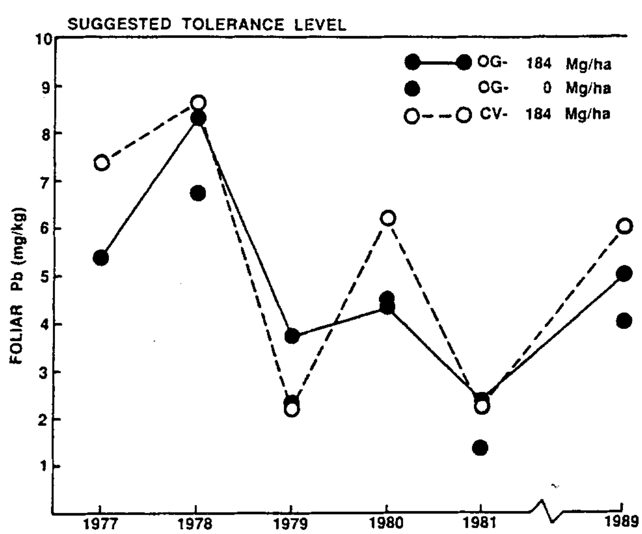


Figure 3. Mean foliar concentration of Pb in orchardgrass and crownvetch collected from the control and sludge-amended plots.

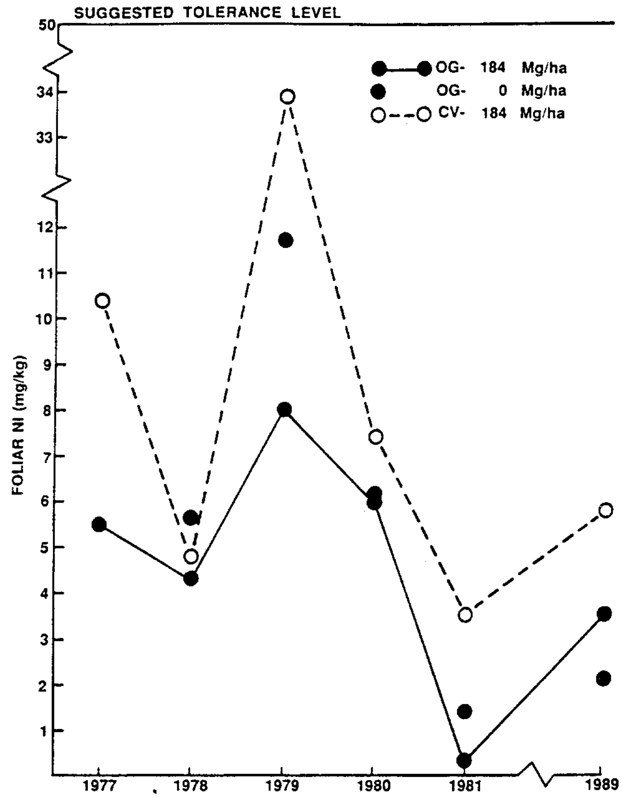


Figure 4. Mean foliar concentration of Ni in orchardgrass and crownvetch collected from the control and sludge-amended plots.

