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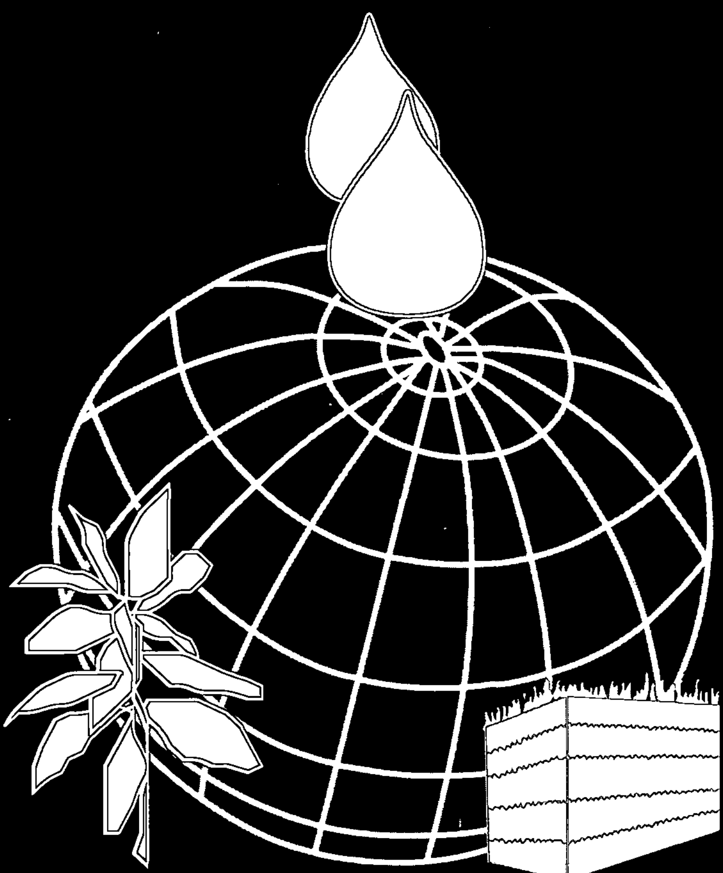
Guide to Soil Suitability and Site Selection for Beneficial Use of

Domestic Wastewater Biosolids



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GUIDE TO SOIL SUITABILITY AND SITE SELECTION FOR BENEFICIAL USE OF DOMESTIC WASTEWATER BIOSOLIDS

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Technical Review

Reviewers whose comments were particularly helpful in developing the guide, include Bob Bastian, Bob Brobst, and Dick Hetherington, EPA; Craig Cogger, Washington State University Cooperative Extension; John Hart and Jim Moore, Oregon State University Extension Service; Lee Sommers and Ken Barbarick, Colorado State University; Steve Wilson and Stuart Childs from Cascade Earth Sciences; and Kurt Leininger from CH_2M Hill.

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Introduction

Land application of treated domestic wastewater biosolids is beneficial when it is done in a manner that protects public health and maintains or improves environmental quality. Biosolids are beneficial recyclable materials that improve soil tilth and soil fertility and enhance the growth of agricultural, silvicultural, and horticultural crops.

This guide differs from other publications on the land application of biosolids because it emphasizes the soil. Natural processes in the soil store and release water and nutrients for plant use, break down organic matter, immobilize metals and organic contaminants, and reduce the number of pathogenic organisms. Understanding these processes requires understanding soil properties because they control both the natural processes and the overall suitability of a site for land application of biosolids.

Interactions among biosolids, soil, crop, and farm management are also emphasized in this guide. Under the right conditions, almost any arable land can be used for the beneficial use of biosolids. The right conditions, however, depend on the nature of the biosolids, the properties of the soil, the kind of crop, the cropping system, and most importantly, the interactions that ultimately control the decisions regarding biosolids application and site management.

Throughout the guide both principles and practical applications are stressed. Whether you're conducting a site evaluation, writing a permit application, or reviewing a project proposal, you need a solid base of technical information and a healthy dose of common sense. This guide emphasizes principles that will supplement your technical information and provides practical, useful information to add to your storehouse of common sense.

The objective of this guide is to assist treatment plant operators, permit writers, and others involved in biosolids management in the development, evaluation, and implementation of plans for the beneficial use of biosolids. The guide provides needed information, explains methods of evaluating the adequacy of information in site studies and project proposals, and identifies available resources.

The guide cannot, however, provide a complete prescription for site management. Because each site represents a unique combination of biosolids, soil, and farming system, a unique set of procedures must be prepared for each combination. In developing site-specific plans, take advantage of local experience and knowledge available from agricultural Extension agents, Natural Resources Conservation Service (NRCS) district conservationists, agricultural consultants, and the farmers who will be using the biosolids.

Framework for Evaluating Biosolids Utilization Proposals

Land application of biosolids benefits both agriculture and society. Agriculture benefits because biosolids supply nutrients for crop growth and improve the physical condition of the soil. Society benefits from the "disposal" of "waste" in a safe and effective manner. All biosolids utilization proposals should clearly indicate how both sets of benefits can be achieved, while at the same time maintaining environmental quality and protecting the public from health hazards associated with pathogens, metals, organic contaminants, and vectors.

Project evaluation has three components:

1. Evaluating the completeness of the data;
2. Evaluating the accuracy of the data;
3. Evaluating the extent to which the project accounts for issues and design considerations stemming from biosolids, soil, and cropping system interactions.

Evaluation of data completeness requires verifying the data on fertilizer recommendations and cropping practices as well as verifying that the chemical and physical characterization of both biosolids and soil are sufficient to make all necessary design calculations. The data also should be sufficient to ensure compliance with all pertinent regulatory standards. *If any of the required data are incomplete or missing, you may need to request additional information before proceeding with the project review.*

Evaluation of data accuracy requires ensuring that both biosolids and soils have been sampled and analyzed according to approved procedures and that the data are consistent with results from similar biosolids and soils analyzed previously. Confidence in data calculations and interpretations depends on this assurance. *If the data are not valid, it is not reasonable to expect a county Extension agent or anyone else to make recommendations for a biosolids utilization plan.*

Evaluation of issues and design considerations requires verifying that all calculations account for all relevant interactions, and that management decisions reflect the principles discussed in this guide. Some of the more important issues include:

1. Ensuring that soil properties and soil surveys, or on-site investigations, have been used to help select and evaluate potential sites;
2. Ensuring that the calculated Annual Whole Sludge Application Rate (AWSAR) accounts for all nutrient interactions in biosolids and soil, and that it delivers the right amount of nutrients at the right time for crop utilization;

Elements of Project Evaluation

- Completeness of data
- Accuracy of data
- Assessment of interactions

Sources of Local Help

- County Extension agents
- Natural Resources Conservation Service district conservationists
- Agricultural consultants
- Farmers and land managers

3. Ensuring that the timing of biosolids applications accounts for any soil, site, or climatic limitations, and is coordinated with crop management plans;
4. Ensuring that appropriate management practices have been specified to mitigate limiting soil properties and protect the public from adverse effects of metals, organic contaminants, and pathogens.

Unit Conversions

Analytical data on biosolids characteristics and the standards established by regulatory agencies are usually expressed in metric units. Farmers and farm advisors, however, usually use English units for expressing nutrient requirements and the amounts of biosolids to apply. Table 1 is designed to help you convert from one unit to the other.

The following tips may be useful in simplifying your calculations and presenting information in terms understandable to your users:

1. Make all conversions at one time, either at the beginning or the end. Rounding errors in metric-English conversions can be very large, and the number of times units are converted should be minimized.
2. Milligrams per kilogram (mg/kg) is the same as parts per million (ppm). Thus, if biosolids analysis data report 65,000 mg NH_4-N/kg, that is the same as 65,000 mg NH_4-N per 1,000,000 mg oven-dried biosolids.
3. When the units are the same in the numerator and the denominator, the same fraction can be expressed in any unit. In this example, the equivalent English unit is 65,000 lb NH_4-N per 1,000,000 lb oven-dried biosolids. This can then be expressed as 65 lb NH_4-N per 1,000 lb oven-dried biosolids, or 130 lb per ton of oven-dried biosolids.

Definitions

Throughout the text, many soil science terms such as adsorption, denitrification, mineralization, soil structure, and soil texture are used. These and several other terms are defined in the glossary at the end of this guide.

Table 1.—Guides for converting between metric and English units

Metric unit[1]	Conversion factor	English unit[2]
Centimeter	0.3937	Inch
Meter	3.2808	Foot
Kilometer	0.6214	Mile
Hectare	2.4711	Acre
Cubic meter	35.3147	Cubic foot
	0.00081071	Acre-foot
	264.25	Gallon
Gram	0.002205	Pound
Kilogram	2.205	Pound
	0.0011	Tons
Metric ton	1.10	Tons
Kilograms per hectare	0.000446	Tons per acre
	0.892	Pounds per acre
Metric tons per hectare	0.892	Tons per acre
Cubic meters per hectare	0.0001069	Million gallons per acre
Gallon of water	8.34	Pounds of water
Gallon of water	0.1336	Cubic feet of water

[1] To convert metric to English, *multiply* the metric unit by the conversion factor in the middle column.

[2] To convert English to metric, *divide* the English unit by the conversion factor in the middle column.

Biosolids Characterization

CHAPTER 2

Planning a program for beneficial use of domestic wastewater biosolids requires complete and accurate data. An important part of project evaluation is ensuring that the data used to make management decisions are both complete *and* accurate.

Complete characterization data for biosolids include the amount of solids produced and the amounts of plant nutrients, trace organic and inorganic contaminants, and pathogens contained in the solids. The data also should indicate the percent solids in the product that will be applied to the land and the process or processes used to reduce pathogens and control vector attraction.

Data accuracy depends on using standard procedures for collecting, handling, and analyzing samples. The publication *Analytical Methods for the National Sewage Sludge Survey* (EPA, 1988) is a useful reference for some of these procedures. Bacterial analyses should follow procedures established in *Standard Methods for the Examination of Water and Wastewater, 18th Edition* (EPA, 1992) and *Control of Pathogens and Vector Attraction in Sewage Sludge* (EPA, 1992). Analyses of inorganic pollutants need to follow protocols described in *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (EPA, 1982). These documents, and any other approved procedures, should be available from the agency that regulates biosolids treatment and disposal in your state.

Some rules of common sense apply to biosolids sampling and sample handling. For example, samples should not be put in a paper bag and left in a truck for several days. Store samples in glass or plastic containers to prevent the loss of liquids, volatilization, and contamination with extraneous organic material. Samples must be representative of the biosolids to be applied. Further information on appropriate sampling equipment, containers, sample preservation, and quality control/quality assurance procedures is available in the documents cited in the paragraph above.

Biological activity does not stop once a sample is taken. Organic matter continues to decompose, and organic nitrogen continues to be mineralized. To obtain good nitrogen data, refrigerate or freeze the sample immediately and store it in that condition until laboratory analyses can be performed. Otherwise, the nitrogen data may not represent the actual amounts of each form of nitrogen that are in the biosolids.

Laboratory procedures for analyzing biosolids are essentially standardized. Nevertheless, there is some variation among laboratories in both the accuracy and the precision of analytical data. Your state regulatory agency should be able to provide a list of reputable laboratories whose work is reliable.

Analytical data are expressed in terms of the dry weight of biosolids. This is the weight of the residue after driving off all the water in a biosolids sample by heating in an oven at 105°C. The dry weight includes all solids suspended in the original biosolids mixture, plus all constituents dissolved in the liquid portion of the biosolids. All references to dry weight, dry pounds, or dry tons are for dry weight determined in this way.

Rules for Biosolids Sampling

1. Collect samples that are truly representative of the biosolids product.
2. Store samples in appropriate glass or plastic containers
3. Refrigerate or freeze samples to prevent changes in nitrogen data.

Biosolids Characteristics

Both the nutrient value of biosolids and the potential for environmental degradation from land-applied biosolids depend on the percent solids of the biosolids; the composition of the biosolids; how biosolids are handled and processed prior to land application; and the manner, timing, and location of the application.

Types of biosolids

Treated domestic wastewater biosolids consist of water, dissolved solids, suspended solids, and settleable solids removed from domestic wastewater during the treatment process. The solid components contain plant nutrients, trace inorganic and organic chemicals, and inert solids, many of which are combined with complex organic compounds. The percent total solids in the biosolids determines the type of biosolids.

Liquid biosolids consist of a mixture of solids and water that readily flows. The solids content usually is within a range of 2 to 5% but may be as low as 0.5% or as high as 10%.

Dewatered biosolids are more concentrated and are produced by mechanically removing some of the liquid. Many dewatering processes produce a biosolids product, called a cake, that contains between 16 and 22% solids, although some dewatered biosolids may have as much as 40% solids.

Dried biosolids consist of an even more concentrated mixture that results from evaporation through air drying or heating. The solids content of a well dried biosolids product typically is 50% or more.

Composted biosolids are produced by combining biosolids with a bulking agent such as sawdust and aerating the resulting mixture under controlled temperatures. Recycled compost also may be used as a bulking agent. The solids content of composted biosolids generally is about 40%.

The Type of Biosolids Influences

- Storage and transportation requirements
- Application methods
- Hydraulic loading
- Fertilizer value

The type of biosolids applied to the land has several implications for a beneficial use program. First, any process that reduces the volume of biosolids reduces the storage and transportation needs and costs.

Second, the solids content dictates the method and timing of application to the land. Liquid biosolids that contain less than 6% solids can be surface applied either from tank trucks with special deflection plates or from irrigation guns. Liquid biosolids also may be injected directly into the soil.

At higher solids contents, the slurry may be too thick to pump. Dewatered biosolids, dried biosolids, and composted biosolids must be hauled in dump trucks and spread mechanically with hammer throw or manure spreader devices.

Third, dewatering, drying, and composting all affect the fertilizer value of biosolids. These changes are discussed further in the section titled "Nutrients" in this chapter.

Biosolids quantity

The quantity of biosolids a wastewater treatment plant produces each year can be expressed either as dry tons or as gallons. If biosolids quantity is expressed as gallons per year, calculate the dry tons of total solids produced as follows:

- Convert the total gallons produced to tons (see Table 1).
- Multiply by the percent solids reported in the laboratory data.

Dry tons is the preferred method for expressing biosolids quantity because it is independent of liquid content, which varies according to the method of biosolids processing and handling.

For liquid biosolids, the quantity produced helps determine biosolids storage and transportation requirements. Biosolids storage is necessary during times when soil conditions are unfavorable for land application. These times occur when the ground is frozen, when soil water tables are high, or when the soil surface is wet. Depending on specific climatic conditions, these times may range from a few days to a few months.

Biosolids storage also may be required because certain crops limit biosolids applications to specific times of year. You probably can't drive over a grain or row crop after the crop has been planted, and public health considerations may preclude biosolids application for part of, all of, or more than one growing season. Applications to permanent pasture, however, generally are limited only by the timing of livestock grazing, provided soil and weather conditions allow site access.

Biosolids transportation needs depend on the quantity of biosolids produced, the percent solids, and the times of year during which biosolids can be applied. The larger the quantity of biosolids produced, the greater the transportation requirements. If biosolids can be applied only during a portion of the year, the required hauling capacity may be even higher. The percent solids dictates whether storage lagoons, storage tanks, or watertight boxes are needed for transportation.

Nutrients

Biosolids are low-analysis fertilizers. They are a valuable source of plant nutrients, but the nutrient concentrations are significantly lower than in most commercial fertilizers. The nutrient content of biosolids depends on the primary source of the biosolids, their age, the methods of processing prior to land spreading, and the method of application.

The actual fertilizer value of a biosolids product and the determination of appropriate agronomic loading rates depend on the specific data reported for that product. It is *essential*, therefore, that these data represent the final processed biosolids product, not an intermediate form.

The most important nutrients in biosolids are nitrogen, phosphorus, and potassium. Other nutrients in biosolids include calcium, magnesium, and sulfur. Biosolids also contain small quantities of plant micronutrients such as copper, boron, iron, zinc, and manganese, and trace amounts of growth stimulants such as selenium, cobalt, arsenic, and vanadium.

Nutrient contents of biosolids usually are expressed either as percent of dry weight or as mg/kg dry weight. Most calculations, however, use the equivalent concentration in lb per dry ton. To convert percent to lb/ton, multiply by 20. To convert mg/kg to lb/ton, multiply by 0.002.

Nitrogen in biosolids occurs in both inorganic and organic forms. Biosolids analytical data usually include the amounts of inorganic ammonium nitrogen and inorganic nitrate nitrogen, and either the total Kjeldahl nitrogen or the total nitrogen. To determine the amount of organic nitrogen, either subtract the ammonium nitrogen from the total Kjeldahl nitrogen, or subtract the sum of ammonium plus nitrate nitrogen from the total nitrogen.

Inorganic forms of nitrogen are dissolved in the biosolids product and are readily available to plants. For this reason, ammonium nitrogen and nitrate nitrogen in the biosolids serve as short-term, or quick-release, fertilizers.

Organic nitrogen in biosolids is a long-term, slow-release fertilizer. As organic matter decomposes in the soil, microorganisms convert the organic nitrogen to inorganic ammonium nitrogen. This process is called *mineralization*. Other organisms then convert the ammonium to nitrate. This process is called *nitrification*. Only after these conversions is the nitrogen in biosolids organic matter readily available to plants.

The fertilizer value of biosolids is changed by dewatering and drying processes to reduce the water content, and by additional processes to reduce pathogens and vector attraction. Dewatering processes reduce the fertilizer value because they remove some of the nutrient-containing liquid. Drying also reduces the fertilizer value because much of the ammonium nitrogen changes to gaseous ammonia and is lost by volatilization. As a result, both dewatered and dried biosolids deliver much less quick-release, readily available nitrogen per dry ton to the soil than do liquid biosolids.

Composting converts most of the inorganic nitrogen in biosolids to organically bound nitrogen through a process called *immobilization*. Therefore, composted biosolids supply little readily available nitrogen to plants. However, the nitrogen released by further decomposition in the soil continues to supply plants for a longer period of time than do other kinds of biosolids.

Much of the fertilizer value in all biosolids products comes from the slow release of organic nitrogen through mineralization. The rate of this release, usually between 8 and 30% during the first year following land application, depends on many factors, including the form of biosolids applied.

In general, the highest rate of release *during the year following application* is obtained with liquid and dewatered biosolids. Dried biosolids and composted biosolids have slower release rates, but because these products have much higher solids contents, more nitrogen will be released in the second and third year after initial application than from other types of biosolids.

Methods of processing also affect the mineralization rate. For aerobically processed biosolids, the mineralization rate may be 30% or more. Anaerobic processing often results in a mineralization rate of about 20%. Composted biosolids have even lower mineralization rates, generally about 8%, during the year after application.

The method of land application also affects the fertilizer value of biosolids. Methods that leave liquid biosolids on the soil surface may result in volatilization of half or more of the ammonia, depending on climate and temperature. On the other hand, liquid biosolids that are injected or worked into the soil immediately following application retain most of their nutrient value.

Phosphorus and potassium are important plant nutrients, but in most cases they are needed in smaller amounts than nitrogen. Their availability to plants is less dependent on the extent of biosolids processing prior to land application than is nitrogen availability. As a result, if the agronomic loading rate is based on nitrogen, you can use the analytical data to calculate the amounts of P and K delivered with it and compare them with crop requirements. If there is still a deficiency, you can add supplemental fertilizer.

Excessive amounts of P delivered in biosolids applied to land usually have no short-term impact on crop production, but monitoring of long-term increases in soil salinity and nutrient balance certainly are appropriate. Particular care may be required to prevent surface runoff and overland transport of biosolids that could lead to an increase in the phosphorus content of nearby rivers and lakes.

Surface spreading of liquid biosolids leads to volatilization of up to one-half of the ammonia nitrogen applied.

Inorganic pollutants

Trace inorganic pollutants (often referred to as metals) in biosolids include arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc. The data from a biosolids analysis usually report concentrations of trace inorganic pollutants in mg/kg dry weight. Multiply these numbers by 0.002 to convert the expression to pounds of pollutant per dry ton of biosolids.

Excessive applications of trace inorganic pollutants are of concern because:

1. Some may be toxic to animals if ingested at high levels for long periods.
2. Some are potential carcinogens.
3. Some tend to accumulate in body tissues and, in large quantities, may impair the functioning of vital organs, particularly the liver and kidneys.
4. Some may enter human food supplies, either through animals that graze on crops that take up trace inorganic pollutants from soils, or through direct consumption of accumulator crops.
5. Some may be toxic to plants.

To protect public health and help assure beneficial use of biosolids, the Clean Water Act required EPA to identify any potentially toxic inorganic pollutants in biosolids and to develop regulations governing allowable concentrations and acceptable management practices for biosolids land application. Current criteria regarding concentrations of trace inorganic pollutants in biosolids are summarized in Table 2.

Table 2.—Regulatory criteria for content of trace inorganic pollutants in biosolids applied to land

Trace inorganic	(A) Maximum level for high quality biosolids (mg/kg)	(B) Ceiling concentration for application of biosolids to land (mg/kg)	(C) Cumulative pollutant loading rate (kg/ha)
Arsenic	41	75	41
Cadmium	39	85	39
Chromium	1,200	3,000	3,000
Copper	1,500	4,300	1,500
Lead	300	840	300
Mercury	17	57	17
Molybdenum	18	75	18
Nickel	420	420	420
Selenium	36	100	100
Zinc	2,800	7,500	2,800

Specific regulations regarding trace inorganic pollutant loading rates and cumulative limits undergo periodic revision. In fact, at this writing, the concentration limits for chromium, molybdenum, and selenium are under review and may be revised. Such reviews and regulatory changes are the result of increasing understanding of the reactions of these substances in soils, their tendency to be immobilized in the soil, their uptake by specific crops, and their effects on plant, animal, and human health and the environment. For these reasons, you should refer to the applicable federal and state regulations in force when a particular land application project is being developed.