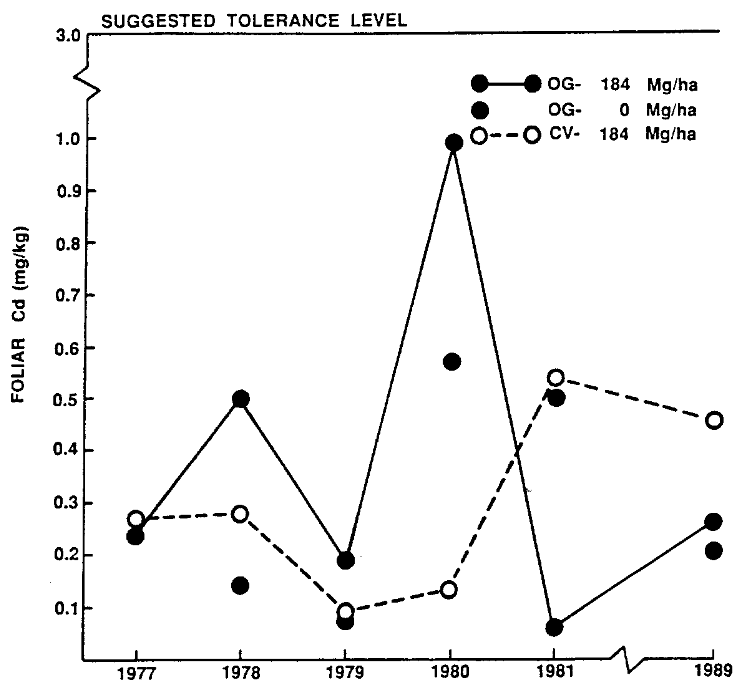


Figure 5. Mean foliar concentration of Cd in orchardgrass and crownvetch collected from the control and sludge-amended plots.

Citation for this Publication:

Sopper, W.E. and Eileen M. Seaker. 1990. Long-Term Effects of a Single Application of Municipal Sludge on Abandoned Mine Land. Proc. of The 1990 Mining and Reclamation Conference and Exhibit, J. Skousen et al. (eds.), Vol. II: 579-587, West Virginia University, Morgantown, WV.

Appendix B
Federal Sewage Sludge Contacts

Table B-1. EPA Regional Sewage Sludge Contacts

REGION 1
Thelma Hamilton (WMT-ZIN)
JFK Federal Bldg.
One Congress St.
Boston, MA 02203
(617) 565-3569
Fax (617) 565-4940

REGION 2
Alia Roufaeal
Water Management Division
26 Federal Plaza
New York, NY 10278
(212) 264-8663
Fax (212) 264-9597

REGION 3
Ann Carkhuff (3WM55)
841 Chesnut St.
Philadelphia, PA 19107
(215) 597-9406
Fax (215) 597-3359

REGION 4
Vince Miller
Water Division
345 Courtland St., NE.
Atlanta, GA 30365
(404) 347-3012 (ext. 2953)
Fax (404) 347-1739

REGION 5
Ash Sajjad (5WQP-16J)
Water Division
77 W. Jackson Blvd.
Chicago, IL 60604-3590
(312) 886-6112
Fax (312) 886-7804

REGION 6
Stephanie Kordzi (6-WPM)
Water Management Division
1445 Ross Ave., #1200
Dallas, TX 75202-2733
(214) 665-7520
Fax (214) 655-6490

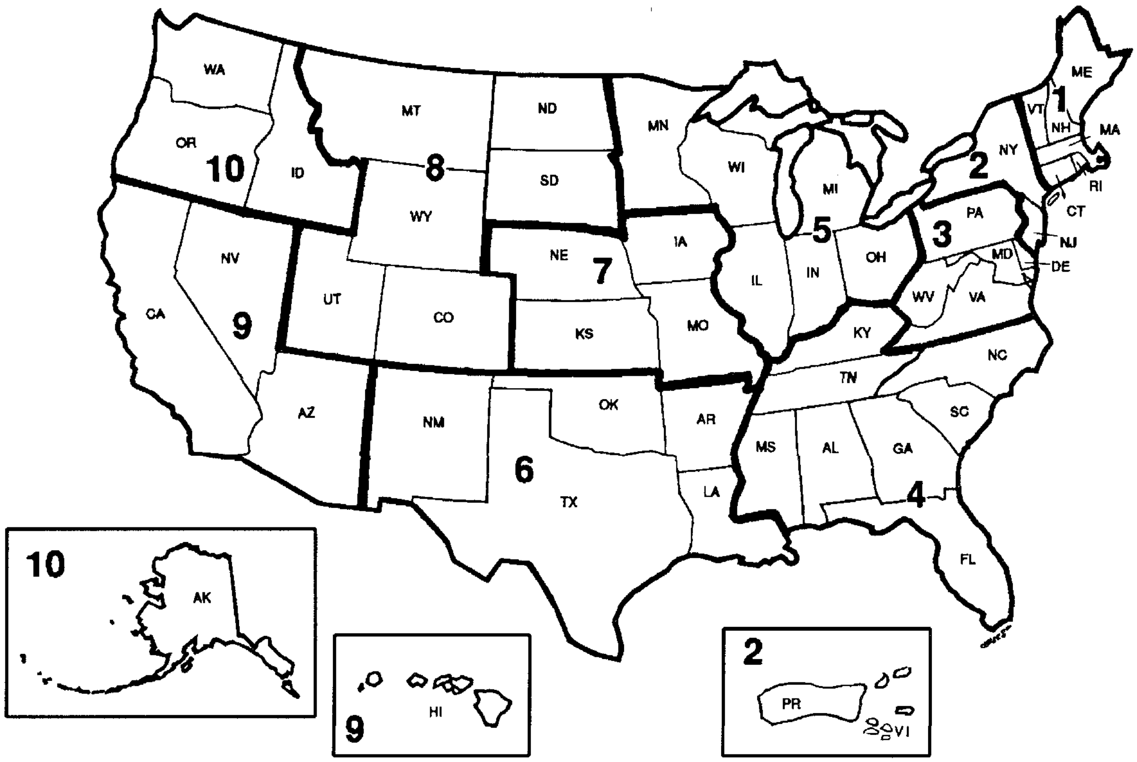
REGION 7
John Dunn
Water Management Division
726 Minnesota Ave.
Kansas City, KS 66101
(913) 551-7594
Fax (913) 551-7765

REGION 8
Bob Brobst (8WM-C)
Water Management Division
999 18th St., Suite 500
Denver, CO 80202-2405
(303) 293-1627
Fax (303) 294-1386

REGION 9
Lauren Fondahl
Permits Section
75 Hawthorne St. (W-5-2)
San Francisco, CA 94105
(415) 744-1909
Fax (415) 744-1235

REGION 10
Dick Hetherington (WD-184)
Water Management Division
1200 Sixth Ave.
Seattle, WA 98101
(206) 553-1941
Fax (206) 553-1775

U.S. EPA Regions



Region—State

4—Alabama
10—Alaska
9—Arizona
6—Arkansas
9—California
8—Colorado
1—Connecticut
3—Delaware
3—Washington, DC
4—Florida
4—Georgia
9—Hawaii
10—Idaho
5—Illinois
5—Indiana
7—Iowa
7—Kansas
4—Kentucky
6—Louisiana

Region—State

1—Maine
3—Maryland
1—Massachusetts
5—Michigan
5—Minnesota
4—Mississippi
7—Missouri
8—Montana
7—Nebraska
9—Nevada
1—New Hampshire
2—New Jersey
6—New Mexico
2—New York
4—North Carolina
8—North Dakota
5—Ohio
6—Oklahoma
10—Oregon

Region—State

3—Pennsylvania
1—Rhode Island
4—South Carolina
8—South Dakota
4—Tennessee
6—Texas
8—Utah
1—Vermont
3—Virginia
10—Washington
3—West Virginia
5—Wisconsin
8—Wyoming
9—American Samoa
9—Guam
2—Puerto Rico
2—Virgin Islands

Figure B-1. Map of U.S. EPA regions.

Appendix C
Permit Application Requirements

Permits that are issued to publicly owned treatment works (POTWs) must include standards for sewage sludge use or disposal. In addition, EPA may issue sewage sludge permits to other "treatment works treating domestic sewage" (TWTDS) (i.e., treatment works that generate, change the quality of, or dispose of sewage sludge).

The EPA's sewage sludge permit program regulations establish a framework for permitting sewage sludge use or disposal. The regulations require submission of a permit application that provides the permitting authority with sufficient information to issue an appropriate permit. A permit application must include information on the treatment work's identity, location, and regulatory status, as well as information on the quality, quantity, and ultimate use or disposal of the sewage sludge managed at the treatment works.