Organic contaminants

Trace amounts of some organic chemicals may be found in most domestic wastewater biosolids, depending on the number and kind of industries and homeowners that discharge wastes into the municipal sewer system. Solvents, paints, pesticides, and polychlorinated biphenyls (PCB's) are some of the classes of organic chemicals that may occur. In general, trace organics such as halogenated hydrocarbons, benzo(a)pyrene, dimethyl nitrosamine, and non-halogenated organic pesticides appear to pose the greatest potential hazard to human health.

Federal source permits generally require periodic analysis of biosolids for several trace organic compounds under a priority pollutant scan. Biosolids data, therefore, should at least include the amounts of these compounds present. The data usually are reported either as parts per million, parts per billion, or as mg/kg dry weight.

Land application of biosolids provides several possible mechanisms for mitigating toxic effects of organic contaminants. Some organics may be subject to volatilization or may be decomposed by sunlight. Some undergo rapid microbial decomposition; others decompose very slowly. Some organics may be immobilized by adsorption on surfaces of clay particles and organic matter in the soil. Others may be leached out of the soil system. Leaching losses are not very likely because the organic matter added to soil with biosolids applications tends to adsorb organics and immobilize them in the soil.

Based on the limited information currently available, organic chemicals in most domestic wastewater biosolids applied to land should not pose a serious threat to plants or animals. The major concern is human toxicity caused by ingestion of plant or animal products, the biosolids themselves, or the biosolids-amended soil.

Because of the extreme diversity in the kinds of organic contaminants that may be found in a particular biosolids product and in the specific interactions between organic chemicals and soil environments, prescribing universal guidelines for managing biosolids that contain organic chemicals is difficult. The best common sense advice is to consult with your state regulatory agency and to comply with all pertinent federal and state standards. If this is done, organic chemicals in biosolids applied to land should not pose a public health problem.

Pathogen reduction

Virtually all pathogenic bacteria, viruses, protozoa, and parasitic helminth ova must be significantly reduced or eliminated from land-applied domestic wastewater biosolids to prevent contamination of human and livestock food and water supplies. Risks associated with these pathogens in land-applied biosolids are discussed further in the publication *Technical Support Document for Reduction of Pathogens and Vector Attraction in Sewage Sludge* (EPA, 1992).

Most of the needed pathogen reduction takes place by processing the biosolids at the wastewater treatment plant prior to land application. The remainder can be accomplished by natural processes at the application site. Pathogen reduction processes are discussed in detail in the publication *Control of Pathogens and Vector Attraction in Sewage Sludge* (EPA, 1992).

All processes to treat biosolids, whether prior to a land application or in the soil itself, are designed to create environments unfavorable to pathogen survival. Pathogens prefer cool, wet, and dark environments and do not survive in warm, dry environments that are exposed to sunlight. In land application systems, pathogenic organisms become a health hazard only if:

1. The numbers of pathogenic organisms in biosolids are not reduced to tolerable limits; or
2. Pathogens are leached into groundwater, carried by runoff into surface water, ingested with plant or soil materials, or transported by vectors.

Pathogen reduction processes used by domestic wastewater treatment plants generally fall into two categories: 1) Processes that Significantly Reduce Pathogens (PSRP's), and 2) Processes that Further Reduce Pathogens (PFRP's). PSRP's include aerobic digestion, air drying, anaerobic digestion, some types of composting, and lime stabilization. PFRP's include composting, heat drying, heat treatment, thermophilic aerobic digestion, beta ray irradiation, gamma ray irradiation, and pasteurization.

Biosolids that have been processed with one of the PSRP's or an equivalent process recognized by EPA are classified as Class B biosolids. Although some pathogens may remain, they are safe to apply to land. Most of the domestic wastewater biosolids produced in the United States are Class B biosolids.

To adequately protect livestock that forage on biosolids-amended crops, and to maintain high standards of public health, certain site restrictions and management practices must be followed. Specific site management requirements for Class B biosolids are given in Subpart B of 40 CFR part 503.32(b)(5).

Surface application of biosolids treated with a PSRP or an equivalent process creates exposure to both drying and sunlight, conditions that facilitate rapid decline of most remaining pathogens and parasites. When Class B biosolids are applied to land used to grow food or forage crops, lag times ranging from 1 to 38 months, depending on the type of crop and the method of application, are required to ensure elimination of potentially harmful pathogens.

Biosolids that have been treated with one or more of the accepted processes that further reduce pathogens (PFRP's) are classified by EPA as Class A biosolids. Class A biosolids must meet very stringent limits on the density of pathogenic bacteria, enteric viruses, and helminth ova. Specific requirements for Class A biosolids are given in Subpart B of 40 CFR Part 503.32(a)(7). Because PFRP's eliminate virtually all pathogenic organisms from biosolids, Class A biosolids can be applied to land safely regardless of the type of crop to be grown.

Both PSRP's and PFRP's affect the fertilizer value of biosolids. In particular, the amounts of readily available nitrogen and the rates of mineralization of organic nitrogen are affected by the process used to reduce pathogens. When determining the amount of biosolids to apply, these interactions must be recognized to ensure delivery of the right amount of nitrogen to meet a fertilizer recommendation.

Vector attraction reduction

Vectors are organisms, mainly rodents, and insects such as flies and mosquitoes, that are capable of transporting infectious agents. Because organic wastes offer a rich food source for vectors, there is a potential for vectors to be attracted to biosolids that have not been adequately stabilized.

Any biosolids product that is applied to the land must be treated to reduce vector attraction. This can be accomplished by any one of 10 procedures for vector attraction reduction as spelled out in EPA biosolids regulations (40 CFR 503.33(b)(1) through (10)). In general, the first eight of these procedures involve reducing the amount of volatile solids or stabilizing the biosolids with temperature or alkali treatment. Procedures 9 and 10 involve injecting biosolids beneath the soil surface or disking surface-applied biosolids into the topsoil immediately after land spreading.

Regulatory Characteristics

Three parameters usually dictate the amount of regulatory oversight of biosolids applications to land and the extent of management and site restrictions: 1) the content of inorganic pollutants; 2) the degree of pathogen reduction prior to land application; and 3) the steps taken to reduce vector attraction.

These parameters define three classes of biosolids quality: exempt biosolids, high quality biosolids, and regular biosolids. All are suitable for land application. Other combinations of trace inorganic content and pathogen reduction exist, but they occur so infrequently as to be treated as special cases. If you have such biosolids, contact your nearest state or EPA biosolids regulator.

Exempt biosolids

These are treated domestic wastewater biosolids that contain such low levels of inorganic pollutants and pathogens that they are virtually exempt from further regulation. To qualify, a biosolids product must have inorganic pollutant contents below the limits given in Column (A) of Table 2, must be a Class A biosolid with respect to pathogen reduction, and must meet one of the eight vector attraction reduction requirements. Under these conditions, biosolids are considered an unregulated fertilizer grade agricultural commodity.

High quality biosolids

These biosolids contain low levels of inorganic pollutants but have been treated only with processes to significantly reduce pathogens (PSRP's). Pollutant concentrations are below the maximums given in Column (A) of Table 2, but the biosolids product is only a Class B with respect to pathogen reduction.

Under these conditions, there is no regulation of inorganic pollutant loadings on soils, but some site restrictions are imposed to make sure that additional treatment to reduce pathogens can be accomplished at the land application site without risk to public health.

Regular biosolids

These are biosolids that have somewhat higher contents of inorganic pollutants than high quality biosolids. The content of one or more inorganic pollutants in the biosolids product exceeds the value given in Column (A) of Table 2, but all inorganic pollutant concentrations must be within the limits given in Column (B) of Table 2. Most regular biosolids have been treated only with a PSRP or equivalent process and are Class B with respect to pathogen reduction.

Use of these biosolids is regulated with respect to both site conditions and cumulative loading of inorganic pollutants. Cumulative loading limits for inorganic pollutants are those specified in Column (C) of Table 2. Accurate records of pollutant contents and biosolids application rates must be kept to ensure compliance with regulations concerning cumulative loading limits.

Regulatory oversight of cumulative loading of trace inorganic pollutants also requires knowledge of the previous history of biosolids application at a site. If, for example, it is known that no biosolids have been applied to a site since July 20, 1993, then biosolids can be applied to that site up to the cumulative loadings specified in Table 2. If biosolids have been previously applied since July 20, 1993, and the cumulative inorganic pollutant loadings from those applications are known, then additional biosolids can be added up to the limits in Table 2.

If, however, the cumulative inorganic pollutant loadings from prior applications are not known, then additional biosolids applications are not allowed. Exceptions may be granted only if baseline soil data indicate that pollutant loading would not cause cumulative limits to exceed the values in Table 2.

Biosolids for home lawns and gardens

Because the use of biosolids as an amendment to home lawns and gardens presents a higher probability for human contact, hence disease transmission, than biosolids applied to farm fields, the standards for application to lawns and gardens are more rigorous. Biosolids intended for these kinds of applications must meet the requirements for exempt biosolids, i.e., inorganic pollutant concentrations below those in Column (A) of Table 2, Class A pathogen reduction, and treated according to one of the eight vector attraction reduction requirements provided at a wastewater treatment plant.

Management Practices

Land application of both regular and high quality biosolids at rates exceeding one dry metric ton per hectare is subject to certain restrictions on site selection and subsequent use of biosolids-amended soils.

Site restrictions

Use of Class B biosolids must ensure that soil and site conditions are selected and managed in ways that protect environmental quality and public health. For this reason, four management practices must be followed in applying bulk quantities (more than one dry metric ton) of either high quality or regular biosolids to land:

1. Sites cannot be used if it is likely that biosolids application could adversely affect a threatened or endangered species;
2. Sites cannot be used if runoff from flooded or frozen ground might carry surface-applied biosolids into a wetland or other body of surface water;
3. Biosolids cannot be applied on agricultural land, forest land, or a reclamation site that is 10 meters or less from surface water bodies;
4. Biosolids must be applied at a rate that is equal to or less than the appropriate agronomic loading rate for the soil and crop at that site.

Lag times

Restrictions on lag times between biosolids application and subsequent uses of sites are imposed to ensure high quality food supplies and minimize direct public exposure. These restrictions include:

1. All food, feed, and fiber crops require a lag time of at least 30 days between biosolids application and harvest.
2. For food crops whose harvested parts are above the soil surface and may come into direct contact with biosolids or biosolids-amended soil, the minimum lag time between application and harvest is 14 months.
3. For food crops whose harvested parts are below the soil surface, the minimum lag time between application and harvest is:
   a) 38 months if biosolids are incorporated into the soil within 4 months of application;
   b) 20 months if biosolids remain on the land surface for more than 4 months before incorporation.
4. Grazing is not allowed within 30 days of biosolids application.
5. Turf to which biosolids are applied in areas of high potential for public exposure, such as lawns, golf courses, parks and athletic fields, may not be harvested for at least 1 year following application.
6. Public access to land application sites must be delayed for at least:
   a) 1 year where the potential for public exposure is high
   b) 30 days where the potential for public exposure is low.

Soil Characterization

Site evaluation, site selection, and site management all begin with an assessment of soil properties. These properties control the biological, physical, and chemical processes in soils that release plant nutrients and immobilize toxic chemicals.

This chapter gives you a working knowledge of the soil properties that influence the beneficial use of biosolids. With this knowledge you should be able to read and understand technical soil profile and map unit descriptions in soil survey reports. You can then retrieve the maximum amount of information from those descriptions. You should also be able to evaluate site feasibility studies and permit applications for the adequacy of soils data and the appropriateness of proposed management plans.

Morphological properties define the nature of the soil profile and are determined in the field. Properties that are based on interpretations of soil morphology are called *inferred* properties. Information about both morphological and inferred properties can be obtained either from direct field observations or from published soil survey reports.

The Roles of Soil

Within a biosolids management program, the three roles of soil are to provide a medium for:

1. Plant root growth;
2. Water entry and transmission;
3. Attenuation of environmental contaminants.

Soil as a medium for plant roots

An aerobic environment is necessary both for plant roots and for the soil microbes that decompose organic residues and destroy pathogens. Aerobic environments provide a favorable balance between air-filled pores and water-filled pores. Soil management for beneficial utilization of biosolids should strive to maintain aerobic conditions in the soil.

Aerobic conditions are related to soil texture, soil structure, and soil water content. Sandy soils, and loamy soils with good structure, provide aerobic conditions. Clayey soils, and soils with poor structure tend to be less well aerated. Soils that are saturated for long periods of time are anaerobic and are not favorable for mineralization. Saturation is more likely in soils that are clayey, or have impermeable horizons, or occur in low-lying landscape positions.

Soil as a medium for water entry and transmission

Rainfall, irrigation water, and the liquid portion of biosolids can be transmitted to surface and ground waters through soil. The rate of transport depends on the soil properties. Soil management for land application of biosolids must regulate water movement over and through the soil in order to prevent contamination of water supplies with nitrates, phosphates, trace inorganics, and organic pollutants.

Soils in high rainfall areas and soils that are irrigated are subject to leaching. Water moving through the soil transports any nutrients or toxic chemicals that are in solution. The more permeable the soil, and the higher the rainfall or irrigation, the greater the potential for leaching.

Runoff occurs when the soil cannot absorb the rainfall or irrigation. Surface runoff increases the potential for contamination of lakes and streams with biosolids transported over the soil surface by runoff water. The runoff potential of a soil depends on the soil's slope and wetness, and whether the soil is frozen. Ground cover, rainfall intensity, and the efficacy of soil conservation measures also influence runoff. Bare soil on steep slopes in an area subject to high-intensity storms represents an extreme case of runoff potential. Thick sod cover and conservation practices such as minimum tillage help reduce runoff.

Soil as a medium for attenuation of environmental contaminants

The contaminants of concern in a biosolids application program are trace inorganic pollutants, toxic organics, and pathogenic organisms. Soil attenuates trace inorganics and organics by immobilization reactions. Some pollutants are immobilized by strong electrical attraction to the negatively charged surfaces of clay and organic matter. Most, however, are immobilized by formation of complex substances with clay, organic matter, and iron and aluminum oxides that are very resistant to dissolution and decomposition. Thus, the higher the amount of clay and organic matter in the soil, the greater its ability to attenuate trace inorganic and organic pollutants.

Soil attenuates pathogens by holding them in an environment that is unfavorable for their survival. Pathogens cannot survive in warm, dry soil. Even in moist soil, aerobic conditions lead to rapid die-off of pathogens. The chance for pathogens to move through the soil to groundwater increases only when biosolids are applied to soil that remains saturated and anaerobic for long periods of time.

Morphological Properties

Soil Texture Affects

- Porosity
- Water movement
- Aeration
- Water retention
- Organic matter
- Plant nutrition
- Trace inorganic adsorption

The most important morphological properties are texture, structure, color, mottles, horizons, and soil depth. The definitions of these properties, their significance for land application of biosolids, and their evaluation in the field are described in the following sections.

Texture

Soil texture refers to the soil's particle size distribution. Soil particles are classified by size into two groups: *fine earth* (<2 mm) and *coarse fragments* (2 mm-10 in). Fine earth is subdivided into sand (.05-2.0 mm), silt (.002-.05 mm), and *clay* (<.002 mm). The sand fraction is further divided into very coarse, coarse, medium, fine, and very fine sand. Coarse fragments include *gravel* (2 mm-3 in), *channers* (2 mm-6 in and flat), and *cobbles* (3-10 in).

Sand particles feel gritty and are so large that each grain is visible. Silt has a smooth feeling, like flour or corn starch. Neither sand nor silt contribute much to the chemical behavior of the soil.

Clay feels sticky and can be molded into ribbons and wires. The particles are flat and can be seen only with high-powered microscopes. Clay has a large amount of surface area per unit volume and is much more active chemically than silt or sand. Many aspects of soil behavior affecting utilization of biosolids depend heavily on the behavior of clays in soils.

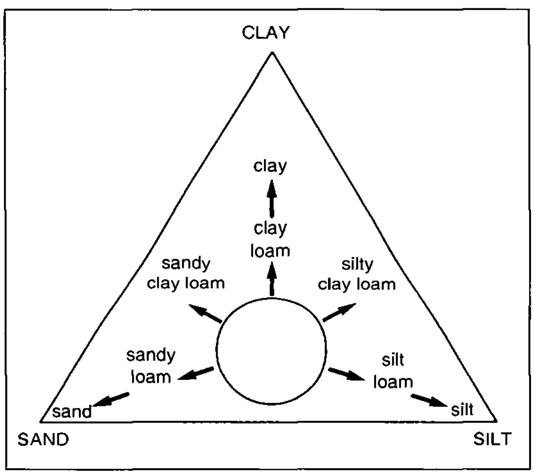


Figure 1.—Generalized textural triangle

Table 3.—Names of soil texture classes

Abbreviation	Textural class	Generalized term
S	Sand	Coarse
Ls	Loamy sand	Coarse
Sl	Sandy loam	Moderately coarse
L	Loam	Medium
Sil	Silt loam	Medium
Sicl	Silty clay loam	Moderately fine
Cl	Clay loam	Moderately fine
Scl	Sandy clay loam	Moderately fine
Sc	Sandy clay	Fine
Sic	Silty clay	Fine
C	Clay	Fine

Every soil contains a mixture of sand, silt, and clay. A textural triangle (figure 1) shows all the possible combinations and is used to form groups, or classes, of soil texture. Specific combinations of sand, silt, and clay have names such as *loam, sandy loam,* and *silty clay loam.* All the names of soil texture classes, their abbreviations, and their grouping into generalized classes are shown in Table 3.

If rock fragments larger than 2 mm are present in sufficient quantity, then names such as *gravelly loam* or *very cobbly clay,* are used. Precise definitions of coarse fragment modifiers are given in Appendix A.

Figure 1 is a generalized textural triangle. A soil that is almost all sand would be very close to the sand corner of the triangle, and the textural class name would be sand. Similarly, a soil dominated by clay would be near the clay corner of the triangle, and the class name would be clay.

Soils that contain a balanced mixture of sand, silt, and clay are called loams. These soils are just below the center of the triangle. Loams require less clay than sand or silt to balance the mixture because clay has such a pronounced effect on both the chemical and the physical behavior.

If the balance of a loam is changed by adding sand, the sand begins to dominate, and the particle size distribution moves away from the loam toward the sand corner. The texture changes from loam to sandy loam, then to loamy sand, and ultimately to sand.

If clay is added to a loam, the texture moves toward the top of the triangle. Adding just a little more clay changes the texture from loam to clay loam. If the sample contains more than 40% clay, the textural class name is simply clay.

If both silt and clay are added to a loam at the expense of sand, the texture moves away from the sand corner towards a point in between the silt and clay corners. The name of this textural class is silty clay loam. Similarly, adding both sand and clay at the expense of silt becomes sandy clay loam.

Texture influences soil suitability for biosolids application and utilization in many ways. Texture is related to the size and shape of soil pores, which affects water movement into and within the soil. Texture influences the balance between water-filled pores and air-filled pores, creating different soil environments for root growth and microorganism activity. Texture also influences the rate of accumulation of organic matter. Organic matter and clay content together determine the soil's capacity to immobilize pollutants and supply nutrients.

The medium-textured soils (loam, silt loam, and fine sandy loam) are usually best for land application of biosolids. The range of pore sizes in these soils allows water to flow through the smaller pores and exchange air in the larger pores. Medium-textured soils provide favorable environments for root growth, store large amounts of water for plant use, and have good nutrient-supplying power.

Sandy soils have more large pores and fewer small pores. Usually they are well aerated, but they store much less water for plant use. Sandy soils are droughty soils, and yields of dryland crops are likely to be lower than on medium-textured soils. Nutrient requirements are lower, and the rate of biosolids application may need to be adjusted accordingly.

Many sandy soils are well suited for the production of irrigated crops. Since water enters and moves throughout the soil readily, irrigation can compensate for droughty conditions. In contrast, rapid water flow through sandy soils increases the risk of groundwater contamination. Groundwater quality problems can stem either from over-irrigation on a site to which dewatered, dried, or composted biosolids have been applied, or from applications of excessive amounts of liquid biosolids.

Clayey soils have more very tiny pores and fewer large pores. Air exchange and water movement are much slower than in medium-textured soils. Water applied as rainfall or irrigation is more likely to cause temporary soil saturation, reducing oxygen supplies to soil microorganisms.

Water entry into clayey soils may be very slow, so runoff is a greater risk. Care should be taken when applying dried or composted biosolids on clayey soils so that runoff doesn't physically wash them from the site.

Coarse fragments don't necessarily render a soil unsuitable for biosolids application, but they do make management more difficult. Coarse fragments reduce the volume of soil through which water can flow and in which water can be stored.

In soils containing coarse fragments, both water flow and water retention depend on the texture of the fine earth. If the fine earth is medium-textured, then the soil may be suitable for biosolids utilization, but application rates may have to be reduced and land area requirements increased. In other soils, coarse fragments exacerbate problems associated with sandy or clayey textures, and management is more difficult.

Structure

Soil structure refers to the aggregation of individual grains of sand, silt, and clay into larger units called *peds.* Plant roots, soil organic matter, and clay particles provide physical and chemical binding agents.

Soil structure is important because it modifies some of the undesirable effects of certain textures on soil behavior. Structure creates relatively large pores, which favor movement of air and water into and through the soil. Even clayey soils can have good rates of infiltration and permeability if they have well-developed, stable structure.