Because the sewage sludge permitting regulations were promulgated several years before the Part 503 standards, they describe the required application information in broad, almost generic terms. Currently, EPA is developing application forms and the Agency is planning to revise the permit application regulations to reflect specifically the Part 503 standards and to enable permit writers to tailor permit requirements to facilities' specific use or disposal practices.

The deadlines for submitting permit applications were revised in 1993 and are as follows:

- Applicants requiring site-specific pollutant limits in their permits (e.g., sewage sludge incinerators) and facilities requesting site-specific limits (e.g., some surface disposal sites) were required to submit applications by August 18, 1993.
- All other applicants with National Pollutant Discharge Elimination System (NPDES) permits are required to submit sewage sludge permit applications at the time of their next NPDES permit renewals.
- So-called sewage sludge-only (non-NPDES) treatment works that are not applying for site-specific limits, and are not otherwise required to submit a full permit application, only need to submit limited screening information and must have done so by February 19, 1994.

The permit application information that must be submitted depends upon the type of treatment works and which sewage sludge management practices the treatment works employs. Questions on permit applications should be directed to the appropriate State and EPA Regional Sewage Sludge Coordinators listed in Appendix B.

Sludge-Only Treatment Works

The limited screening information submitted by a sewage sludge-only treatment works typically will include the following:

- Name of treatment works, contact person, mailing address, phone number, and location.
- Name and address of owner and/or operator.
- An indication of whether the treatment works is a POTW, privately owned treatment works, federally owned treatment works, blending or treatment operation, surface disposal site, or sewage sludge incinerator.
- The amount of sewage sludge generated (and/or received from another treatment works), treated, and used or disposed.
- Available data on pollutant concentrations in the sewage sludge.
- Treatment to reduce pathogens and vector attraction properties of the sewage sludge.
- Identification of other facilities receiving the sewage sludge for further processing or for use or disposal.
- Information on sites where the sewage sludge is used or disposed.

Facilities Submitting Full Permit Applications

A full permit application is much more comprehensive than the limited screening information described above for sewage sludge-only facilities. A full permit application typically will include the following information:

General Information

- Name of treatment works, contact person, mailing address, phone number, and location.
- Name and address of owner and/or operator.
- An indication of whether the treatment works is a POTW, privately owned treatment works, federally owned treatment works, blending or treatment operation, surface disposal site, or sewage sludge incinerator.
- Whether the treatment works is a Class I sludge management facility (i.e., a pretreatment POTW or another facility designated Class I by the permitting authority).
- The NPDES permit number (if any) and the number and type of any relevant Federal, State, or local environmental permits or construction approvals applied for or received.
- Whether any sewage sludge management occurs on Native American lands.
- A topographic map showing sewage sludge management facilities and water bodies 1 mile beyond the property boundary and drinking water wells 1/4 mile beyond the property boundary.
- Results of hazardous waste testing for the sewage sludge, if any.
- Data on pollutant concentrations in the sewage sludge.

Information on Generation of Sewage Sludge or Preparation of a Material From Sewage Sludge

- The amount of sewage sludge generated.
- If sewage sludge is received from off site, the amount received, the name and address of the offsite facility, and any treatment the sewage sludge has received.
- Description of any treatment at the applicant's facility to reduce pathogens and vector attraction properties of the sewage sludge.
- Description of any bagging and distribution activities for the sewage sludge.
- If sewage sludge is provided to another facility for further treatment, the amount provided, the name and address of the receiving facility, and any treatment occurring at the receiving facility.

Information on Land Application of Sewage Sludge

- The amount of bulk sewage sludge applied to the land.
- The nitrogen content of bulk sewage sludge applied to the land.
- The name and location of land application sites, and a copy of the land application plan if all sites have not been identified.
- The name and address of the owner and the person who applies bulk sewage sludge to each site.
- The site type and the type of crop or other vegetation grown.
- Description of any processes at each land application site to reduce vector attraction properties of the sewage sludge.
- Ground-water monitoring data, if available.
- If bulk sewage sludge is subject to cumulative pollutant loading rates, information on how the necessary tracking and notification requirements will be met.
- If bulk sewage sludge is applied to the land in a different state, information on how the permitting authority in the receiving state will be notified.

All permit applications must be signed and certified. The permitting authority may request additional information to assess sewage sludge use or disposal practices, determine whether to issue a permit, or identify appropriate permit requirements.

Appendix D
Conversion Factors

Table D-1. Conversion Factors (Metric to U.S. Customary)

Metric			U.S. Customary Unit	
Name	**Abbreviation**	**Multiplier**	**Abbreviation**	**Name**
Centimeter(s)	cm	0.3937	in	inches
Cubic Meter	m^3	8.1071×10^{-4} 35.3147 264.25	acre-ft ft^3 Mgal	acre-foot cubic foot million gallons
Cubic Meters Per Day	m^3/d	2.6417×10^{-4}	Mgal/d or MGD	million gallons per day
Cubic Meters Per Hectare	m^3/ha	1.069×10^{-4}	Mgal/acre	million gallons per acre
Degrees Celsius	°C	1.8 (°C) + 32	°F	degrees Fahrenheit
Gram(s)	g	0.0022	lb	pound(s)
Hectare	ha	0.24711 0.004	acre mi^2	acre square miles
Kilogram(s)	kg	2.205	lb	pound(s)
Kilograms Per Hectare	kg/ha	0.0004	T/ac	tons per acre
Kilograms Per Hectare Per Day	kg/ha/d	0.893	lb/ac/d	pounds per acre per day
Kilograms Per Square Centimeter	kg/cm^2	14.49	lb/in^2	pounds per square inch
Kilometer	km	0.6214	mi	mile
Kilowatt	kW	1.34	hp	horsepower
Liter	L	0.0353 0.264	ft^3 gal	cubic foot gallons
Liters Per Second	L/s	0.035 22.826 15.85 0.023	ft^3/s gal/d gal/min Mgal/d	cubic feet per second gallons per day gallons per minute million gallons per day
Metric Tonne	t	1.10	T	ton (short)
Metric Tonnes Per Hectare	t/ha	0.446	T/ac	tons per acre
Meter(s)	m	3.2808	ft	foot (feet)
Meters Per Second	m/s	2.237	mi/h	miles per hour
Micrograms Per Liter	µg/L	1.0	ppb	parts per billion
Milligrams Per Liter	mg/L	1.0	ppm	parts per million
Square Centimeter	cm^2	0.155	in^2	square inch
Square Kilometer	km^2	0.386	mi^2	square mile

Table D-2. Dry Weight Basis

BIOSOLIDS FACT SHEET

EPA REGION VIII—*NPDES Branch—Permits Program*
999 18th Street, Suite 500, Denver, Colorado 80202
Mr. Robert Brobst

EPA REGION X—*NPDES Branch—Permits Program*
1200 6th Avenue, Seattle, Washington 98101
Mr. Richard Heatherington

3.3 DRY WEIGHT BASIS (FS/793/03/1)

Laboratory results for sludge are typically reported in one of two forms, wet weight (i.e., mg/L) or a dry weight (i.e., mg/kg). You should request your laboratory to provide the results on a dry weight basis. In the event that the laboratory results are reported on a wet weight basis (i.e., in mg/L), the results for each pollutant in each sample must be recalculated to determine the dry weight concentration. To accomplish this conversion, the percent total solids in the sludge sample must be known.

The following equation can be used to determine the dry weight concentration because the equation uses the assumption that the specific gravity of water and sewage sludge are both equal to one. However, this assumption holds true only when the solids concentration in the sludge is low. The calculated dry weight concentration may vary slightly from the actual concentration as the solids content increases because the density of the sewage sludge may no longer be equal to that of water. Typically, this concern is unrealized as the solids content of sludge is usually low. EPA is aware of this potential problem and may make a determination regarding this matter at a later date.