Good soil structure also means good aeration and a favorable balance between pores that contain water and pores that contain air. Structure creates a favorable environment for root growth and microbial activity in all soils, especially in the finer-textured soils.

Maintaining strong, stable aggregates is an important management objective in any farming operation, including those that utilize biosolids as a fertilizer material. Three factors influence the maintenance of strong, stable aggregates: organic matter, clay, and heavy equipment.

Organic matter is vital to the formation and maintenance of good soil structure. Living roots help surround soil particles and bind them together. Exudates from roots and other soil biota provide a kind of "glue" that stabilizes peds. Decomposed organic matter, or humus, is particularly valuable in the development of structure.

Biosolids are valuable soil amendments because they can improve soil structure. Mixing biosolids into the surface soil helps restore the structure of overworked soils. Land on which row crops have been grown repeatedly is particularly prone to structural deterioration, and the use of biosolids on this kind of land can be very beneficial.

Good Soil Structure

- Promotes aeration
- Promotes infiltration
- Improves air-water balance

Clays help aggregate soil particles due to their chemical activity and their tendency to shrink and swell. One mechanism of structure formation is the attraction between negative charges on clay surfaces and positive charges on the edges of clay particles and organic soil constituents.

Soil structure is very sensitive to the weight of heavy equipment. Driving on wet soil breaks down soil aggregates and compacts the soil. Surface soil compaction retards germination and emergence of plant seedlings, and reduces the infiltration rate substantially, thus increasing the potential for surface runoff. To avoid these problems, wait until the surface soil has dried out before driving on the soil. Sod crops (hay and pasture) protect the structure much more than grain or row crops.

One of the reasons biosolids are such valuable soil amendments is their potential for improving soil structure.

Soil structure is characterized by the shape, size, and grade of the peds. Common shapes are illustrated in figure 2. Granular peds are common in surface soils, and plates occur in some soils just below the surface horizon. Blocks and prisms are both common in subsoils. Ped size is described with terms such as fine, medium, and coarse. Peds are measured in millimeters, and the range in values for each term depends on the shape. The relationships are given in Appendix A.

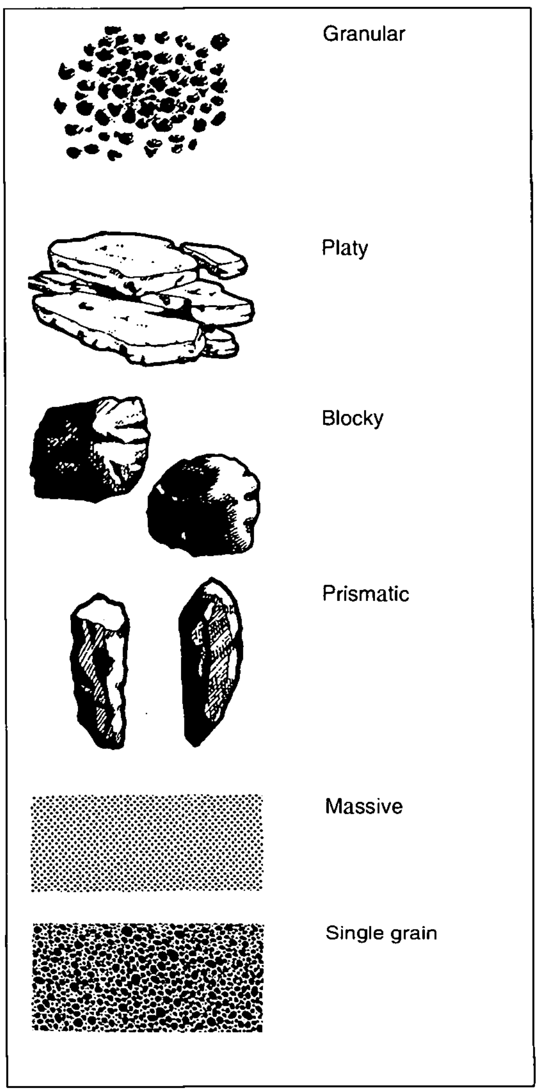


Figure 2.—Common shapes of soil structure

Structural grade refers to the degree of structural development and the strength of the peds. The structural grade is described as strong, moderate, weak, and structureless. These terms also are defined in Appendix A.

Structural grade is important for biosolids utilization because it affects soil porosity and soil strength. Soils with moderate or strong structures are ideal because they have good mixtures of large and small pores and optimum environments for growing plants. The peds tend to resist breakdown under the impact of falling water drops or from normal traffic. Soils with weak structure tend to have fewer large pores. They are less permeable and have slower infiltration rates. Peds are not as stable, and the soil surface is more likely to form a nearly impermeable crust.

Color

Inferences from Soil Color

- Organic matter content
- Degree of aeration
- Evidence of water tables

Soil colors provide clues about the nature of the root zone. Dark colors usually mean favorable amounts of organic matter. Gray colors often indicate soils that are poorly aerated due to long periods of wetness. Yellowish-brown and reddish-brown colors indicate favorable air-water relations.

Because different people might perceive and describe the same color differently, soil scientists describe soil color quantitatively by matching the color of a soil clod with a standard color chip in a special book of soil colors. This method is described in detail in Appendix A. Nevertheless, generalization of soil colors into a few broad groups helps to interpret their significance for biosolids utilization on land.

Dark brown, very dark brown, and black colors are caused by accumulations of organic matter in soils. Usually the darker the color, the more the organic matter in the soil and the more fertile and productive the soil is. Organic matter is a major factor in structure development, so the darker the soil, the better formed and more stable the soil peds.

Some soils have black colors extending well down into the subsoil. If the soil beneath is gray, then the black color in these soils indicates prolonged wetness in cool to cold climates. Organic matter in cool, wet soils breaks down much more slowly than in warm, moist soils. The extra organic matter that accumulates darkens the soil to a greater depth.

Brown and yellowish-brown colors indicate well-aerated soil. As soil microorganisms and plant roots use up oxygen in soil pores, oxygen from the air above the soil readily moves in to replace it. Well-aerated soils are ideal for crop growth and beneficial use of biosolids. Brown and yellowish-brown colors are caused by iron oxide coatings on soil particles. Chemically, these coatings are the same as rust on a piece of iron. Iron oxide is stable, and the coatings remain on soil particles as long as there is plenty of oxygen in soil pores. If oxygen is not available, as in soils that are saturated for long periods, the iron oxide coatings are removed, and the soil turns gray. This is why brown colors indicate that the soil has good air-water relations and is never wet for prolonged times.

Red and reddish brown colors also are caused by iron oxide coatings and indicate well-aerated soils. The soil is red, rather than brown, only because the chemical form of the iron oxide is a little different. These soils are very strongly weathered and tend to be more leached, more acid, and less fertile than brown soils.

Gray colors are the colors of wet soils. When soil pores are full of water, oxygen can't get in. This creates a reducing environment, and the iron oxide coatings begin to change to the more soluble ferrous form. Gradually the iron oxide coatings are stripped away and leached out of the soil. The gray color is the natural color of the mineral grains of the soil, darkened a little by organic matter.

Soils that have gray colors near the surface are poorly suited for biosolids application during times when the water table is high. But if the soil occurs in a climatic region having a prolonged dry period, biosolids application may be feasible, especially if dried or composted biosolids are being applied.

Many wet soils are permeable enough that artificial drainage can lower the water table. If the soil permeability is at least moderately slow, and tile drainage has been or can be installed to lower the water table to a depth of 3 feet, then a wet soil can be used for most types of biosolids application.

Before draining a wet soil, check two things. One, outlets must be available to receive the drained water. Two, ensure that draining a wet soil does not violate provisions of the Food Security Act of 1985, or any other legislation pertaining to natural wetlands. Check with local offices of the Extension Service, Natural Resources Conservation Service, Corps of Engineers, and state and federal Fish and Wildlife Services for possible regulations that affect wet soils.

Light gray and white colors in soils of humid regions also are caused by stripping of iron oxide coatings, revealing the true color of mineral grains. These colors don't always indicate wetness, though. If the soil below the white zone is brown or red and well-aerated, the white zone is not limited by wetness. If the underlying soil is gray, then the white layer is probably saturated for long periods of time. In arid regions, white subsoil may be the result of deposition of calcium carbonate and not an indicator of wetness. But if there is a surface crust of white color, this indicates that water is rising to the surface from a shallow water table, bringing soluble salts that are left on the surface as the water evaporates. These soils are not only periodically wet, they are often very alkaline and very slowly permeable, and are more limiting for biosolids application.

Before draining a wet soil, check with state or local officials for possible regulations that affect the use of wet soils.

Mottles

Some soils have spots of one color in a matrix of a different color. The spots are called mottles, and the soil is said to be mottled. Some mottles appear as splotches of reddish brown color in a gray matrix. Others appear as gray mottles in a brown matrix. Both kinds are described in terms of their abundance, size, contrast, and color. Abundance refers to the percentage of exposed surface area occupied by mottles. Size is the approximate diameter of mottles. Contrast is the relative difference between the mottle color and the matrix color. These terms are defined more fully in Appendix A. Mottle colors are described using the same technical procedure that is used to describe soil colors.

Mottling is caused by fluctuating water tables. When the water table is high, the soil is saturated and iron oxide is reduced. When the water table drops, oxygen begins to reenter the soil through root channels and large pores, which drain first. As oxygen comes into contact with moist soil containing reduced iron, the iron quickly oxidizes, forming an insoluble precipitate at the surface of a soil ped. The result is a yellowish-brown mottle surrounded by gray soil.

Mottles are spots of gray or brown color that indicate the height of fluctuating water tables.

By understanding these processes, we can use observations of soil colors and soil mottles to make inferences about the height and duration of water tables in soils, even though the soil may be quite dry when we look at it. Soil colors and mottles are used to define classes of internal soil drainage. These are discussed in the section on inferred properties.

There are three situations, however, in which mottles do not indicate wetness. These are the chemical weathering of rocks, relict mottling, and coatings on soil peds.

Rocks are the parent materials of soils and are composed of a variety of different minerals. Each mineral reacts differently to the processes of chemical weathering. Some turn yellow, some

Any horizon that differs markedly in texture, structure, or density from the one above or below affects water movement.

red, some gray, and some are destroyed completely. The result of rock weathering can be a mixture of colors that may look like drainage mottles, even though the soil is well drained. This situation is often encountered in the lower part of a soil as it grades into weathered bedrock. It also may be encountered in some glacial till soils in which a wide variety of rocks and minerals has been mixed together in the parent material.

The key to avoiding a false interpretation of rock weathering is to study climate, soil, and landscape factors carefully. In humid regions, soils that are gray and mottled and occur in concave depressions, low-lying areas, or on broad, flat terraces, are probably wet soils. Soils that occur on rounded hilltops, sloping hillsides, and narrow ridges, as well as soils in arid regions, are likely to be well drained soils with brown colors. Color variations in these soils are more likely to be associated with rock weathering than wetness.

Relict mottles are mottles that formed when the soil environment was wetter than it is now. Once formed, mottles are a relatively permanent feature of the soil, even if the climate changes. Thus, mottles in soils on convex uplands for which there is no other evidence of periodic water tables are probably relict mottles and do not indicate wetness.

Some peds have coatings of substances other than iron oxide. Organic matter, clay, and even moisture films can create colors that differ from the matrix color. These coatings should not be confused with mottles caused by reduction and oxidation of iron, and they should not be interpreted as indicating wetness. The best way to avoid this mistake is to break open soil peds and evaluate the color from a freshly exposed interior surface.

Kinds of Restrictive Layers:

- Claypans—some Bt horizons
- Fragipans—Bx horizons
- Duripans—Bkqm horizons
- Petrocalcic layers—Bkm horizons
- Dense till—Cd horizons
- Weathered bedrock—Cr horizons
- Hard bedrock—R horizons

Soil horizons

A soil horizon is a layer of soil parallel to the earth's surface. Each horizon is defined and described in terms of its morphological properties: texture, structure, color, etc. Together, all of the horizons in a soil constitute the soil *profile*. A soil profile description is a complete set of horizon descriptions for all the horizons that occur in a soil.

Soil horizons are named using combinations of letters and numbers. Six general kinds of horizons can occur in soil profiles (see Figure 3): O, A, E, B, C, and R. These are called *master horizons*. Gradual changes from one master horizon to another give rise to *transition horizons*. These are named with two letters, for example, AB, BA, and BC. *Special kinds* of master horizons are recognized by adding lower case

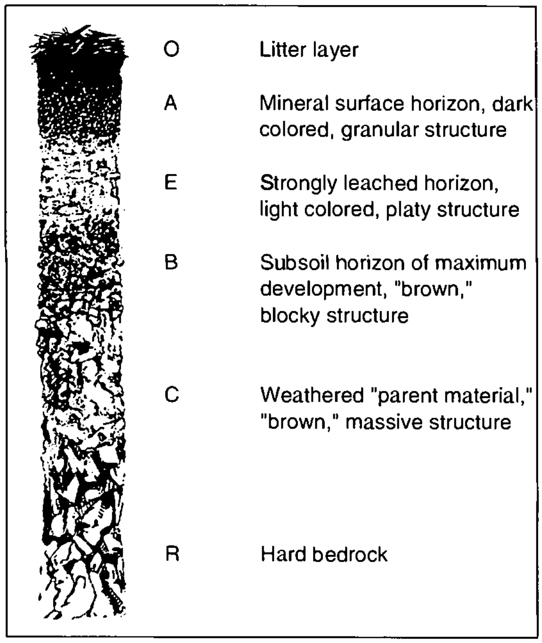


Figure 3.—Generalized soil profile

letters, as in Ap, Bt, Bk, and Cr. Master horizons, transition horizons, and special kinds of master horizons all are described more completely in Appendix A.

A single soil profile never has all possible horizons. Most soils have an A horizon, one or two specific types of B horizons, a C horizon, and one or two transition horizons. Some soils have only an A horizon and one or more C horizons. Others have bedrock (R horizon) at shallow depths. Some soils have an A-E-B-C horizon sequence, or even an O-E-B-C profile.

Soil horizons are important for biosolids utilization because of their effect on transmission of air and water through soil. Any horizon that differs markedly in texture, structure, or density from the one above or below affects water movement.

Horizons that are very clayey and have a weak or massive structure, and horizons that have very high densities, are called *restrictive layers*. Examples of restrictive horizons include *claypans* (Bt, or argillic, horizons that are clayey and massive), *fragipans* (Bx horizons that are silty and very dense), and *Cd horizons* (very dense glacial till). Water cannot move into and through these layers as fast as it moves down through the soil above them. During periods of excess rainfall or irrigation, water *perches* on top of the restrictive layer, saturating the soil and creating shallow, but temporary, water tables.

Restrictive layers thus limit the times during which a soil can be used for land application of biosolids. Liquid biosolids can be applied only during dry seasons, when there is no perched water table. Dried biosolids can be applied to the surface at other times, as long as the water table is not at the surface and the soil is capable of supporting the weight of application equipment.

Another hazard associated with restrictive layers is increased potential for surface runoff. As soon as the soil above the restrictive layer fills with water, any additional increments of water must run off. The shallower the depth to a restrictive layer, the sooner this occurs, and the more likely biosolids lying on the surface will be carried into surface waters. This hazard is particularly serious on soils that are sloping, in addition to having a restrictive layer.

Gray horizons that are saturated for long periods of time are said to be *gleyed.* They are called Bg horizons. The limitations they present are similar to those caused by restrictive horizons. Gleyed soils can be used for land application of biosolids as long as the soil is dry enough to support the weight of application vehicles and as long as liquid wastes are prevented from entering horizons of saturated soil.

Rapidly draining horizons have sandy textures and are often gravelly or cobbly. They have the potential to transmit biosolids liquids into groundwater aquifers before soil treatment is complete. The risk is not very great with surface applications, however. Most biosolids, even liquid ones, do not carry enough water to wet the soil above a rapidly draining layer enough to cause rapid transmission of incompletely treated waste. There is some potential, though, that heavy rain or irrigation right after a biosolids application could move some liquid directly into the rapidly draining layer.

Soil profile descriptions are an excellent source of information about the kinds of horizons that are present in a soil. By reading a profile description, you can find out if abrupt textural changes occur, if restrictive horizons, gleyed horizons, or rapidly draining horizons are present, and if they are, at what depth they occur.

Soil depth

The terms shallow, moderately deep, and deep have very specific meanings in soil science. They apply when the soil profile contains bedrock (R horizon), weathered bedrock (Cr horizon), or a cemented horizon (Bkqm or Bkm).

Shallow always means that one of these horizons occurs at a depth between 0 and 20 inches. Moderately deep means that one occurs at a depth between 20 and 40 inches. Deep means that none of them occur within a depth of 40 inches.

These terms *do not apply* to restrictive layers, gleyed horizons, or rapidly draining materials. Descriptions of soils that contain these horizons usually indicate that the soil is deep, even though the restrictive layer may occur at a depth less than 20 inches.

Study the profile descriptions and map unit descriptions in a soil survey report carefully to determine if a particular soil has a restrictive layer, and if so, the depth at which it occurs.

Inferred Properties

Several aspects of soil behavior are difficult to measure directly in the field, but inferences can be made about these properties on the basis of primary morphological properties. Inferred properties that are particularly important for land application of domestic wastewater biosolids include permeability, infiltration, internal drainage class, available water holding capacity, leaching potential, shrink-swell potential, trafficability, pH, and nutrient availability.

Permeability

Soil permeability is the rate that water moves through the soil. Permeability depends on the amount, size, shape, and arrangement of soil pores, and on the degree of homogeneity of the pore structure from horizon to horizon.

Water moves through soil pores in response to two general kinds of forces. One is gravity, which pulls on water all the time. The other is an attraction between water molecules and the surfaces of soil particles. Very thin films of water are bound very tightly to soil particles. The thicker the water film, the lower the attractive force at the outer edge of the film. As a result, water moves along an energy gradient from moist soil, where the attractive forces are relatively weak, toward dry soil, where the attractive forces are relatively strong.

In saturated soils, water moves through large pores because the gravitational attraction is much greater than the water-soil attraction. Water moving in this way is called *gravitational water.* As long as the soil remains saturated, we refer to this water movement as *saturated flow.*

If a saturated soil is allowed to drain under the influence of gravity with no further additions of water, then gravitational water is gone after a few days. All the water remaining in the soil is held against the force of gravity by the attractive force between water and soil particles. We refer to the water content at this point as *field capacity.*

Any further water movement occurs as *unsaturated flow.* Water moves around the soil particles from thick films toward thin films, i.e from lower attractive forces toward higher forces, or from moister soil toward drier soil. The rate of

Soil profile descriptions in soil survey reports are an excellent source of information about soil horizons

- Abrupt textural changes
- Gleyed horizons
- Mottled horizons
- Rapidly draining horizons
- Restrictive layers

unsaturated flow is variable, depending on the pore structure and the moisture content of the soil. The maximum rate occurs when the soil is at field capacity. As plants remove water and the soil dries, all of the moisture films become thinner, and the rate of flow decreases substantially.

Because of the complexity of the soil pore system, permeability in the field is difficult to measure. A soil's *hydraulic conductivity* is easier to determine by measuring the rate of *saturated flow* in a *vertical direction* through a sample of soil in the laboratory. By relating the lab data to a soil's texture, structure, and horizons, then the soil permeability can be *estimated* by observing soil properties. The specific relationships between soil morphology and the classes of hydraulic conductivity are summarized in Table 4.

Several properties influence permeability. Coarse-textured soils, for example, have larger pores and more rapid permeability than fine-textured soils. Coarse fragments can't conduct any water; their effect is to reduce the volume of soil available for movement and retention of water. Good soil structure enhances permeability by providing stable aggregates that have small pores within peds and large pores between them. Organic matter enhances permeability through its effect on forming and stabilizing soil structure. Whenever the pore structure changes drastically and abruptly from one horizon to another, there is a major impact on permeability. But if the texture and structure change gradually from one horizon to the next, the rate of water movement is relatively unaffected, and water continues to move down through the profile.

Soil scientists use the permeability of the least permeable horizon in a soil to characterize the permeability of the whole soil. Because of the effect of soil layering, however, each horizon's permeability should be evaluated separately. This is the only way to determine if restrictive layers or layers of coarse grained materials are present, the depth at which they occur, and whether there is enough soil above these layers to provide adequate protection for groundwater.

Soil Properties that Influence Permeability

- Texture
- Coarse fragments
- Structure
- Organic matter
- Restrictive layers

Soils that have moderate or moderately slow permeability are well suited for land application of sewage biosolids.

Table 4.—Relationships between hydraulic conductivity, permeability class, and soil morphology

Hydraulic conductivity (in./hr.)	Permeability class	Morphological characteristics
<0.06	Very slow	Massive, clayey (>35% clay) horizons with few or no roots Continuous strongly cemented horizons with few or no roots
0.06-0.20	Slow	Clayey (>35%) horizons with either weak structure, platy structure, or slickensides Continuous moderate or weak cementation
0.20-0.60	Moderately slow	Clayey (>35%) horizons with moderate structure but no slickensides Medium-textured soils (18-35% clay) with weak structure Sandy soils that are cemented Soils with very few medium or larger continuous vertical pores
0.60-2.0	Moderate	Medium-textured soils (18-35% clay) with moderate structure Fine sandy loams Soils with a few medium or larger continuous vertical pores
2.0-6.0	Moderately rapid	Medium-textured soils (18-35% clay) with strong structure Sandy loams and loamy fine sands Soils with common medium or larger continuous vertical pores
6.0-20.0	Rapid	Coarse sandy loams and fine sands Soils with many medium or larger continuous vertical pores
>20.0	Very rapid	Sands and coarse sands that contain more than 15% coarse fragments

Table 5.—Sample data included in soil survey reports

Soil name and map symbol	Depth (in.)	Clay (%)	Moist bulk density (gm/cc)	Permeability (in/hr)	Available Water Capacity (in/in)	Soil reaction (pH)	Shrink-swell potential	Erosion factors K	T	Organic matter (%)
52B, 52D	0-11	27-40	1.20-1.40	0.6-2.0	0.16-0.18	5.6-6.5	Mod	0.32	2	2-4
Hazelair	11-15	35-50	1.05-1.20	0.2-0.6	0.13-0.19	5.1-6.5	High	0.28		
	15-36	60-70	1.00-1.20	<0.06	0.09-0.12	5.1-6.5	High	0.24		
	>36	—	—	—	—	—	—	—		
53	0-5	3-10	1.20-1.40	6.0-20	0.05-0.07	5.6-6.5	Low	0.10	5	2-4
Heceta	5-60	3-15	1.30-1.60	6.0-20	0.05-0.07	5.6-6.5	Low	0.10		
54D, 54G	0-12	18-27	0.90-1.00	0.6-2.0	0.19-0.21	4.5-5.5	Low	0.32	3	4-8
Hembre	12-44	25-32	1.00-1.15	0.6-2.0	0.16-0.20	4.5-5.5	Low	0.28		

Soils that have a slowly or very slowly permeable restrictive layer at shallow depth have serious limitations for application of liquid biosolids.

Tabular data in soil survey reports (see Table 5) give numbers for the permeability of each different layer in the soil. For this purpose, horizons that have similar properties are grouped together, and only the major differences are shown. The numbers given in these tables represent the value of the laboratory test of hydraulic conductivity. Since the sample is very small and measures only vertical flow, this test does not reflect actual field behavior because it does not consider unsaturated flow. Nevertheless, the test provides a form of soil characterization that allows comparison of different soils.

In general, soils that have moderate or moderately slow permeability (see Table 4) are well suited for application of all types of biosolids. Soils that have slow permeability throughout and do not have a water table problem are suitable for application of dewatered, dried, and composted biosolids. Liquid biosolids also can be applied as long as care is taken not to saturate the soil. Slowly permeable soils that do have a water table problem are usually somewhat poorly drained or poorly drained (see page 21). As long as the permeability is uniform throughout, lowering the water table with tile drains may be possible. Where this is done, biosolids can be applied safely.

Soils that have a slowly or very slowly permeable restrictive layer at relatively shallow depth (for example, 12 to 20 inches) have serious limitations for applications of liquid biosolids. Other biosolids, however, can be applied as long as the soil above the restrictive layer is not saturated.

Soils that are very slowly permeable throughout are poorly suited for land application of liquid biosolids. The rate of water movement is too slow to provide both adequate treatment and sufficient oxygen supplies. Correction of this limitation is very difficult and costly without any guarantee of complete success. Even very slowly permeable soils, however, may be used for dried or composted biosolids during seasons when the soil is dry enough to support heavy equipment.

Soils with moderately rapid or rapid permeability are useable for land application of biosolids, but leaching of nitrates and other chemicals in solution could be a problem in areas where a lot of water is added to the soil. The risk can be reduced by applying only dried or composted biosolids and avoiding times of high rainfall or excessive irrigation.

Infiltration

Infiltration is the rate that water enters the soil. Infiltration depends primarily on the pore geometry at the soil surface, and pore geometry depends on the texture and structure of the surface soil. The relationship between texture and infiltration is illustrated by the data shown in Table 6. Clearly, coarse-textured soils have much faster infiltration rates than fine-textured soils. Note that even small increases in clay content, as in the change from sand to loamy sand, can have marked effects on infiltration.

Table 6.—Typical infiltration rates of soil texture classes

Soil texture	Infiltration rate inches per hour
Sand	2.0 - 5.0
Loamy sand	1.0 - 1.5
Loam	0.5 - 0.75
Silt loam	0.2 - 0.3
Clay loam	0.15 - 0.3
Silty clay loam	0.1 - 0.2
Clay	0.05 - 0.15

Soil Properties that Affect Infiltration

- Texture
- Aggregate stability
- Organic matter
- Antecedent moisture
- Subsoil permeability
- Plant cover

Aggregate stability is the most important effect of soil structure on infiltration. Strong, stable peds at the soil surface create and maintain relatively large pores. Organic matter is particularly important in this regard. Soils that are well supplied with organic matter are more likely to have moderate infiltration rates than soils that are deficient in organic matter. If the organic matter content is low, and soil peds are not very stable, then the impact of falling water drops breaks the peds apart. Soil grains wash into the larger pores, clogging them and sealing the soil with a crust of very low porosity. This process of ped breakdown is called *slaking,* and the formation of a crust that seals the soil is called *puddling.*

Infiltration also depends on the moisture content and the permeability of the soil beneath the surface. The higher the moisture content, the slower the infiltration rate. This means that soils that are nearly saturated are not going to accept wastewater liquids readily. These soils are too wet to drive on, so the only situation in which a problem might occur is with application of liquid biosolids through irrigation cannons.

Permeability affects infiltration because water has to move away from the surface before additional water can enter the soil. Obviously if water is applied continuously at rates greater than soil permeability, then saturated conditions form and additional water can't enter the soil. A likely consequence is surface runoff accompanied by surface water contamination.

Infiltration is important for land application of biosolids because of its relationships to water quality. By itself, rapid infiltration is a desirable trait, but if coupled with rapid permeability and high rates of hydraulic loading, then there is a greater risk of groundwater contamination with either nitrates or pathogens.

Slow infiltration is a more common problem. This increases the potential for surface runoff and subsequent contamination of surface waters. The problem is exacerbated by the tendency for soil structure to deteriorate in the surface soil, further lowering the infiltration rate.

Since infiltration is tied to water quality, maintaining optimum infiltration rates is an important objective of soil management for biosolids application. These rates can be maintained by:

1. Not driving on wet soil to avoid compaction and structural breakdown;
2. Keeping organic matter levels high by incorporating biosolids and other organic residues into the soil;
3. Using sod crops in the rotation as much as possible.

Techniques for Maintaining Optimum Infiltration Rates

- Don't drive on wet soil
- Keep organic matter levels high
- Grow sod crops wherever possible

Internal drainage class

Internal drainage refers to the ability of free water to escape from a soil. Internal drainage is not the same thing as permeability because permeability indicates only the *rate* that water moves *if* it has some place to go. Classes of internal drainage are based on the height that a water table rises in the soil and the length of time that the soil remains saturated.

Rapidly permeable soils that are never saturated are called *excessively drained.* Soils that are rarely saturated above 3 or 4 feet are called *well drained.* Soils that are periodically saturated in the lower part of the soil profile are called either *moderately well drained* or *somewhat poorly drained,* depending on the depth to the water table and the duration of saturated conditions. Soils that are thoroughly saturated for long periods of time are called *poorly drained,* or even *very poorly drained.*

Internal drainage is important because it affects both the oxygen supply and the temperature of the environment in which plant roots and soil microorganisms live. Ideally, about half the pores in the soil should contain water. The other half should be filled with air. Well drained soils can provide this condition, but poorly drained soils cannot.

Drainage affects temperature because wet soils are cold soils. Biological processes, especially those that decompose organic residues and release nitrogen for plant use, do not operate as fast in cold soils. As a consequence, if biosolids are applied to a cool season grass or pasture crop, nitrogen may not be released until later in the year, after the soil has warmed up and after the crop's peak demand for nitrogen has passed. The excess nitrogen that is released later in the year may be lost either into the groundwater by leaching or into the atmosphere by *denitrification.*

When oxygen is limiting, denitrification occurs in wet soils because some of the inorganic nitrogen is converted to nitrogen gas and escapes to the atmosphere. Denitrification losses usually are not large, but if you do not account for them in planning your application rate to meet crop needs, the crop may suffer from nitrogen deficiency.

Internal drainage is also important because it indicates the volume of soil available for plant root development and uptake of soil nitrogen. Because these processes occur mainly in aerobic environments, only the soil above a water table is available for biosolids utilization. The more poorly drained the soil, the more restrictive it is for both crop growth and beneficial utilization of biosolids. Soils of any drainage class, however, can be used for land application of biosolids, provided that shallow water tables are neither

Classes of Internal Drainage

- Excessively drained
- Somewhat excessively drained
- Well drained
- Moderately well drained
- Somewhat poorly drained
- Poorly drained
- Very poorly drained

present at the time of application nor for a period of time thereafter.

The extent to which drainage is limiting depends on the type of biosolids, the permeability of the soil, and the climate. Poorly and somewhat poorly drained soils are most restrictive for application of liquid biosolids. If they have uniformly slow or moderately slow permeability, however, they may be artificially drained, provided suitable outlets are available. These soils are less limiting than soils that have very slow permeability or shallow restrictive layers that preclude effective drainage.

Climate dictates the amount and frequency of rainfall, hence the frequency with which water tables are high. In humid continental climates, where summer storms occur periodically, there may be only a few weeks when water tables in somewhat poorly and poorly drained soils are low enough to apply biosolids safely. In arid regions and in marine climates, water tables may be low enough during dry periods to allow land application of biosolids for several months.

Water table fluctuations in soils are rarely observed directly. Most of the time soils are studied in the field during dry seasons, and the internal drainage class is determined by inference from the evidence in the soil's morphology. Color, mottling, permeability, restrictive horizons, pH, and landscape position are the most important indicators of soil drainage class.

Soil variability across the U.S. precludes the use of a single, standard definition of soil drainage classes. Interactions between rainfall, temperature, organic matter, biological activity, and parent materials are so complex that interpretations of internal drainage must be tailored to regional conditions.

In general, a soil that is sandy or gravelly and has rapid or very rapid permeability is *excessively drained.* A soil that is brownish or reddish, has moderate to slow permeability, and is not mottled in the upper meter or so, is *well drained.* The lower part of the soil occasionally may be saturated for a day or so, but neither the frequency nor the duration of water tables is enough to adversely impact a biosolids utilization program.

A *moderately well drained* soil is brown or red in the upper part and has a few gray or yellowish brown mottles in the lower part. Water tables periodically rise into the lower part of the soil, saturating it for short periods of time. When the water table retreats, the large pores drain easily, but small pores within soil peds stay wet long enough for some iron to be reduced. The effect is not large but it is enough to create either some small gray mottles within peds or some small yellowish brown mottles on the surfaces of peds.

A *somewhat poorly drained* soil is mottled higher in the profile, although the surface horizon is usually not mottled, and there may be a second horizon of well-oxidized, unmottled soil beneath the surface soil. Water tables rise higher and persist longer than in moderately well drained soils.

Somewhat poorly drained soils often have slow or very slow permeability. If the duration of saturated conditions is relatively short, mottles may appear as spots of bright color in a matrix that still has a brown color. As the duration increases, however, the soil gradually becomes grayer and grayer, until the horizon is characterized by a dark gray matrix containing many prominent yellowish brown or reddish brown mottles.

Another manifestation of somewhat poor drainage is high pH and high sodium content. This occurs in arid regions, where locally high water tables cause water to move upward through the soil, carrying salts and sodium with it, and depositing those salts at the surface as the water evaporates. These soils have limited agricultural value and are difficult to reclaim. Biosolids application, however, may be particularly beneficial in improving the physical condition of the soil.

A *poorly drained soil* usually is either mottled in the surface horizon or is gray and unmottled throughout the profile. The soil is wet for such long periods of time that most of the iron has been reduced and leached away, leaving only the gray color of uncoated mineral grains.

Some poorly drained soils can be improved with artificial drainage if the permeability is at least slow. Often, the permeability is very slow, there is a shallow restrictive layer, or the landscape position is so low that outlets are not available. These soils are suited for land application only if the water table retreats naturally for a period of several weeks during the growing season.

Available water holding capacity (AWHC)

Available water holding capacity refers to the amount of water that soils can store for plants to use. Like permeability and infiltration, the water holding capacity depends on the amount and size distribution of soil pores. Not all of the pores can retain water for plant use. Consequently, only a portion of the total amount of water in a soil is available.

Gravitational water is not available because it drains out of the soil as soon as the water table drops. When the soil is at field capacity, plants can remove water easily, but each increment of water removed makes it increasingly difficult for

Internal drainage does not prevent land application of biosolids provided that shallow water tables are not present at the time of application.

Indicators of Restricted Drainage

- Gray colors
- Mottles
- Very slow permeability
- Shallow restrictive layers
- Very high pH
- Low-lying landscape positions

The higher the water holding capacity, the more productive the soil, and the better it is for beneficial use of wastewater biosolids.

Factors Conducive to High Leaching Potential

- Rapid infiltration
- Rapid permeability
- High rainfall
- Heavy irrigation
- Heavy applications of liquid biosolids

plants to withdraw the next increment. When a soil is so dry that a plant cannot remove any more water, the soil is said to be at the *wilting point.* This marks the low moisture end of the available water supply. Water in the soil between field capacity and the wilting point is called *available water.* Water that remains in the soil at the wilting point is called *unavailable water.* It is held so tightly in very small pores, or in very thin moisture films, that most plants cannot extract it. Some soils, especially the clays, contain large amounts of unavailable water.

AWHC is important for land application of biosolids for two reasons. First, it is a measure of the ability of the soil to sustain vigorous growth and high yields of common agronomic crops. In general, the more productive the soil, the better it is for beneficial utilization of wastewater biosolids. Second, it is a measure of the soil's capacity to store water applied to the soil as rainfall, irrigation, or liquid biosolids. The higher the AWHC, the more suitable the soil, particularly for application of liquid biosolids.

AWHC, like permeability, is difficult to measure in the field. AWHC can be measured in the laboratory, but this test has the same kinds of limitations as the hydraulic conductivity test. The usual practice is to estimate AWHC using the key morphological properties of texture, coarse fragments, and depth of rooting. Structure and organic matter increase the volume of water-storing pores, especially in the A horizon.

AWHC is expressed as the number of inches of water stored in the entire depth of soil. If the available water from a column of soil wet to field capacity could be drained into a pan with an area identical to that of the soil column, then the depth of water in the pan would be a measure of the AWHC of the soil.

A deep (>40 inches), medium-textured soil with no coarse fragments and no restrictive horizons can store 12 inches or more of available water. This is an excellent soil for crop growth and for land application of biosolids.

Soils that are shallow to bedrock or to restrictive layers, and soils that have a large volume of coarse fragments, may have AWHC's as low as 1 or 2 inches. These are very poor soils for growing most common crops, and for most biosolids utilization programs.

Soil AWHC also can be expressed as the depth of available water per unit depth of soil. This is particularly useful in non-uniform soils, because you can calculate the amount of available water in each horizon separately, then sum over all horizons within the depth of rooting.

Each class of soil texture has a characteristic AWHC, expressed commonly as inches of available water per inch of soil depth (Appendix B). If you're working in the metric system, the same numerical value can be used as cm of water per cm of soil.

To determine the total AWHC for a given horizon, multiply the inches per inch of available water by the thickness of the horizon. If coarse fragments are present, multiply again by the proportion of the soil that is fine earth. See Appendix B for an example of this procedure.

Information on water holding capacity is given in two places in soil survey reports. The first is the map unit description, which reports the total soil AWHC as a range (for example, 10 to 12 inches or 1 to 3 inches). The second is the tabular data (see Table 5) in which the AWHC is given for each major layer in the soil. As with permeability data, horizons with similar properties are grouped together. The AWHC data, however, represent water storage capacities that already take into account the presence of coarse fragments. Simply multiply a representative value times the thickness of the layer and sum over all horizons within the effective depth of rooting.

Leaching potential

Leaching refers to the removal of materials in solution by water passing through the soil. Leaching potential is a composite interpretation developed from information on a soil's infiltration, permeability, water holding capacity, and hydraulic loading. It is one component in the soil water budget, which balances all water inputs against all water losses.

Whether from rainfall, irrigation, or wastewater liquids, water added to the soil follows several possible pathways. Some may be taken up by plants and transpired into the atmosphere. A small amount may be lost directly from the soil by evaporation. These two are often combined into a single factor called evapotranspiration. Some water may be lost by runoff from the soil surface, and some may be stored in the soil, if the available water holding capacity is not full.

Water not accounted for by any of the above processes passes through the soil. This water creates the leaching potential. Whether this water moves slowly by unsaturated flow or rapidly by saturated flow, any soluble nutrients, trace inorganics, or organics move through the soil with it.

A high leaching potential would occur if liquid biosolids were added to a rapidly permeable soil already wet to field capacity. A very low leaching potential would occur if dried biosolids were added to a soil that has moderately slow permeability and is dry to the wilting point. Combinations of permeability, water holding capacity, climate, and type of biosolids intermediate between these two extremes would represent intermediate leaching potentials.

Biosolids applications alone rarely create enough hydraulic loading to increase the leaching potential significantly. For example, a biosolids product containing 2% solids and 25 lb of available nitrogen per dry ton, applied in sufficient amount to deliver 150 lb N per acre, adds about 2.5 inches of water to the soil. Even this level of hydraulic loading should not cause a problem on deep well drained soils that are not already wet to field capacity.

Recognizing the leaching potential that exists under natural soil and rainfall conditions, or under irrigation, is important. If the leaching potential is naturally high, then even dried biosolids applied to the soil are subject to leaching. In such cases, site management should time the application of biosolids to coincide with periods of low hydraulic loading. The objective is to provide sufficient time for immobilization of pollutants before the next pulse of added water passes through the soil.

Trafficability

Trafficability refers to the soil's ability to support the weight of farm equipment, heavy trucks, or irrigation equipment with a minimum of compaction or structural deterioration. Trafficability is important because:

1. Compaction and rutting of the soil reduce infiltration and permeability;
2. Loss of traction can delay and increase the cost of the biosolids application;
3. Crops don't grow as well in compacted and rutted soil, and the potential for surface runoff is greater.

Trafficability depends mainly on three things: texture, moisture content, and plant cover. Soil moisture is the most important factor. All soils support weight when they're dry and lose strength when they're wet. The most important rule is: *Avoid driving on any soil when there's free water (gravitational water) in the top 18 inches.* Wait until the soil has dried out at least to field capacity before driving over it. This is as true for normal agricultural operations as it is for land application of biosolids.

Sandy and gravelly soils provide the best support for vehicular traffic. Unless they are completely saturated you should be able to drive on them soon after a rain. A sandy soil can be compacted, however, so wait until the soil is dry enough.

Loams and sandy loams should be able to support most traffic if they are at least as dry as field capacity. The higher the content of silt and clay, however, the less stable the soil. Again, if you're not sure if the soil is dry enough, be safe and wait.

Silt loams, silty clay loams, clay loams, and clays have the lowest strength and are the most susceptible to compaction. Even at field capacity these soils contain a lot of water. The weight and vibrations from heavy vehicles are likely to break down soil aggregates, compact the soil, and seal the surface. For these soils, wait until the soil is considerably drier than field capacity, even to the point where the surface few inches is practically at the wilting point.

There is a simple field test to determine if the soil is above or below field capacity. Take a sample with a shovel or an auger, grab a handful, and work it in your hand, squeezing it between your thumb and fingers. If it sticks to your fingers, the moisture content is above field capacity. If you can work it easily but it doesn't stick to your hand, it's approximately at field capacity. If it won't stick together in a single, cohesive mass, it's considerably drier than field capacity.

Soils with a thick, continuous sod crop provide better vehicle support than bare soils. Plants remove some of the water, speeding up the drying of the soil, and the sod acts as a cushion that prevents breaking through to the mineral soil.

If a soil is wetter than field capacity, especially if it's a silt loam or silty clay loam, even a sod cover may not be sufficient to support traffic. Attempting to drive on such soils may result in the same loss of traction as in a bare soil.

Soil that is too sticky to work with your fingers is too wet to drive on.

Shrink-swell potential

To a greater or lesser degree, clays tend to expand when they wet up and shrink when they dry. Modest shrink-swell activity is beneficial in forming a well-developed, blocky structure common to medium-textured soils.

Certain clays undergo large volume changes upon wetting and drying. These clays are commonly called montmorillonites, or smectites. When they dry, they shrink so much that deep, wide cracks form in the soil. The masses of soil themselves are so hard and have such tiny pores that neither roots nor water can penetrate readily. Upon wetting, these clays expand so much that all of the cracks are tightly closed, and the soil is one large, structureless mass of clay. In this condition, both infiltration and permeability are very slow, and the soil provides a hostile environment for aerobic biological activity.

Most soil survey reports contain information on the shrink-swell potential of the soils in that area (see Table 5). Any soil, all or part of which is rated "high" for shrink-swell behavior, requires careful management for biosolids utilization. One of the best ways to overcome the

Any soil, all or part of which is rated "high" for shrink-swell behavior, requires careful management for biosolids utilization.

limitations of these soils is to continually add and incorporate organic matter into the surface soil.

Soil pH

Soil pH is a measure of the degree of acidity or alkalinity of the soil. Technically pH is a measure of the concentration of hydrogen ions in the soil solution. Numbers on the pH scale run from 0 to 14. A neutral soil has a pH of 7.0. Lower numbers indicate more acid soils and higher numbers indicate more alkaline soils. Each whole number unit on the scale represents a 10-fold increase or decrease in hydrogen ion concentration.

Most agricultural crops to which biosolids may be applied do best when the soil pH is between 6.0 and 7.0. Phosphorus availability in particular is at a maximum when the soil pH is nearly neutral. In strongly acid soils, where the pH is less than 5.0, some elements such as iron and aluminum may become toxic to plants, and phosphorus is often deficient. At very high pH values, those greater than 9.0, phosphorus also is very slowly available, and high sodium contents severely restrict plant growth.