Determine the pollutant concentration on a dry weight basis using the following abbreviated conversion:[1]

$$\mathbf{PC(dry,mg/kg)} = \left(\frac{\mathbf{PC(wet,\ mg/L)}}{\mathbf{\%\ total\ solids}}\right)$$

where **PC = Pollutant Concentration**

A unit conversion is incorporated into the equation.

[1] *Analytical Methods Used in the National Sewage Sludge Survey*. August 1988. U.S. EPA Office of Water Regulations and Standards (WH-552), Industrial Technology Division, Washington, DC.

FS/793/03/1

Dry Weight Basis

Determine the pollutant concentration on a dry weight basis using the following conversion:

$$PC(dry,mg/kg) = \left(\frac{PC(wet,\ mg/L)}{\%\ total\ solids}\right)$$

Example #1: Determine the dry weight concentrations of the pollutants.

- The laboratory analysis of your sludge yielded the following results:

As - 6.6 mg/L Cd - 5.5 mg/L Cr - 192.5 mg/L Cu - 374 mg/L
Pb - 44 mg/L Hg - 0.22 mg/L Mo - 0.88 mg/L Ni - 44 mg/L
Se - 2.2 mg/L Zn - 330 mg/L

- The percent solids was determined to be 22%.

Therefore, using the given equation, the dry weight concentration of As can be determined as follows:

$$\frac{6.6\ mg/L\ (As,wet)}{22\ \%} = \frac{6.6\ mg/L}{0.22} = \underline{30\ mg/kg}\ \ As,\ dry\ weight$$

Remember to convert the percent total solids to a decimal by multiplying by 100.

The remainder of the converted results are:

Cd=25mg/kg, Cr=875mg/kg, Cu=1,700mg/kg, Pb=200mg/kg, Hg=1mg/kg, Mo=4mg/kg, Ni=200mg/kg, Se=10mg/kg, Zn=1,500mg/kg

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$$\frac{(\quad)mg/L}{(\quad)\ \%} = \frac{(\quad)mg/L}{0.} = (\qquad)mg/kg\ dry\ weight$$

Table D-3. Conversion of Sludge Volume to Dry Metric Tons.

EQUATIONS FOR CONVERTING SLUDGE VOLUME TO DRY METRIC TONS[a]

Applicability:

The amount of sewage sludge used or disposed must be reported as metric tons, dry weight.

Procedure:

Step 1: Convert the common measure (e.g., cubic yards or gallons) to the English System or short tons, dry weight.

$$\textit{Dry short tons} = \textit{gallons of sewage sludge} \times \frac{8.34\ lb}{gallon} \times \frac{ton}{2000\ lb} \times \textit{Percent Solids}$$

8.34 lb/gal is the density of water. This equation is therefore applicable to liquid sludges (less than 5 percent solids). Site-specific densities may be determined and substituted in this equation for a more accurate result.

$$\textit{Dry short tons} = \textit{cubic yards (wet) of sewage sludge} \times \frac{Y\ lb}{cubic\ yard} \times \frac{ton}{2000\ lb} \times \textit{Percent Solids}$$

Y lb/cubic yard is the site-specific bulk density of the sewage sludge. It must be determined for each type of sludge prepared and substituted in the equation for accurate results.

Step 2: If you are starting with the English System or short tons, convert them to dry weight.

$$\textit{Dry tons} = \textit{Wet tons} \times \textit{Percent Solids}$$

Step 3: Convert the English System or short tons to metric tons.

$$\textit{Dry metric tons} = \textit{Dry short tons} \times .907$$

[a] Source: U.S. EPA. 1993. Preparing sewage sludge for land application or surface disposal. EPA/831/B-93/002a. Washington, DC.