Acid agricultural soils can be limed to correct excess acidity. Usual rates of liming are on the order of 2 to 4 tons per acre. It is not feasible to lime acid forest soils, but in such situations, trees generally are well adapted to growing under acid conditions.

Excessively high soil pH can be corrected by a combination of treatment with gypsum or elemental sulfur, leaching, and drainage to remove salts. Such treatments are expensive and relatively impermanent, however, and may create additional environmental problems where salts leached from the soil are discharged. Thus, it is unlikely that a site would be treated to lower pH simply to make it more suitable for the land application of biosolids.

Information on soil pH can be obtained from soil survey reports. In some soil surveys, pH data are tabulated under the heading of soil reaction (see Table 5). The data are given as expected ranges of pH for a given layer and are particularly useful for making comparisons among soils that may be used for land application of biosolids. Some soil surveys and soil profile descriptions report the pH as a reaction class, using terms such as slightly alkaline, or strongly acid. Each of these terms refers to a standard range in pH values. These are defined in Table 7.

Factors that Affect Cation Exchange Capacity

- Amount of organic matter
- Soil pH
- Amount of clay
- Kinds of clay minerals

Table 7.—Reaction classes for pH values

pH	Reaction class
<4.5	Extremely acid
4.5 - 5.0	Very strongly acid
5.1 - 5.5	Strongly acid
5.6 - 6.0	Moderately acid
6.1 - 6.5	Slightly acid
6.6 - 7.3	Neutral
7.4 - 7.8	Mildly alkaline
7.9 - 8.4	Moderately alkaline
8.5 - 9.0	Strongly alkaline
>9.0	Very strongly alkaline

Nutrient availability

The best way to determine nutrient availability is to take a representative sample and have it tested. This is discussed in more detail in Chapter 5. You can, however, make some preliminary inferences about nutrient availability from some key soil properties. The most significant of these are texture, color, and soil pH.

Plants extract nutrients from the soil only if the nutrients are dissolved in the soil solution. Dissolved nutrients are in an electrically charged, or ionic form. Many nutrients, such as calcium, potassium, magnesium, and iron carry a positive charge. These are called cations. Others, such as phosphorus and nitrate nitrogen, carry a negative charge and are called *anions.*

Cations—calcium, magnesium, potassium. The availability of nutrient cations depends on the soil's *Cation Exchange Capacity* (CEC). The atomic structure of tiny, flat clay particles generates a small amount of negative electrical charge within each particle. To balance this charge, cations in the soil solution are attracted to and held near the surfaces of the clay particles. This process, called *adsorption,* retains cations in the soil so they are not readily lost by leaching.

Organic matter in soils also provides sites of negative charge for cation adsorption. In soils that are nearly neutral, i.e. that have a pH around 7.0, some of the hydrogen ions in organic soil compounds dissociate, creating additional sites of negative charge. Cations in the soil solution can be adsorbed at these sites as well.

If the soil becomes more acid, the concentration of hydrogen ions in the soil solution increases, and the hydrogen reclaims its place on the negatively charged site. This blocks the site from exchange with other cations in the soil solution, and the soil CEC decreases. For this reason, the exchange capacity associated with organic matter is referred to as pH-dependent CEC.

The numerical value for soil CEC is a measure of the total amount of negative charge available to adsorb cations. The CEC value is expressed in terms of milliequivalents per 100 grams of soil. A typical CEC value is 17 meq/100 grams soil. The actual value for a specific soil's CEC depends on four things: amount of clay, amount of organic matter, pH of the soil, and kind of clay minerals. The CEC increases as the amounts of clay and organic matter increase, and it is higher in neutral soils than in acid soils.

The kind of clay minerals affects CEC because different clays have different atomic structures, and therefore different CEC values. Clays that are very sticky and have high shrink-swell potentials have relatively high CEC's. Soils that contain these clays may have CEC values of 40 or 50 meq/100 gm.

Clays in brown soils of cool climates typically have CEC's in the upper teens to mid 20's. Clays in the red soils that are common in the southeastern U.S. have relatively low CEC values, typically in the low teens.

In review, the availability of the nutrient cations is directly related to the soil's cation exchange capacity. The higher the CEC, the more these cations are retained in the soil, where they are available for plant uptake. The lower the CEC, the greater the need for supplemental sources of nutrients for optimum plant growth, and the greater the potential for loss of nutrients by leaching into the groundwater.

CEC is not subject to large changes through soil management. The most important practice is to maintain high levels of soil organic matter. Additions of domestic wastewater biosolids can be beneficial for this purpose. Encouraging optimum plant growth and returning crop residues also help maintain high organic matter levels. Liming the soil to raise soil pH helps release some of the pH-dependent CEC. Preventing soil erosion not only protects environmental quality but also keeps the organic matter-rich topsoil in place.

Anions—nitrate, phosphate. The availability of nutrient anions depends mainly on their solubility in water and the rate of water movement in soil. Anion exchange capacity does exist, but it is very small relative to the cation exchange capacity and has little effect on the retention of nitrate and phosphorus in the soil.

Nitrate is very soluble in water and moves with the flow of soil water. When plants are actively growing, their uptake of soil water creates a hydraulic gradient toward plant roots, and the nitrate goes with the soil water into the plant. Conversely, when there is a hydraulic gradient downward, as there is following a rain or an irrigation, water in the soil moves toward the groundwater, and nitrate in solution goes in that direction.

Because of nitrate solubility, nitrate management depends heavily on the rate and timing of nitrate applications. Nitrate should not be added to the soil, either as biosolids or as ordinary fertilizer, when plants don't need or can't use it, or at times of high leaching potential.

Nitrate management also depends on good management of the organic nitrogen reservoir. The objective is to encourage mineralization to coincide with times when plants are growing vigorously and can use the nitrogen released. Land application of biosolids should therefore be timed to match conditions that favor either slow mineralization or uptake of mineralized nitrogen. Should mineralization occur when plants are not present, or at times when plants can't use all the nitrate produced, leaching into groundwater may occur.

Phosphorus availability follows another set of rules. As with all other plant nutrients, phosphorus is available only when it is in ionic form in the soil solution. There are several forms of available phosphorus, all of which are some variety of phosphate and are negatively charged anions.

Much of the phosphorus in soil occurs as organic phosphorus. Decomposition of organic matter slowly releases this phosphorus so that it can enter the soil solution as phosphate ions.

Inorganic phosphate compounds are not very soluble in most soils, and leaching losses are rare. A greater problem exists in encouraging phosphorus to go into solution and supplementing with more readily available forms of phosphorus fertilizer when natural soil processes provide insufficient amounts.

The key soil properties for judging phosphorus availability are soil color and soil pH. Many soils that have strong red or reddish brown colors are very old, highly weathered soils that contain relatively high amounts of iron and aluminum oxides in the clay fraction. These clays readily react with phosphate ions to form complex precipitates that are insoluble.

Soil pH controls phosphate solubility. In acid soils, especially the highly weathered reddish soils, phosphate forms complex, insoluble precipitates with aluminum ions. In alkaline soils, insoluble calcium phosphates form. The best remedy for both situations is to maintan the soil pH as nearly neutral as possible. Values of soil pH between 6.0 and 7.0 generally are acceptable for maintaining phosphate availability.

Nitrate should not be added to soil when plants don't need or can't use it, or at times of high leaching potential.

Plan biosolids applications so that mineralization of organic nitrogen coincides with times of vigorous plant growth.

Phosphate is sparingly soluble in most soils. Leaching losses are rarely a problem.

Site Selection

Any site on which a commercial crop can be produced using normal farming practices holds some potential for beneficial use of domestic wastewater biosolids. Distinguishing the better sites from the poorer sites is the focus of this chapter. The best sites can accept biosolids in any form and without restrictions on the timing of the application, other than those imposed by the crop itself.

Poor sites may restrict the type of biosolids applied, the method of application, and the timing of the application. Poor sites also are likely to be more expensive to manage because additional biosolids processing may be necessary, storage may be needed during times that are unfavorable for application, or special practices are needed to mitigate problems caused by high water tables, restrictive layers, or steep slopes.

Several keys are used to facilitate the determination of soil-site suitability ratings for land application of biosolids. These suitability ratings, when used in conjunction with the maps in soil survey reports, provide powerful tools for making preliminary evaluations of proposed sites for beneficial use of biosolids.

Keys for Rating Soil Suitability

For all soil-site evaluations, the frame of reference is the set of properties of an "ideal" soil. Departures from the ideal point to specific limitations that lower the suitability rating for land application of biosolids. Rating keys, therefore, are based on departures from the ideal soil. Once the limitations have been identified, management practices for dealing with them can be specified.

The ideal soil

The ideal soil is deep, well drained, and medium-textured (silt loam, loam, or very fine sandy loam). It has a black to very dark brown surface and a brown or yellowish-brown subsoil. It is neither red nor gray nor mottled.

The subsoil has no restrictive layers (claypan, fragipan, or dense glacial till) within 40 inches. No tillage pan or traffic pan has formed beneath the Ap horizon.

The ideal soil should have more than 3% organic matter and a pH between 6.5 and 8.2. The available water holding capacity should be 12 inches or more.

The texture and organic matter together give the ideal soil moderate or strong grades of structure in all horizons. But the structure must be stable, and the soils must have a low shrink swell potential.

The ideal soil must allow water to enter and pass through easily, but not too fast. The infiltration rate should be moderate to rapid, and the permeability should be moderately slow to moderately rapid throughout.

The ideal setting for the ideal soil is a nearly level to very gently rolling surface having slopes between 0 and 3%. The site must not be on an active floodplain.

Departures from the ideal soil

Very few soils qualify as ideal. Most depart in at least a small way, for at least one of the critical properties. Those soils that have only a few small departures are still suitable for land application of biosolids; their limitations can be overcome easily with a minimum of special management practices.

The greater the number of properties that depart from ideal and the greater the degree of departure, the more severely limited is the soil. Many of these soils can still be used for biosolids application, but very careful management is required, for these sites are much less forgiving than sites with more suitable soils.

The number and degree of departures from ideal form the basis for rating soil suitability for biosolids application. The keys in Tables 8 to 12 show how soil properties are used to rate a soil. In these keys, the ideal soil is rated excellent. Soils with a few, easily managed departures are rated good. Fair suitability and poor suitability represent increasing degrees of the severity of limitations that must be overcome with careful management.

These suitability ratings are *not* absolute, quantitative predictors of soil behavior for beneficial use of biosolids. They are *guides* to the *relative* suitability of a soil and facilitate comparison among soils of alternative sites.

Fair or poor ratings do *not* mean that the site cannot be used in a biosolids application system. They indicate that there are more problems to manage and that it will probably cost more to overcome the limitations. Many such sites, however, can and do play an important role in an overall biosolids management operation.

The suitability of a soil depends as much on interactions among several properties as it does on each property individually. These interactions are expressed by combining information from two, three or four major properties in each key.

For example, in the depth-texture key (see Table 8), texture, coarse fragments, and depth to bedrock all interact to express the nature of the physical environment for root growth and biological activity.

In the infiltration key (see Table 9), texture, structure, organic matter, and shrink-swell potential interact to control the rate of entry of rainfall, irrigation water, and biosolids liquids.

The drainage-permeability key (see Table 10) shows how the effect of soil drainage class depends on the permeability of the soil, whether a restrictive layer is present, and if so, at what depth.

Nutrient availability (see Table 11) depends on interactions among texture, pH, and organic matter.

The utility of sloping sites (see Table 12) for land application depends not only on the steepness of the slope but also on the infiltration rate, the depth to bedrock or a restrictive layer, and the type and density of plant cover.

The procedure for using these five keys begins by assembling all the data required for each key. Morphological data (texture, structure, coarse fragments, depths to bedrock or restrictive layers) may be taken either from soil profile descriptions in soil survey reports or from soil profile descriptions made by professional soil scientists in pits dug at a proposed site.

Data on inferred properties (drainage, permeability, and shrink-swell behavior) may be obtained from map unit descriptions and tables in soil survey reports. These inferences also can be drawn from the morphological properties of the soils described at the site.

Chemical data (pH and organic matter) may be available in some soil surveys or from laboratory analysis of properly collected samples. For preliminary evaluation, field tests of pH and field estimates of organic matter may suffice.

Site data (% slope and type of plant cover) may be taken either from map unit descriptions or from on-site observations.

The next step in the procedure is to use the data assembled to enter each key and determine the suitability rating for that particular interaction. Some of the keys give dual ratings, one for liquid biosolids and one for dewatered or dried biosolids. This recognizes that soils and sites are more sensitive to liquid biosolids applications, and that the impacts of unfavorable permeability or water table conditions may be less severe where dewatered or dried biosolids are applied.

The final step in the evaluation process is to determine the overall suitability of the site. This is simply the lowest of the five separate ratings obtained from the keys.

Several examples for using the keys are shown in Table 13. The soils included are representative soils from widely separated geographic areas of the United States. Two examples are discussed here.

Table 8.—Depth/texture key for rating soil suitability for land application of biosolids

Subsoil texture[1]	Coarse fragments[2]	Depth to bedrock (in.) > 40	20-40	< 20
Sand	None	G[3]	G	F
Loamy sand	Gravelly, Cobbly	F	F	P
	Very grav., very cob.	P	P	P
	Extremely grav., cob.	P	P	P
Sandy loam	None	E	G	F
Loam	Gravelly, Cobbly	G	G	F
Silt loam	Very grav., very cob.	F	F	P
	Extremely grav., cob.	P	P	P
Sandy clay loam	None	G	G	F
Clay loam	Gravelly, Cobbly	G	G	F
Silty clay loam	Very grav., very cob.	F	F	P
	Extremely grav., cob.	P	P	P
Sandy clay	None	G	F	P
Silty clay	Gravelly, Cobbly	F	F	P
Clay	Very grav., very cob.	P	P	P
	Extremely grav., cob.	P	P	P

[1] Use the texture of the subsoil horizon within 40 inches that has the highest clay content. See page 12 for definitions of soil textures.
[2] Refer to Appendix A for definitions of coarse fragment classes.
[3] E = Excellent; G = Good; F = Fair; P = Poor.

Table 9.—Infiltration key for rating soil suitability for land application of biosolids

Use data from the surface horizon only

Grade of structure[1]	Organic matter (%)	Sand / Loamy sand	Sandy loam / Loam / Silt loam	Sandy clay loam / Clay loam / Silty clay loam	Sandy clay / Silty clay / Clay — Shrink-swell Potential[2] Low-Med	Sandy clay / Silty clay / Clay — Shrink-swell Potential[2] High
Weak	0-1	G/E[3]	F/G	F/G	P/F	P/F
	1-3	G/E	G/E	F/G	P/F	P/F
	> 3	G/E	G/E	G/E	F/G	P/F
Moderate	0-1	G/E	G/E	G/E	P/F	P/F
	1-3	G/E	G/E	G/E	F/G	P/F
	> 3	G/E	E/E	E/E	F/G	P/F
Strong	0-1	G/E	G/E	G/E	F/G	P/F
	1-3	G/E	E/E	E/E	F/G	P/F
	> 3	G/E	E/E	E/E	G/E	P/F
Massive	0-1	G/E	P/F	P/F	P/F	P/F
	1-3	G/E	F/G	P/F	P/F	P/F
	> 3	G/E	F/G	F/G	P/F	P/F
Single grain	—	G/E	—	—	—	—

[1] Refer to page 14 and Appendix A for definitions of structural grades.
[2] Refer to page 23 for definition of shrink-swell potential.
[3] Entries to the left of the slash are for liquid biosolids. Entries to the right are for dewatered, dried, and composted biosolids. E = Excellent; G = Good; F = Fair; P = Poor.

Table 10.—Drainage/permeability key for rating soil suitability for land application of biosolids

	Drainage class[1]				
	ED & SWED	WD	MWD	SWPD	PD & VPD
A. Soils with uniform permeability[2] (same class or adjacent classes)					
Very rapid	P/F[3]	P/F	P/F	P/F	P/F
Rapid & Moderately rapid	F/G	G/E	G/E	F/G	P/F
Moderate & Moderately slow	G/E	E/E	E/E	G/E	F/G
Slow	—	G/E	G/E	F/G	F/G
Very slow	—	F/G	F/G	P/F	P/F
B. Soils with slowly or very slowly permeable restrictive layers[4]					
Depth to restrictive layer					
< 20 inches	P/F	F/G	P/F	P/F	P/F
20-40 inches	F/G	G/E	F/G	F/G	P/F
> 40 inches	G/E	E/E	G/E	F/G	P/F
C. Soils with rapidly draining horizons[5]					
Depth to rapidly draining horizon					
< 20 inches	P/F	F/G	F/G	P/F	P/F
20-40 inches	F/G	G/E	G/E	F/G	P/F
> 40 inches	G/E	E/E	E/E	G/E	F/G

[1] ED = Excessively drained; SWED = Somewhat excessively drained; WD = Well drained; MWD = Moderately well drained; SWPD = Somewhat poorly drained; PD = Poorly drained; VPD = Very poorly drained.
[2] Refer to page 18 for definitions.
[3] Entries to the left of the slash are for liquid biosolids. Entries to the right are for dewatered, dried, and composted biosolids. E = Excellent; G = Good; F = Fair; P = Poor.
[4] Refer to page 16 for definitions.
[5] Refer to page 17 for definitions.

Table 11.—Nutrient availability key for rating soil suitability for land application of biosolids

Use data from the surface horizon only

Soil texture	Organic matter (%)	Soil pH[1] <4.5	4.5-5.5	5.5-6.5	6.5-8.2	8.2-9.0	>9.0
Sand, Loamy sand	0-1	P[2]	P	P	F	F	P
	1-3	P	P	F	F	F	P
	> 3	P	P	F	G	G	P
Sandy loam, Loam,	0-1	P	P	F	F	F	P
Sandy clay loam,	1-3	P	F	F	G	G	P
some Clays	> 3	F	F	G	E	G	F
Loam, Silt loam,	0-1	P	P	F	G	F	P
Silty clay loam,	1-3	P	F	G	E	G	F
Clay loam, most Clays	> 3	F	F	G	E	G	F

[1] See page 24 for definition.
[2] Ratings apply equally to all biosolids. E = Excellent; G = Good; F = Fair; P = Poor.

Table 12.—Slope effect key for rating soil suitability for land application of biosolids

Slope (%)	Depth to bedrock or to restrictive layer (in.)	Infiltration rating (from Table 9) E	G	F	P
	< 20	G[1,2]	G	F	P
0-3	20-40	E	E	G	G
	> 40	E	E	G	G
	< 20	F	F	P	P
3-7 or 3-8	20-40	G	G	F	P
	> 40	E	G	G	F
	< 20	F	F	P	P
7-12 or 8-15	20-40	F	F	F	P
	> 40	G	F	F	P
	< 20	P	P	P	P
2-20 or 15-30	20-40	F	F	P	P
	> 40	F	F	P	P
	< 20	P	P	P	P
> 20 or > 30	20-40	P	P	P	P
	> 40	F	P	P	P

[1] Ratings apply equally to all biosolids. E = Excellent; G = Good; F = Fair; P = Poor.
[2] Increase the rating one class for applications on forested soils that have organic surface horizons.

The Woodburn soil is a deep, moderately well drained soil on nearly level lacustrine terraces in the Willamette Valley of western Oregon. Textures are silt loam in the surface horizon and silty clay loam in the subsoil. There are no restrictive layers and no tillage pans. The surface horizon has weak structure, but it contains over 3% organic matter. The permeability is moderate above 32 inches and slow below 32 inches. The pH is 5.6-6.5 throughout.

The first key, depth and texture, gives this soil a good rating because the subsoil texture is a little heavier than ideal. The second key, infiltration, gives the soil a good rating for liquid biosolids and an excellent rating for dried biosolids. Weak structure is the limiting factor.

The third key, drainage and permeability, also gives the soil a good rating for liquid biosolids and an excellent rating for dried biosolids. The only limitation is a temporary water table between 24 and 40 inches.

The fourth key, nutrient availability, gives the soil a good rating for all types of biosolids. The soil pH is a little lower than ideal, but high levels of organic matter and medium texture partially compensate. The fifth key, slope, gives the soil an excellent rating for both liquid and dried biosolids applications.

Overall, the Woodburn soil has one excellent and four good ratings for liquid biosolids, and three excellent and two good ratings for dewatered or dried biosolids. The suitability is considered "good" for either type of biosolids application.

The Volusia soil is a deep, somewhat poorly drained soil formed in dense glacial till on low, rolling uplands in the southern tier of New York State. The textures are channery silt loam throughout the profile. The surface horizon has weak structure and contains more than 3% organic matter. The pH is between 5.1 and 5.5.

Volusia has a dense, slowly permeable fragipan at 17 inches that restricts movement of both water and plant roots. Both the colors and the presence of mottles indicate that perched water tables stand above the fragipan for significant periods of time.

Table 13.—Suitability ratings for five representative soils in the United States

	Soil series (state)				
	Cecil (SC)	**Clarion (IA)**	**Plainfield (WI)**	**Volusia (NY)**	**Woodburn (OR)**
Soil Properties					
Texture of subsoil	Clay	Loam	Sand	Silt loam	Silty clay loam
Coarse fragments	None	None	None	Channery	None
Depth (in)	> 40	> 40	> 40	> 40	> 40
Texture of surface	Sandy loam	Loam	Loamy fine sand	Silt loam	Silt loam
Structure grade	Weak	Weak	Weak	Weak	Weak
Organic matter, %	1-3	> 3	1-3	> 3	> 3
Shrink-swell potential	Low	Low	Low	Low	Low
Drainage class	WD	WD	ED	SWPD	MWD
Permeability	Moderate	Moderate	Rapid	Very slow	Slow
Depth to restrictive layer (in)	> 40	> 40	> 40	17	> 40
Depth to rapidly draining layer (in)	> 40	> 40	> 40	> 40	> 40
pH of surface soil	5.1-5.5	6.1-6.5	6.6-7.3	5.1-5.5	5.5-6.5
Slope (%)	6-10	2-5	2-6	8-15	0-3
Suitability ratings (Tables 8-12)					
Depth/Texture key	G/G	E/E	G/G	G/G	G/G
Infiltration key	G/E	G/E	G/E	G/E	G/E
Drainage/Permeability key	E/E	E/E	F/G	P/F	G/E
Nutrient Availability key	F/F	G/G	F/F	F/F	G/G
Slope key	F/G	G/E	G/E	F/F	E/E
Overall rating					
Liquid biosolids	Fair	Good	Fair	Poor	Good
Dewatered/Dried biosolids	Fair	Good	Fair	Fair	Good

Despite the fragipan, this is considered to be a deep soil, and the textures by themselves are favorable for beneficial use of biosolids. Only the coarse fragments cause the depth/texture rating to drop from excellent to good. The infiltration key rates Volusia as good for liquid biosolids and excellent for dried biosolids, the only limitation being weak structure.

Interactions between drainage, permeability, and the restrictive layer, however, cause the soil to have a poor drainage/permeability rating for liquid biosolids and a fair rating for dried biosolids.

The nutrient availability key gives the soil only a fair rating because both the clay content and the pH are considerably lower than ideal. The slope rating is fair for all kinds of biosolids applications because of the relatively high runoff potential on 8-15% slopes of soils that have a shallow restrictive layer.

Overall, Volusia earns two good, two fair, and one poor for liquid biosolids, and one excellent, one good, and three fair for dried biosolids. The suitability for liquid biosolids is rated as poor, but for dewatered or dried biosolids, the suitability is fair.

Overcoming soil limitations is largely a matter of applying good common sense in conjunction with a good understanding of soil, biosolids, crop, and climate.

How to deal with limiting properties

Overcoming limitations is largely a matter of applying common sense in conjunction with knowledge of soil, biosolids, crop, and climate. Most of the possibilities have already been discussed in Chapter 3.

Since the intrinsic texture or depth of the soil is difficult to modify, manage such limitations by applying only dried or dewatered biosolids and timing applications to coincide with dry seasons.

The best way to manage rapid infiltration in coarse-grained soils is to use dried biosolids products having relatively high percent solids. Do not apply biosolids during rainy seasons when the leaching potential is high.

The best cure for low infiltration rates is to add organic matter. Biosolids are excellent amendments because they provide a source of organic matter. Mixing biosolids into the surface soil by disking is preferable to leaving them on top of the soil surface. If infiltration has been reduced by formation of a tillage or compaction pan just below the surface horizon, shattering the pan by ripping the soil when it is dry may be very helpful.

Drainage problems in some soils of uniform permeability may be corrected with artificial drainage. This may not be a cost-effective solution, however, and there are federal and state regulations that preclude drainage of some wetlands.

If you can't drain the soil, then minimize the problem by using dewatered or dried biosolids and plan on applying them only during dry seasons after water tables have receded. This may be the only remedy for soils that have temporary, perched water tables above slowly permeable restrictive layers.

If pH is limiting, you may be able to solve the problem by liming. The feasibility of liming depends on the economics of the farming operation. If the pH is not much below 6.5, for example, only 2 to 4 tons of lime may be required, and if a high value crop is being grown, then liming to mitigate acid soils is feasible.

Steep slopes need to be managed to encourage infiltration and minimize surface runoff. Appropriate ways to deal with steep slopes in a biosolids utilization program are to use high-solids products, to apply only on pasture or hay fields, and to practice soil conservation with cross-slope farming, reduced tillage, and diversion terraces.

How to Use Soil Surveys to Facilitate Site Selection

Soil surveys are inventories of the soil resources of an area. The information in a soil survey is useful in finding possible biosolids utilization sites and assessing the relative suitabilities of the alternative sites under consideration.

Kinds of Soil Survey Information

Maps
- Delineations
- Symbols and legends

Text
- Map unit descriptions
- Soil profile descriptions

Tables
- Soil and water features
- Physical and chemical properties
- Engineering properties
- Estimated yields

Components of soil surveys

Published soil survey reports contain three interrelated parts: maps, text, and tables. Soil maps show the spatial distribution of the different kinds of soils that occur in an area. The text describes the properties of each of the kinds of soils shown on the maps. The tables provide additional data about soil properties and interpretations of those properties for a variety of land uses.

Maps. Lines drawn on soil maps surround areas called *delineations.* Each delineation represents the size, shape, and location of a specific body of soil. Each delineation contains a symbol that identifies the *map unit* of that delineation. Each map unit has two components: the dominant kind or kinds of soil, and other soils that are known to occur but are too small to be shown separately at this scale of the map. These other soils are called *inclusions.*

On most soil maps the smallest area that can reasonably be shown is 3 to 4 acres. Any body of soil smaller than that is an inclusion in a larger delineation of a different kind of soil. Inclusions also occur because the boundaries between different soils are not sharp lines but gradual zones of transition. The lines on a soil map are placed as nearly as possible at the center of that transition zone. It is unrealistic to expect natural soil boundaries to change abruptly within a few feet, as the map might suggest.

Inclusions are important because they may affect the suitability of a site. That's why soil maps, though very helpful in preliminary site analyses, must be supplemented with on-site evaluations before final decisions are made.

Text. Soil survey text contains both map unit descriptions and soil profile descriptions.

Map unit descriptions give the name of the dominant soil, the texture of the surface horizon, and the range of slopes on which the soil occurs. Information on depth, drainage, permeability, AWHC, and landscape of the dominant soil is also presented. Map unit descriptions identify the other kinds of soils that are most likely to be found as inclusions and indicate how much of the area the inclusions are likely to occupy.

Soil profile descriptions give detailed, technical information on the properties of each major kind of soil, or *soil series,* found in the soil survey area. Each series is described in terms of the horizons that are present and the texture, color, structure, pH, and other properties of each horizon.

Tables. Tabular information summarizes key properties and interpretations for each map unit. Of all the tables, four are particularly relevant to land application of wastewater biosolids.

The table on *Physical and Chemical Properties* provides information on clay content, permeability, AWHC, pH, shrink-swell potential, and in some cases, organic matter content.

The table on *Soil and Water Features* gives information on runoff potential (hydrologic group), flooding, water tables, and depth to bedrock.

The table on *Engineering Properties* contains additional data on texture and coarse fragments.

The table on *Yields Per Acre of Crops and Pasture* shows the kinds of crops that are commonly grown and the relative yields that can be obtained under good management.

Using soil survey information to rate soil suitability

The objective here is to extract from soil surveys all the information needed to make a preliminary evaluation of site suitability by rating each of the soils present according to the criteria in tables 8-12. Soil surveys can be used either to evaluate sites that have already been identified or to help locate potential sites for future consideration.

Evaluation of known sites. The first step is to locate the area in question on the Index to Map Sheets. This index identifies the specific map sheet or sheets that include the area. Turn to those specific map sheets and locate the area. Make a list of all map unit symbols for the delineations that cover the potential land application area. Use the *legend* to determine the specific soil name that corresponds to each symbol.

The next step is to read about the soils in both the map unit descriptions and in the soil profile descriptions. Much of the information needed is in these narratives. Finally, consult the relevant tables to complete your data collection process.

You should now have enough information to rate the dominant soil of a map unit using the five keys in tables 8-12. Then write the suitability for each delineation on the map or color each delineation according to its suitability class.

Two things should now be apparent: the *amount* of land in each suitability class, and the *pattern of admixture* of soils in different classes. The pattern is much more significant. Areas of uniform suitability, even if they are uniformly fair or even poor, are easier to manage than areas of non-uniform suitability. Such an area is illustrated in Figure 4.

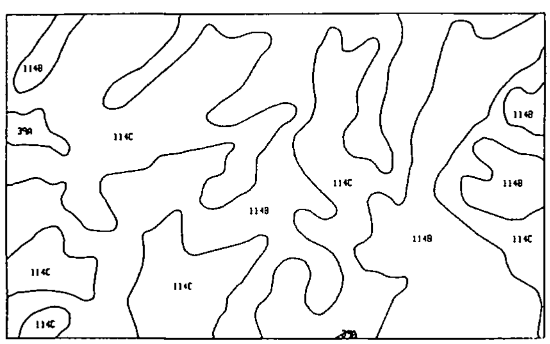


Figure 4.—Soil map showing a pattern that is not limiting for land application of sludge.

Using Soil Surveys for Preliminary Site Evaluation

- Locate the site on the Index to Map Sheets
- Locate the site on the corresponding detailed map sheet
- List all map unit symbols shown
- Identify symbols in the legend
- Read map unit descriptions
- List inclusions likely to be present
- Read descriptions of dominant soils and inclusions
- Consult tables for relevant data

When small areas of fair or poor soils are distributed entirely throughout larger areas of good or excellent soils, the *pattern* may limit the management of the entire site to that of the least suitable soil. Figure 5 shows a pattern of an area of dominantly well drained and moderately well drained soils dissected by thin strips of poorly drained soil.

Using Soil Surveys for Locating Potential Sites

- Consult the General Soil Map
- Select a soil association dominated by suitable soils
- Locate a large area of that association on the General Soil Map
- Locate the same area on the Index to Map Sheets
- Turn to the corresponding detailed maps and study the soil patterns
- Consult text and tables as necessary

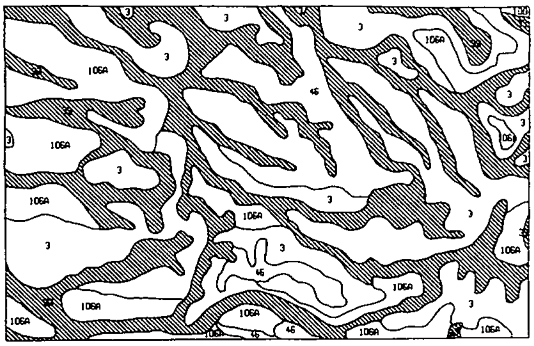


Figure 5.—Soil map showing a limiting pattern for land application of sludge

One problem with limiting patterns is that suitable soil areas may be too small to manage independently, yet managing the whole area as if it were suitable increases the potential for contamination of surface or groundwater in the poorly suited areas.

Another problem is that access to the more suitable areas may be limited to times when the trafficability of the poorly suited soils is acceptable. The only viable solution to management of these kinds of soil patterns is to manage the entire area as though it all consisted of the more limiting soils in the pattern.

The last step in using soil survey information is to consider possible effects of the inclusions within each map unit delineation. The descriptions of each map unit state explicitly what kind of included soils are most likely to occur. Read the map unit and soil profile descriptions of the inclusions to determine their properties. If necessary, determine the suitability rating for each of the inclusions.

Locating potential sites. The other use of soil surveys is to help find some possible sites for biosolids application. Start with the General Soil Map, a small scale map of the entire soil survey area. Map units for the General Soil Map are *Soil Associations.* Each soil association consists of two or three major soils that occur in a regular, predictable pattern on the landscapes represented by the corresponding areas shown on the General Map. The legend for the General Map is printed on the same page as the map. Each association is described in more detail in the text, usually near the beginning of the report.

Use these two sources to identify associations dominated by deep, well and moderately well drained soils on nearly level landscapes. Associations dominated by poorly drained soils, soils on flood plains, or soils on steep slopes are not as likely to have large areas of suitable soils.

Return to the General Soil Map and locate the areas where the more suitable associations occur. Locate the corresponding areas on the Index to Map Sheets and select two or three map sheets. Turn to these sheets and find the areas dominated by map units of suitable soils. There may not be any good areas for land application on a particular map sheet, but you can use this process for some initial screening to identify areas that warrant further investigation.

Limitations to the use of soil maps

Published soil surveys are excellent tools for generalized site evaluation and preliminary site screening. Soil surveys cannot be used for detailed site evaluations because of the scale of the map. This is not the fault of the soil survey, nor does it reflect on the accuracy with which the map was made. It means only that standard soil survey maps cannot resolve soil differences that are smaller than four or five acres in size. To assume otherwise is to use the information provided incorrectly.

The only solution to this problem is to make an on-site investigation, and, if necessary, have a more detailed soil map made by a professional soil scientist. This investigation will reveal exactly what kinds of inclusions are present, their location, and the extent to which they, or the pattern of admixture of other soils, may limit the use of the site.

Detailed on-site studies are particularly necessary for major projects and projects in which liquid biosolids are going to be applied. Where only dried biosolids will be applied, or where biosolids will be applied only once or at infrequent intervals, the information obtained from the soil survey may be adequate to assess site suitability.

Crop Management Factors

CHAPTER 5

Designing, implementing, or evaluating a plan for beneficial use of domestic wastewater biosolids requires working within the farmer's or site operator's existing management system. Biosolids utilization is not likely to alter decisions on the crops to grow, the crop rotations to use, and whether to drain, irrigate, or lime the soil. The crop management system dictates when a field is accessible, the frequency of biosolids applications, the expected amount of nutrients the biosolids must deliver, and the application methods.

Crop management factors that bear directly on the design of a biosolids utilization program include crop choice, nutrient management, water management, and conservation practices. Application of biosolids to farmland also requires the management practice of long term monitoring.

Choice of Crop

Biosolids can be applied to row, grain, pasture, horticultural, and tree crops. Some crops, such as leafy green vegetables and root crops, may accumulate trace inorganics, and should not be grown on soils to which biosolids have been applied. The crops most likely to be used in a biosolids management program are pasture and forage, grain and grass seed, and row crops. Row crops include food crops (crops grown for direct human consumption or animal feeds) and non-food crops such as cotton, Christmas trees, and ornamentals.

Pasture and forage crops offer the greatest flexibility for application of biosolids because access is not limited by the crop's growth stage. Biosolids may be applied whenever climatic and soil moisture conditions are favorable. The sod created by pasture and forage crops also promotes infiltration, controls erosion, and enhances site trafficability.

One disadvantage of pasture sites is that biosolids cannot be easily worked into the soil. With surface applications, up to 50% of the NH_4-N in the biosolids may be lost by volatilization. This must be considered when calculating the amount of biosolids needed to meet nutrient requirements. Furthermore, some of the benefits of biosolids as a physical soil conditioner cannot be realized with surface applications. Another disadvantage is that a waiting period after application, usually 30 days, is necessary before animal grazing can resume.

Grain and grass seed crops are well suited for biosolids utilization, although application may be limited to a single annual application approximately a month prior to planting. At that time, you can drive over the soil and apply biosolids in any form and work them into the soil. This preserves both the ammonia and the physical benefits.

For fall-seeded crops, biosolids can be applied in August or September. Usually there are enough times when the soil is dry enough to apply biosolids without undue risk of runoff, leaching, or soil compaction.

In some climatic regions, fall applications to warm, moist soil may create nearly optimum conditions for mineralization of organic nitrogen. As a result, the production of nitrate is out of phase with crop needs. The excess nitrate is subject to leaching as soil moisture increases through the following winter and spring.

For spring-seeded grains, the window of opportunity for applying biosolids is much narrower. In many areas the soil does not dry out enough to support traffic until planting time. In this situation, it may be necessary to apply the biosolids, plow and/or disk them into the soil, and plant the grain immediately.

Low amounts of readily available N in most biosolids indicate that supplemental fertilizers may be needed to start spring seeded crops. Subsequent mineralization, however, is more likely to match plant needs throughout the remainder of the growing season. These relationships must be considered when determining the total amount of biosolids to apply to the field.

Row crops, especially annual ones, are generally planted in the spring, and the same principles apply as for spring grains. A single application prior to planting is the most common procedure. Access is good, but trafficability may be limiting, and starter fertilizers may be necessary.

Farmers need to be aware that unprocessed fruit and vegetable crops cannot be planted on biosolids-amended soils for several months (see "lag times" in Chapter 2). Processed fruits and vegetables can be grown on biosolids-amended soils, but some processors may not accept such crops simply to avoid possible repercussions from consumers.

Row crops grown for animal feed, such as corn and soybeans, and row crops that are not eaten, such as cotton, are good choices for a biosolids utilization program.

Nutrient Management

Biosolids are fertilizer materials and are therefore an integral part of the nutrient management program. The crop type, yield, rotation, and soil test data are all used to design an overall soil fertility management program.

Work closely with farmers and their Extension agents or crop consultants to make sure that biosolids can be properly fitted into the overall crop management plan.

The amount of fertilizer nutrients that biosolids must deliver depends on:

- Kind of crop
- Expected yield
- Amounts of residual nutrients
- Amounts of other commercial fertilizers used

Fertilizer recommendations are based on a combination of farmer experience and long-term research to correlate soil test data with crop response to added fertilizer. These research results are available in many states as fertilizer guides published by the Extension Service. County Extension agents and agronomic consultants use fertilizer guides to assist farm managers develop nutrient management programs.

Fertilizer nutrients are expressed in terms of pounds N, pounds P_2O_5, and pounds K_2O. For example, a bag of fertilizer labeled 16-8-8 delivers 16% N, 8% P_2O_5, and 8% K_2O by weight.

Biosolids data, by contrast, are expressed in terms of the elemental concentrations of N, P, and K, not their oxide equivalents. Although biosolids data and fertilizer conventions are the same for nitrogen, biosolids P must be converted to P_2O_5, and biosolids K to K_2O, in order to accurately assess the nutrient value of a biosolids product.

To convert P to P_2O_5, multiply by 2.27, or to convert P_2O_5 to P, multiply by 0.44. Thus, adding 100 pounds of biosolids P to soil is the same as adding 227 pounds of P_2O_5. Conversely, if a fertilizer recommendation calls for 100 pounds of P_2O_5, that would require only 44 pounds of biosolids P.

To convert K to K_2O, multiply by 1.20, or to convert K_2O to K, multiply by 0.83. Adding 50 pounds of biosolids K to a soil adds the equivalent of 60 pounds of K_2O, whereas a fertilizer recommendation calling for 50 pounds of K_2O would require only 42 pounds of biosolids K.

The amount of fertilizer nutrients that biosolids must deliver depends on the kind of crop, expected yield of the crop, amount of residual nutrients in the soil, and use of commercial fertilizers or lime.

The kind of crop and the expected yield of the crop determine the total nutrient requirement for the crop. Grass pastures and hay crops, for example, may require up to 250 pounds per acre of fertilizer nitrogen during the growing season. If the grass contains a legume, only 70-80 pounds of nitrogen should be applied. Spring grains and grass seed crops need about 150 pounds N per acre, whereas row crops require approximately 250 pounds N per acre.

Higher yields mean greater nutrient uptake, and this implies a greater need for nutrients to be supplied from fertilizers or biosolids. Crop yields depend on the weather and the farmer's management program. Historical records of crop yields, and the knowledge of local county Extension agents and crop consultants may be your best guides to estimating crop yields.

Fertilizer recommendations must account for residual nutrients from all sources. Prior crops, residue management, and prior biosolids applications affect the amount of residual nutrients in the soil.

If biosolids are applied to a field where spring grain will be grown and the previous crop was grass hay or pasture, then there is essentially no residual nitrogen. All of the crop's needs must come from supplemental sources. If the previous hay crop contained a legume, then as much as 75 lb N/a may remain in the soil. If the previous crop was a row crop, as much as 50 lb/a of residual N may remain. If the previous crop was a grain crop, there may be only 25 lb/a residual N.

Crop residues are valuable soil amendments and should be returned to the soil. Both biosolids and crop residues add plant nutrients, help maintain soil organic matter levels, and improve the physical condition of the soil.

Harvesting pasture, hay, and silage crops leaves little residue to return to the soil. Residual nutrients from these crops are correspondingly low. Field corn, grain, and grass seed crops leave relatively large amounts of residue. Working these residues into the soil returns larger amounts of nutrients. Removing these residues, either by burning or by baling, lowers the residual nutrient supply.

Prior applications of biosolids may result in significant increases in nutrient pools. The rule of thumb for nitrogen is: the mineralization rate of organic nitrogen in subsequent years is about half of the previous year's rate. Calculations of residual nitrogen from prior biosolids applications are illustrated in Chapter 6.

Some biosolids deliver more potassium and phosphorus than a crop needs in a single year. These excesses add to the residual nutrient supply, especially when biosolids are applied to the same field several years in a row.

The amount of biosolids to apply depends on whether the fertility plan intends to meet all, or only a portion, of a crop's needs with land-applied biosolids. Many row crops, for example, require more nitrogen at the beginning of the growing season than can be supplied by slow mineralization of organic nitrogen. Farmers can meet this need by placing fertilizer in a band near the seed when planting. This reduces the amount of biosolids required to provide the remaining nitrogen needed.

For fall-planted grains, nutrient management may include a broadcast application of fertilizer in the spring. This would substantially reduce the amount of biosolids applied and worked into the soil prior to planting. This spring fertilizer need might be met with biosolids, if a liquid biosolids product, which could be applied with an irrigation gun, were used.

Soil Testing

Regular soil testing is essential in evaluating residual nutrient supplies and formulating fertilizer recommendations. Soil testing is also essential in planning and designing good crop and biosolids management programs.

Getting a good sample is vital in getting good soil test information. Neither the biosolids generator nor the biosolids regulator should be expected to sample or test the soil. For biosolids utilization programs, the farmer, site operator, county Extension agent, or crop consultant should sample the soil. Soil samples should truly represent the field on which biosolids will be applied. Most state agricultural Extension Services can provide a list of acceptable soil testing laboratories and have publications on obtaining a good sample (see Figure 6).

If a field contains two or more distinctly different kinds of soils, separate samples of each soil should be taken. For each kind of soil, several subsamples should be taken from all over the field, mixed together in a bucket, and a small portion withdrawn for analysis. The soil should not be contaminated with manure, biosolids, lime, fertilizer, or other substance.

Soil test data on available potassium and phosphorus are the basis for recommendations on supplemental potassium and phosphorus amounts.

Nitrogen values may fluctuate widely as environmental conditions and biological activity in the soil change. Therefore, soil tests for nitrate are not often used to measure residual N or as the basis for crop nitrogen requirements.

Instead, research results on crop responses under controlled conditions are used to forecast nitrogen needs. If soil test nitrate values are reported, check that the samples were properly handled prior to analysis. Proper handling means minimizing the opportunity for mineralization between sampling and analysis. This can be done by refrigerating or freezing the sample. If the sample is dry to the wilting point, little mineralization will occur, as long as the sample is maintained in the dry state.

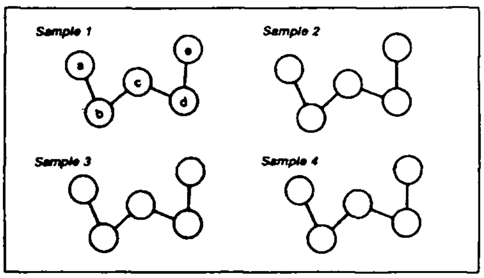
Soil testing is essential in order to plan good crop and biosolids management programs. The most important part of a good soil testing program is getting a good sample of soil to test.

Sampling Soils for Testing

E.E. Schulte, L.G. Bundy and J.B. Peters

Importance of Taking Good Soil Samples

A soil test is the only practical way of telling whether lime and fertilizer are needed. However, if a soil sample does not represent the general soil conditions of the field, the recommendations based on this sample will be useless, or worse, misleading. An acre of soil to the depth of plowing weighs about 1,000 tons. Less than one ounce of soil is used for each test in the laboratory. Therefore, it is very important that the soil sample is characteristic of the field. The following directions will help you take good soil samples.



Method of taking composite samples from four, five-acre sections of a 20-acre field. All composite samples should be a combination of cores a, b, c, d and e, as shown in Sample 1.

When to Take Soil Samples

Take soil samples at any convenient time. However, to receive your recommendations early enough to enable you to get the lime and fertilizer needed, it is best to sample in the fall. Another advantage of fall sampling is that fertilizer discounts are usually offered then. Hayfields can be sampled after any cutting.

Winter sampling, or sampling when the soil is frozen, is permissible only when it is possible to take a *uniform boring or core of soil to* plow depth. Normally, this requires using e portable power boring tool. Using e pick or spade to remove a few chunks of frozen soil from the surface is *not* satisfactory.

Where to Take Soil Samples

If the field is quite uniform, one *composite* sample from every five acres is sufficient. A composite sample consists of e core or boring taken from at least five different places in the area to be sampled, as shown in the sketch. Avoid sampling such areas as:

a) Dead furrows or back furrows
b) Lime, sludge or manure piles
c) Animal droppings
d) Fences or roads
a) Rows where fertilizer has been banded
f) Eroded knolls
g) Low spots

In general, do not sample any area of a field that varies widely from the rest of the field in color, fertility, slope, texture (sandy, clayey, etc.), drainage or productivity. If the untypical area is large enough to receive lime or fertilizer treatments different from the rest of the field, sample it separately. If manure or crop residues are on the soil surface, these organic materials should be pushed aside and not included in the soil sample.

On contoured fialds, sample each strip separately if it is five acres or larger, taking at least one composite sample per five acres. Coras from two or three small strips may be combined to give a singla composite sample if the combined araa doesn't exceed five acres and if all strips have identical cropping and management histories.

Special considerations for no-till fields. Fields that have not been tilled for five years or more may develop an acid layer at the surface from the use of nitrogen fertilizer. Such an acid layer could reduce the effectivenass of triazine herbicides. Soil phosphorus (P) and potassium (K) ere also likely to build up in the surface soil if it is not tilled. If an acid layer is suspected, take a separate sample to e depth of only two inches. When sending the soil to the lab, indicate the sampling depth was only two inches. This sampla will be tested

Figure 6.—Example brochure on soil test sampling

Water Management

Water management deals with deficiencies and excesses of water in the soil. Deficiencies are managed with irrigation, and excesses are managed with drainage.

Irrigation affects biosolids management in two ways. First, crop yields are higher on irrigated land than on dryland, which increases the amount of nutrients that the biosolids must deliver. Second, irrigation increases the hydraulic loading of the soil, which increases the potential for both leaching and runoff. The risk is not large, however, as long as the irrigation system is well designed and the irrigation program is well managed.

Wet soils that are artificially drained require more careful management than naturally well drained soils.

Good biosolids management, with respect to irrigation, includes not irrigating immediately after the biosolids application, avoiding over-irrigation, and refraining from applying biosolids on flood or furrow irrigated fields. County Extension agents and crop consultants can provide advice on irrigation practices and scheduling.

Drainage of wet soils affects crop management and land application of biosolids. Farmers and site operators are unlikely to drain soils only to accommodate a biosolids application program. Soils that are already drained present a wider choice of suitable crops. Higher yields, higher nutrient requirements, and higher biosolids application rates are more likely on drained soils.

Artificially drained soils require more careful management than naturally well drained soils. Drainage with surface ditches may lower the water table, but because the ditches drain into natural streams, care is required to avoid direct input of biosolids into surface drainage ditches. Limiting biosolids applications to the dry times of year when water tables are naturally low and ditches are empty is a good management practice.

Runoff and erosion control are absolutely essential to sound management of a biosolids application program. The best way to promote infiltration and reduce erosion is to keep the soil under a permanent sod crop.

Drainage through subsoil tile lines effectively lowers the water table, but tile drains ultimately empty into surface waters. Leaching of excess nitrogen applied either as biosolids or as commercial fertilizer can and does occur. Planning biosolids applications so that the release of nitrogen coincides as nearly as possible with plant uptake of nitrogen is a good management practice for this situation.

Soil Conservation Practices

Runoff and erosion control are essential to sound management of land application of biosolids. Overland flow increases the potential for contamination of surface waters with biosolids. Erosion decreases soil productivity, increases sediment loads in streams, and carries biosolids into surface waters.

Soil conservation practices are designed to promote infiltration and slow down the velocity of water that flows over the surface. The best way to promote infiltration and reduce erosion is to keep the soil under permanent sod crop plant cover, such as pasture and hay crops. Some perennial grass seed crops are also very effective in reducing runoff and erosion.

For cultivated crops, particularly grain crops, reduced tillage can be an effective erosion control measure. Reduced tillage, as opposed to conventional tillage, does not turn the soil over with a moldboard plow. Instead the soil is disked or mixed slightly with sweep plows in such a way as to partially incorporate crop residues, loosen the soil, break up compacted layers, and leave a rough soil surface.

Some studies have shown that additions of biosolids enhance the erosion control effectiveness of reduced tillage. The organic matter in biosolids augments the organic matter in crop residues and enhances the formation of stable soil aggregates that increase the porosity and infiltration rate of the surface soil.

Widely spaced row crops provide little protection for the soil surface, particularly in early stages of growth. For these crops, reduced tillage is better than conventional tillage, and injecting or working biosolids into the soil is better than surface applications.

As soil slope increases, the potential for runoff and erosion increases dramatically. Permanent cover sod crops are particularly valuable for controlling erosion on steep soils. Residue incorporation and reduced tillage methods are particularly important for grain and row crops.

Effective erosion control on steep slopes may require additional conservation practices. Cross-slope farming, i.e., planting crop rows on the contour instead of up and down hills, is one practice.

Diversion terraces are low ridges constructed at intervals across a slope. These terraces interrupt the flow of water down slope so that high velocities of flow cannot occur. Water caught behind a terrace has more time to soak into the soil, and excess water can be diverted across the slope to a grassed waterway, where it can be conducted safely downslope without causing erosion.

Sometimes runoff is inevitable, even from pastures and well-protected crop fields. This is especially true during high-intensity storms and when the soil is frozen. Regardless of other conservation practices that may be in place, biosolids should not be put on the soil at these times.

Monitoring and Record-keeping

If biosolids are going to be applied to a farm field over a number of years, the soil should be sampled and tested regularly to monitor residual nutrient supplies, accumulations of trace inorganics and organic contaminants, and increases in soil salinity from year to year. For row crops, grains, and other cultivated crops, annual sampling is a good idea. For pastures that are managed at a low level of intensity, sampling does not need to be done as frequently.

Some biosolids may be quite high in soluble salts. Long-term, heavy applications may cause an increase in soil salinity, even to the point where salt-sensitive crops are affected.

Nitrogen in soil generally does not accumulate to levels dangerous for plant survival. The only problems with excess nitrogen are excessive vegetative growth that leads to a plant condition called lodging, and in some cases, a delay in flowering and fruit development.

The major risk from long term applications of nitrogenous materials is the possible increase of nitrate nitrogen in groundwater sources used for drinking water. This occurs only when nitrate nitrogen leaches through the soil. The relevant parameters are the amount of biosolids applied, soil permeability, timing of mineralization in relation to crop uptake, and interactions with rainfall or irrigation water.

Phosphorus does not accumulate to toxic levels in the soil. However excessive amounts of available phosphorus may lead to decreased crop vigor through nutrient imbalances. For this reason, long-term phosphorus accumulations should be monitored.

Phosphorus is not very mobile in the soil and is not subject to large leaching losses. Heavy applications over a long period of time, however, will move some phosphorus through the soil. The rate and distance of movement may be of concern near lakes whose eutrophication rate could increase rapidly with small additions of phosphorus.

The greatest concern about excessive phosphorus loading is overland flow. Either the physical transport of biosolids or the erosion of soil enriched with phosphorus could cause significant deterioration of surface water quality. Monitoring programs should watch for signs that excessive additions of phosphorus to lakes and streams could occur.

Excess potassium is not a serious problem if biosolids are applied only once or at intervals separated by several years. It is possible, though, that regular additions of excess potassium could elevate soil salinity to harmful levels or could cause potassium to accumulate to the point that potassium interferes with magnesium nutrition of plants. One result of this is a condition known as grass tetany, which afflicts animals that graze on Mg-deficient forages. For this reason, regular soil-test monitoring of potassium levels in biosolids-amended soils is a good idea.

Similarly, regular monitoring of trace inorganic and organic chemicals in biosolids-amended soils is important to ensure that accumulated amounts do not exceed cumulative limits set by regulatory agencies.

A good monitoring program also means a good record-keeping program. Careful, complete records should be kept of the amounts of dry solids, trace inorganics, organics, and nutrients applied to *each* field *each* year. These records are necessary to evaluate the significance of data collected in the monitoring program and to document compliance with all pertinent regulatory standards.

Avoid application of biosolids during times of high-intensity storms and times when the soil is frozen.

Design Calculations

The general procedure for designing a biosolids application system is as follows:

1. Assemble data on biosolids, soil, cropping system, and fertilizer recommendations.
2. Calculate amounts of nutrients the biosolids must deliver. Subtract from fertilizer recommendations the amounts supplied by residual nutrients and the amounts supplied by other commercial fertilizers.
3. Calculate the amount of available N per dry ton of biosolids. Add the fractions of NH_4-N and NO_3-N recovered to the amount of organic N mineralized.
4. Calculate the Agronomic Loading Rate. Divide lb biosolids N required by lb/ton available N in the biosolids product.
5. Calculate the amounts of P and K delivered in the agronomic loading rate. Compare with fertilizer recommendations for P_2O_5 and K_2O.
6. Calculate the application area required. Divide the total amount of biosolids produced each year by the amount applied per acre.
7. Calculate the Allowable Accumulation Period. Multiply lb per dry ton of each trace inorganic by the Agronomic Loading Rate, then divide each trace inorganic's annual loading rate into the cumulative limit set by regulatory standards.

Every location, every site is unique. Domestic wastewater biosolids are extremely variable in the amounts of total N, organic N, phosphorus, potassium, trace inorganics, and organics they contain. The numbers used in this guide represent a single, specific example and are intended only to illustrate the principles involved in calculating nutrient requirements and loading rates.

Before completing calculations for a particular biosolids product, soil, and crop, you should consult with agriculture professionals, soil scientists, and wastewater treatment agencies in your area to make sure you have the right numbers for that situation.

Here's a list of some of the specific numbers needed:

1. Crop requirements and fertilizer recommendations for N, P, and K.
2. Amounts of residual N supplied by previous crops, crop residues, and prior applications of biosolids.
3. Amounts of available P and K in the soils at your application sites.
4. Amounts of N, P, and K that may be supplied with other commercial fertilizers.
5. Amounts of nitrate nitrogen and ammonia nitrogen actually delivered to and recovered from the soil.
6. Annual mineralization rates for the type of biosolids, climate, and time of year applied.

Make sure that fertilizer recommendations account for *all* sources of residual nutrients in the soil:

- the previous crop
- returned crop residues
- prior biosolids applications

Carryover Nitrogen from Previous Biosolids Applications

Organic nitrogen applied in biosolids continues to decompose and release mineral nitrogen over a period of several years. Nitrogen carryover from prior biosolids applications is an important issue that may need careful checking in your calculations.

The critical point is whether or not the amount of fertilizer nitrogen recommended for a crop has already accounted for nitrogen mineralized from prior biosolids applications.

Extension agents are accustomed to developing fertilizer recommendations based on residual nitrogen from both the previous crop and crop residues. They may not be as accustomed to calculating the amount of carryover nitrogen from previous biosolids applications before making recommendations for additional fertilizer.

The sample calculations that follow in this guide assume that the recommended fertilizer nitrogen has accounted for all residual nitrogen sources, including prior biosolids applications. If this were not true, then you may need to calculate the carryover and reduce the biosolids loading rate accordingly.

Here's how the procedure works.

First, check with professional agronomists in your area to determine specific rates of mineralization of organic nitrogen in years subsequent to the initial application. A common approximation is to use a rate that is one half of the previous year's rate.

Second, calculate the amount of nitrogen mineralized in each year for 2 or 3 years after the initial application. Suppose, for example, an anaerobically processed biosolids delivers 100 lb per ton of organic nitrogen when it is first applied. If the first year's mineralization rate is 20%, then each dry ton of biosolids will have 20 lb of nitrogen mineralized and 80 lb of organic nitrogen remaining in the soil to start year 2.

If the mineralization rate for year 2 is 10%, then 8 lb (0.1 x 80 lb) of organic N per ton of biosolids will be mineralized, and 72 lb will remain. In year 3, the mineralization rate might be 5%, and 5% of 72 lb yields 3.6 lb per ton of mineralized nitrogen for year 3.

Third, calculate the cumulative amount of carryover N. If the same kind of biosolids were to be applied at the same rate for three years consecutively, then at the beginning of the third year the amount of carryover nitrogen from previous biosolids applications would be 3.6 lb from the first year's application plus 8 lb from the second year's application, for a total of 11.6 lb.

This is the amount that should be subtracted from the fertilizer recommendation. If the fertilizer recommendation did not allow for this residual nitrogen, then the amount of nitrogen required from the current year's biosolids application should be reduced by that amount.

Sample Calculations

The steps necessary to calculate agronomic loading rates, sizes of application areas, and allowable accumulation periods are detailed below. They are intended to be logical, orderly, consistent, and simple. English units of measurement (gallons, pounds, tons, and acres) are preferred because they are more familiar to most operators, Extension agents, and farmers.

Current regulatory standards for cumulative loadings of trace inorganics (Table 2) are assumed to be valid. Should they change, you may need to adjust your calculations of allowable accumulation period accordingly.

Each step in the calculations is illustrated using the actual data for a liquid biosolids product generated by a city of about 10,000 people. This biosolids product was anaerobically processed, and the example assumes that it will be applied to a row crop.

Step 1.—Assemble relevant data

Kinds of Data	Example	
Biosolids		
Type	Liquid Anaerobically Processed	
Volume		
Gallons produced yearly	2,673,550 gal	
Percent solids	1.93%	
Dry tons produced yearly	215.17 tons	
$\text{Dry tons} = \frac{\text{Gallons} \times 8.34}{2{,}000} \times \frac{\%\ \text{Solids}}{100}$		
Nutrients (% x 20 = lb/ton)	**Percent**	**lb/ton**
Total Kjeldahl N	10.7	214.0
NH_4-N	5.45	109.0
NO_3-N	0.015	0.3
Organic N (TKN - NH_4-N)	5.25	105.0
Phosphorus	0.78	15.6
Potassium	0.015	0.3
Trace inorganics (mg/kg x .002 = lb/ton)	**mg/kg**	**lb/ton**
Arsenic	11	0.02
Cadmium	6	0.01
Chromium	61	0.12
Copper	453	0.91
Lead	442	0.88
Mercury	3	0.01
Molybdenum	11	0.02
Nickel	34	0.07
Selenium	10	0.02
Zinc	897	1.79
Application method	Once per year, spring Disked into soil	
Soil		
Data from soil testing laboratory		
pH	6.0	
Soil test P (Bray P1)	10 ppm	
Soil test K (NH_4OAc extractable)	120 ppm	
Estimated residual N (includes prior biosolids applications)	35 lb/acre	
Crop		
Information from farmer, farm advisor, fertilizer guides		
Type	Field corn	
Expected yield	170 bushels	
Rotation	Follows grain	
Total fertilizer N recommendation (accounts for all residual N)	265 lb/acre	
Supplemental fertilizer N	30 lb/acre, banded	
Fertilizer P requirement	75 lb P_2O_5/acre	
Fertilizer K requirement	50 lb K_2O/acre	

Step 2.—Determine the amount of available N the biosolids must provide

Procedure	Example
Biosolids N needed **= Total Fertilizer N recommended - Supplemental Fertilizer N**	Biosolids N needed = 265 lb/acre - 30 lb/acre Biosolids N needed = 235 lb/acre available N

Step 3.—Calculate the amount of available nitrogen per dry ton of biosolids

Procedure	Example
Use the lb/ton data for NH_4-N, NO_3-N, and organic N in Step 1.	NH_4-N = 109 lb/ton NO_3-N = 0.3 lb/ton Organic N = 105 lb/ton
A. Available NH_4-N **= lb/ton NH_4-N x Fraction Recovered** Assuming the biosolids analysis data are for the processed biosolids that will be applied to the land, the fraction recovered can be taken as 0.85 for biosolids that are worked into the soil and 0.5 for biosolids that are left on the soil surface.	Available NH_4-N =109 lb/ton x0.85 = 92.6 lb/ton
B. Available NO_3-N **= lb/ton NO_3-N x Fraction Recovered** Assuming the analytical data are for the processed biosolids that will be applied to the land, the fraction recovered can be taken as 1.0.	Available NO_3-N =0.3 lb/ton x1.0 = 0.3 lb/ton
C. Mineralized Organic N **= lb/ton Organic N x Mineralization Rate** The mineralization rate for the year immediately following land application usually varies from about 8 to 30%, depending on the type of biosolids, the type of processing, the method of application, the time of application, the cropping system, and the local climate. Consult local agronomists and soil scientists to determine the best number for your land application program.	A reasonable mineralization rate for anaerobically processed liquid biosolids is 20%. Available Org-N =105.0 lb/ton x0.2 = 21.0 lb/ton
Total Available N in biosolids **= A + B + C above.**	Total Available N in biosolids = 92.6 + 0.3 + 21.0 = 113.9 lb/ton

Step 4.—Calculate the Agronomic Loading Rate (ALR)

Procedure	Example
ALR (tons/acre) = $\frac{\text{biosolids N needed for crop (lb/acre)}}{\text{available N in biosolids (lb/ton)}}$	*From Step 2:* the amount of biosolids N needed is 235 lb/ acre. *From Step 3:* the available N in the biosolids is 113.9 lb/ton. ALR = $\frac{235 \text{ lb/acre}}{113.9 \text{ lb/ton}}$ = 2.1 tons per acre

Step 5.—Determine the fertilizer P and K value of the biosolids

Procedure	Example
A. Calculate the amounts of P and K delivered annually **P (lb/acre) = biosolids P (lb/ton) x ALR (tons/acre/year)** **K (lb/acre) = biosolids K (lb/ton) x ALR (tons/acre/ year)**	Using the data from Step 1 and the ALR from Step 4, P = 15.6 lb/ton x 2.1 tons/acre = 32.8 lb P per acre K = 0.3 lb/ton x 2.1 tons/acre = 0.6 lb K per acre
B. Convert P to P_2O_5 and K to K_2O (see page 36). **P x 2.27 = P_2O_5** **K x 1.20 = K_2O**	32.8 lb P/acre x 2.27 = 74.5 lb P_2O_5 per acre. 0.6 lb K/acre x 1.20 = 0.72 lb K_2O per acre.
C. Compare nutrients delivered in biosolids with fertilizer recommendations for P and K.	Phosphorus added to the soil very nearly equals the recommended fertilizer rate of 75 lb P_2O_5 per acre. For cool season, spring crops, however, the farmer may wish to band-place 20 lb or so P_2O_5 per acre just to make sure there is enough P available to meet initial crop demands. In this case the small excess P delivered by the biosolids should not create a problem, but careful monitoring of available P in the soil is a good idea. This biosolids product has virtually no fertilizer potassium value. Supplemental fertilizer will be needed to provide the 50 lb K_2O per acre recommended (see Step 1).

Step 6.—Calculate the area of land required

Procedure	Example
Acres land = $\frac{\textbf{tons dry biosolids produced annually}}{\textbf{Agronomic Loading Rate}}$	*From Step 1:* The amount of dry biosolids produced is 215.17 tons per year. *From Step 4:* The Agronomic Loading Rate is 2.1 tons per acre. Acres land = $\frac{\text{215.17 tons biosolids /year}}{\text{2.1 tons/acre}}$ = 103 acres/year

Table 14.—Cumulative loading rates for trace inorganics

Trace Inorganic	Loading Rate mg/kg	Loading Rate lb/acre
Arsenic	41	37
Cadmium	39	35
Chromium	3,000	2,676
Copper	1,500	1,338
Lead	300	268
Mercury	17	15
Molybdenum	18	16
Nickel	420	375
Selenium	100	89
Zinc	2,800	2,498

Step 7.—Calculate the allowable accumulation period

Procedure

A. Calculate the amount of each trace inorganic applied per acre per year.

Trace inorganic (lb/ton) x ALR = Amount trace inorganic (lb/acre/year)

Example

Use trace inorganic data from Step 1 and the ALR from Step 4.

Arsenic:	0.02 lb/ton x 2.1 ton/acre/year = 0.04 lb/acre/year
Cadmium:	0.01 lb/ton x 2.1 ton/acre/year = 0.02 lb/acre/year
Chromium:	0.12 lb/ton x 2.1 ton/acre/year = 0.25 lb/acre/year
Copper:	0.91 lb/ton x 2.1 ton/acre/year = 1.91 lb/acre/year
Lead:	0.88 lb/ton x 2.1 ton/acre/year = 1.85 lb/acre/year
Mercury:	0.01 lb/ton x 2.1 ton/acre/year = 0.02 lb/acre/year
Molybdenum	0.02 lb/ton x 2.1 ton/acre/year = 0.04 lb/acre/year
Nickel	0.07 lb/ton x 2.1 ton/acre/year = 0.15 lb/acre/year
Selenium	0.02 lb/ton x 2.1 ton/acre/year = 0.04 lb/acre/year
Zinc	1.79 lb/ton x 2.1 ton/acre/year = 3.76 lb/acre/year

B. Calculate the number of years for each trace inorganic to reach its cumulative limit, as defined by regulatory standards (see Table 14).

Years to reach cumulative limit =

$$\frac{\text{cumulative limit (lb/acre)}}{\text{annual amount of trace inorganic applied (lb/acre/year)}}$$

Use data from Table 14 and Step 7A above.

Arsenic:	37 lb/acre / 0.04 lb/acre/year = 925 years
Cadmium:	35 lb/acre / 0.02 lb/acre/year = 1,750 years
Chromium	2,676 lb/acre / 0.25 lb/acre/year = 10,704 years
Copper:	1,338 lb/acre / 1.91 lb/acre/year = 701 years
Lead:	268 lb/acre / 1.85 lb/acre/year = 145 years
Mercury	15 lb/acre / 0.02 lb/acre/year = 750 years
Molybdenum	16 lb/acre / 0.04 lb/acre/year = 400 years
Nickel:	375 lb/acre / 0.15 lb/acre/year = 2,500 years
Selenium	89 lb/acre / 0.04 lb/acre/year = 2,225 years:
Zinc	2,498 lb/acre / 3.76 lb/acre/year = 664 years

C. The Allowable Accumulation Period is the minimum number of years to reach any one trace inorganic's cumulative limit.

In this example, the allowable accumulation period is 145 years, the minimum for Lead.

Practical Applications

One of the objectives of this guide was to assist those responsible for evaluating project proposals. This chapter presents detailed checklists for that purpose. Project developers and permit writers can use the same checklists as a guide to the kinds of information that should be included.

Another objective was to identify sources of information pertaining to soils, crops, and land application of wastewater biosolids . Several of those sources are listed in this chapter.

Guidelines for Evaluating Project Proposals

The framework for project evaluation discussed in Chapter 1 identified data completeness, data accuracy, and issues and interactions as the three components of the evaluation process. The worksheets that follow are designed to guide your review with respect to each of these three components.

The first step in evaluating project proposals is to assess the completeness of the data. The more complete the data, the better the proposal is likely to be. If data are missing or incomplete, it may be necessary to request additional information before proceeding with the review.

The next step in project evaluation is to check the accuracy of the data. This is crucial, for no matter how well planned the project might be, if the raw data are bad, the calculations and designs based on the data are likely to be bad as well.

One way to judge data accuracy is to see if samples of both biosolids and soils have been collected, handled, stored, and analyzed according to standard, approved procedures. For biosolids, standard procedures should be available from the agency that manages the biosolids utilization program in your state. That agency may also be able to provide a list of analytical laboratories whose work is known to be reliable. For soils, standard sampling and analytical procedures are available from your county Extension agent. That person can also provide a list of reliable soil testing laboratories.

Another way to judge data accuracy is to compare the data with results for similar biosolids and soils analyzed previously. If the data are consistent, then you can be reasonably comfortable with their accuracy. If there are significant deviations, then you should at least expect a good explanation of the reasons for the differences, and you may wish to request a re-analysis for the anomalous data.

Should there be any doubt about the accuracy of the data, get a second opinion. Agricultural consultants, agricultural Extension agents, and waste management specialists in state environmental regulatory agencies all may be able to provide assistance.

The final step in project evaluation is to assess the adequacy with which interactions among biosolids, soil, and cropping system have been addressed. This is the most difficult step, but it's critical because the amount of biosolids to apply, the timing of the application, the prevention of disease and other public health problems, and the protection of environmental quality all depend on these interactions.

The most important criterion for evaluating interactions is to judge them against the principles and the common sense discussed in this Guide. If the proposal demonstrates a clear understanding of the principles that control these interactions, and if the calculations and management plans account for the effects of the interactions, then the project is probably a good one.

Conversely, if the proposed project violates one or more of the principles of biosolids behavior in soil, or if the interactions are disregarded in developing the proposal, then the proposal should either be rejected outright or returned for further planning and development.

One other criterion for evaluating interactions is to check their consistency with other successful land application projects. If the management plan is patterned after one or more previous projects that are known to function properly, and if all limiting factors have been accounted for, then the proposal is probably adequate.

To help you conduct your evaluation of interactions, the worksheet for interactions is designed with questions that require a yes or no answer. Any question answered "no" should be taken as a warning that the report may be inadequate or incomplete. At the very least, further information may be required, and it may be necessary to disapprove of the entire project.

Project proposals that are based on complete and accurate data, that are well thought out, and that address all the pertinent interactions among biosolids, soil, and cropping system are suitable for approval.

In summary, proposals that are based on complete and accurate data, are well planned, and address all the pertinent interactions, are suitable for approval. Proposals that are incomplete, fail to substantiate data accuracy, and fail to account for important principles and interactions, should be disapproved.

Proposals between these two extremes need careful evaluation. Some proposals may need to be returned for more data, better data, or clarification of explanations regarding data anomalies, mitigation of soil limitations, or effects of interactions on system design. Other proposals may be approved subject to specific conditions. Some examples of restrictive clauses that may be included in permits are given in Appendix C.

Proposals based on questionable or incorrect data should be disapproved. If the proposals don't make sense or fail to account for soil conditions and farm management plans, they should not be approved.

Finally, remember to seek help from local experts for difficult situations that require professional judgment. With their help, and with your own understanding of the principles and interactions involved in the biosolids-soil-crop system, you should soon become sufficiently experienced to make many of these judgment calls.

Worksheet for Evaluating Biosolids Data

I. Completeness (see pages 4-7)

A. Quantity

Gallons produced annually	______
Dry weight produced annually (Kg or Tons)	______
Percent solids	______

B. Type

Liquid	______
Dewatered	______
Dried	______
Composted	______

C. Nutrients (% or mg/kg)

Total Kjeldahl N	______
NH_4-N	______
NO_3-N	______
Organic N	______
Total P	______
Total K	______

D. Trace inorganics (mg/kg)

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

E. Organic contaminants (mg/kg)

Aldrin/dieldrin	______
Benzo(a)pyrene	______
Chlordane	______
DDT, DDE, DDD	______
Dimethyl nitrosamine	______
Heptachlor	______
Hexachlorobenzene	______
Hexachlorobutadiene	______
Lindane	______
PCB's	______
Toxaphene	______
Trichloroethylene	______
______	______

F. Pathogen reduction processes (PSRP's, PFRP's)

Aerobic digestion ____________
Anaerobic digestion ____________
Lime stabilization ____________
Air-dried ____________
Composted ____________
Heat-dried ____________
High temperature digestion ____________
Gamma irradiation ____________
____________ ____________
____________ ____________
____________ ____________

G. Method of land application

Spread on surface
- Spreader plate ____________
- Portable sludge cannon ____________
- Dry manure spreader ____________

Incorporated into the soil
- Liquid injection ____________
- Surface applied and disked ____________

II. Accuracy (see page 1)

A. When were biosolids sampled?

Just prior to land application? ____________
Before processing and treatment? ____________

B. Were sampling and analytical procedures identified?

Yes ____________ No ____________

C. Were samples taken according to approved procedures?

Yes ____________ No ____________

D. How were samples handled prior to analysis?

Stored in proper container to avoid contamination? ____________
Length of time between sampling and analysis? ____________
Refrigerated or frozen if necessary? ____________

E. How were samples analyzed?

By an approved laboratory? Yes ______ No ______
Using standard procedures? Yes ______ No ______

F. Are the results consistent with data from other biosolids of this type?

Yes ______ No ______

Worksheet for Evaluating Soils Data

I. Completeness

A. Soil types present, list (see page 32)

(e.g. Windthorst fine sandy loam, 3-5% slopes)

____

____

____

____

____

____

B. Data needed to rate suitability for land application (see pages 12-24, tables 8-12)

Texture of surface soil	____________
Texture of subsoil	____________
Depth to bedrock or cemented pan	____________
Coarse fragments in surface soil	____________
Coarse fragments in subsoil	____________
Structure grade of surface soil	____________
Organic matter content	____________
Shrink-swell potential	____________
Drainage class	____________
Permeability of surface soil	____________
Permeability of subsoil	____________
Kind of restrictive layer	
Claypan	____________
Fragipan	____________
Duripan	____________
Petrocalcic	____________
Weathered bedrock (Cr)	____________
Solid bedrock (R)	____________
None	____________
Depth to restrictive layer	____________
Depth to coarse-grained layer	____________
pH of surface soil	____________
Slope of soil surface	____________

C. Water table information (see pages 20-21)

Are somewhat poorly drained or poorly drained soils present?	Yes ______No ______
Position of water table (in. below surface)	____________
Duration of water table (days or months)	____________
Times when water table is high (months)	____________

D. Analytical data (see pages 24-25)

pH	______
Available P (Bray #1)	______
Available K (NH_4OAc extract)	______

E. Site data

Size (acres)	______
Slope (%)	______
Amount of rainfall (inches)	______
Distribution of rainfall (months)	______
Times when soil is frozen (months)	______

II. Accuracy (see pages 32-34)

A. Sources

Modern soil survey report	______
Other NRCS information	______
On-site investigations	
By a certified soil scientist	______
By someone other than a soil scientist	______

B. Sampling (see page 37)

According to approved procedures? Yes ______ No ______

Steps taken to avoid contamination? Yes ______ No ______

C. Analysis (see page 37)

Done by an approved laboratory? Yes ______ No ______

Done according to standard procedures? Yes ______ No ______

D. Consistency

Are data consistent with results from other soils similar to these?

Yes ______No ______

Worksheet for Evaluating Cropping Systems Information

I. Completeness

A. Crop (see page 35)

Kind of crop	________
Trace inorganic accumulator?	Yes ______ No ______
Expected crop yield	________
Anticipated planting date	________
Anticipated harvest date	________
Can/will biosolids be applied while the crop is growing?	Yes ______ No ______

B. Fertility management (see pages 35-36)

Previous crop	________
Crop residue management	________
Estimated residual nitrogen	________
Fertilizer N requirement	________
Commercial N fertilizer used	
Pre-plant	________
Mid-season	________
N required from biosolids	________
Fertilizer P requirement (lb P_2O_5 per acre)	________
Fertilizer K requirement (lb K_2O per acre)	________

C. Water management (see page 38)

Are wet soils artificially drained?	Yes ______ No ______
Surface ditches?	Yes ______ No ______
Subsurface tiles?	Yes ______ No ______
Will the crop be irrigated?	Yes ______ No ______
Flood?	Yes ______ No ______
Furrow?	Yes ______ No ______
Sprinkler?	Yes ______ No ______
Big gun?	Yes ______ No ______

D. Runoff and erosion control (see page 38)

Perennial sod crop	Yes ______ No ______
Reduced tillage	Yes ______ No ______
Contour farming	Yes ______ No ______
Terraces and diversions	Yes ______ No ______
Grassed waterways	Yes ______ No ______
Cross-slope drains	Yes ______ No ______
Other ________	Yes ______ No ______

II. Accuracy (see pages 35, 39)

A. Sources of data

Land Grant University fertilizer guides	Yes ______	No ______
Consultation with farmers	Yes ______	No ______
County Extension agent recommendations	Yes ______	No ______
Crop consultant recommendations	Yes ______	No ______
Other ______________________	Yes ______	No ______

B. Consistency of data

Are crop yields, fertilizer recommendations, and management practices typical for this area? Yes ______ No ______

Worksheet for Evaluating Issues and Interactions

I. Soil Surveys and Site Investigations (see pages 32-34)

A. Soil identification

Were soil surveys used in the planning stage to make preliminary determinations of the soils present? Yes ______ No _______

Were the data in the tables and map unit descriptions of soil surveys used as the basis for evaluating soil suitability for land application of biosolids? Yes ______ No _______

Were soil identifications made from soil maps verified by field investigations at the site? Yes ______ No _______

Were additional soils data obtained from soil pits dug at the site? Yes ______ No _______

B. Soil patterns

Were the inclusions in soil map units (pages 32-33) identified, their properties listed, and their limitations for land application accounted for? Yes ______ No _______

Were patterns of admixture of soils of different suitability classes recognized? Yes ______ No _______

Were plans made for managing sites in which more limiting soils are disbursed among more suitable soils? Yes ______ No _______

II. Nitrogen Issues and Interactions

A. Mineralization rate (see pages 5,11, 35-36, 44)

Was the determination of the mineralization rate made by a qualified professional? Yes ______ No _______

Did the determination of the mineralization rate account for effects of:

- method(s) of biosolids processing prior to application? Yes ______ No _______
- method of application? Yes ______ No _______
- timing of application? Yes ______ No _______
- climatic conditions? Yes ______ No _______

B. Agronomic Loading Rate (see pages 5-6, 20, 35-36, 41-45)

Did the calculation of the amount of biosolids to apply account for these losses:

- volatilization during processing? Yes ______ No _______
- volatilization during application? Yes ______ No _______
- denitrification in the soil? Yes ______ No _______

Did the calculation of the amount of biosolids to apply account for these fertilization factors?

- the type of crop? Yes ______ No _______
- the expected yield of the crop? Yes ______ No _______
- the farmer's usual management practices? Yes ______ No _______
- the timing of biosolids application in relation to mineralization rates and crop demands for N? Yes ______ No _______

the amount of fertilizer recommended? Yes _______ No _______

the estimated residual N in the soil?

from the previous crop? Yes _______ No _______

from crop residues? Yes _______ No _______

from prior biosolids applications? Yes _______ No _______

the amount of pre-plant commercial fertilizer used? Yes _______ No _______

the amount of mid-season commercial fertilizer used? Yes _______ No _______

III. Protection of Environmental Quality

A. Leaching to groundwater (see pages 11, 13, 17-23, 38)

Have plans been made to minimize the potential for transport of mobile constituents through the soil due to any of the following?

application on wet soils with high water tables Yes _______ No _______

application during periods of high rainfall Yes _______ No _______

heavy irrigation after biosolids application Yes _______ No _______

application on sandy or gravelly soils that have rapid or very rapid permeability, especially if irrigated Yes _______ No _______

B. Runoff and erosion (see pages 11, 13, 19-20, 38)

Have plans been made to minimize the potential for surface runoff that could transport biosolids to streams and lakes with respect to:

weather conditions in the area? Yes _______ No _______

applications on sloping soils during rainy seasons or after irrigation? Yes _______ No _______

applications on frozen soils? Yes _______ No _______

conservation practices on sloping soils? Yes _______ No _______

non-application buffer areas around upland waterways? Yes _______ No _______

IV. Mitigation of Limiting Soil Conditions (see pages 15, 27-32)

A. Have limiting properties of soils rated fair or poor been identified?

Yes _______ No _______

B. Have methods for dealing with soil limitations been specified?

Proper timing on soils with high water tables? Yes _______ No _______

Proper timing and application rates on soils with slowly permeable restrictive layers? Yes _______ No _______

Proper timing and application rates on soils with rapid or very rapid permeability? Yes _______ No _______

Proper timing and conservation practices on sloping soils? Yes _______ No _______

V. Protecting Public Health

A. Trace inorganics and organic contaminants (see pages 5-6, 47)

Have all loading rates for trace inorganics been calculated correctly? Yes ______ No ______

Has the allowable accumulation period been based on the most limiting loading rate? Yes ______ No ______

B. Pathogens and vector reduction (see pages 7-9)

Have all PSRP's and PFRP's and their effects on the pathogen content of the biosolids been identified? Yes ______ No ______

Have appropriate vector reduction treatments been completed? Yes ______ No ______

Have lag times between biosolids application and crop grazing or harvest taken into account the type of crop and its position in the food chain? Yes ______ No ______

Have steps been taken to restrict public access to the application site? Yes ______ No ______

C. Drinking water

Is it absolutely clear that the project will not contaminate drinking water supplies with nitrates, trace inorganics, organics, or pathogens? Yes ______ No ______

VI. Monitoring and Compliance

A. Monitoring (see page 39)

Are there plans for monitoring:

- Nitrates, trace inorganics, organics in ground water? Yes ______ No ______
- Nitrogen, phosphorus, and pathogens in surface water? Yes ______ No ______
- Accumulations of soil P and K? Yes ______ No ______

Have plans been made for careful, thorough record-keeping? Yes ______ No ______

B. Compliance (see pages 5-9, 15)

Does the plan conflict in any way with regulations affecting natural or man-made wetlands? Yes ______ No ______

Does the plan comply with all pertinent local, state, and federal regulations? Yes ______ No ______

Sources of Information

The following is a short list of available sources of helpful information on land application of domestic wastewater biosolids. These sources can direct you to more detailed sources if necessary.

Contacts

- Soil scientists, crop scientists and agronomists in Agricultural Experiment Stations and Extension Services at state Land Grant universities
- County Extension agents
- Natural Resources Conservation Service district conservationists
- Private crop, soil or agronomic consultants
- Field representatives of farm service companies
- Representatives of state environmental management agencies

Publications

Soils

County soil survey reports

Donahue, R L., R.W. Miller, and J.C. Shickluna, *Soils: An Introduction to Soils and Plant Growth*, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1983.

Harpstead, M.I. and F.D. Hole, *Soil Science Simplified,* Iowa State University Press, 1980.

Singer, M.J. and D.N. Munns, *Soils: An Introduction,* MacMillan Publishing Co., NY, 1987.

Stevenson, F.J., *Cycles of Soil: Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients,* John Wiley and Sons, New York, 1986.

Crop Management

State fertilizer guides

State soil sampling and testing brochures

Tisdale, S.L., W.L. Nelson, and J.D. Beaton, *Soil Fertility and Fertilizers,* MacMillan Publishing Co., NY, 1985.

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"Analytical Methods for the National Sewage Sludge Survey," EPA Office of Water Regulations and Standards WH-522, Industrial Technology Division, August 1988.

"Control of Pathogens and Vector Attraction in Sewage Sludge," *EPA-625/R-92-013*, December 1992.

"Controlling Pathogens in Municipal Wastewater Sludge for Land Application, Third Draft," Prepared by Eastern Research Group, Inc., Arlington, MA, for EPA Pathogen Equivalency Committee, November 1988.

Elliott, L.F. and F.J. Stevenson, eds., "Soils for Management of Organic Wastes and Wastewaters," American Society of Agronomy, Madison, WI, 1977.

"Guidance for Writing Case-by-Case Permit Requirements for Municipal Sludge," EPA Office of Water Enforcement and Permits, September 1988.

Journal of Environmental Quality, American Society of Agronomy, Madison, WI.

Logan, T.L and R.L.Cheney, "Utilization of Municipal Wastewater and Sludge on Land—Metals," *in* Page, A.L. ed., *Utilization of Municipal Wastewater and Sludge on Land,* Univ. California, Riverside, 1983.

"Process Design Manual for Land Application of Municipal Sludge," *EPA-625/1-83-016,* October 1983.

Runge, E.C A., K.W. Brown, B.L. Carlile, R.H. Miller, and E.M. Rutledge, eds., "Utilization, Treatment, and Disposal of Waste on Land," Soil Science Society of America, Madison, WI, 1985.

Sommers, L.E. and K.A. Barbarick, "Constraints to Land Application of Sewage Sludge," *in* Runge, E.C.A. et al, eds., *Utilization, Treatment, and Disposal of Waste on Land,* Soil Science Society of America, Madison, WI. 1985.

Standard Methods for the Examination of Water and Wastewater, 18th edition, American Public Health Association, Washington, DC, 1992.

State Extension and Agricultural Experiment Station publications on land application of sewage sludge.

Technical Support Document for Reduction of Pathogens and Vector Attraction in Sewage Sludge, EPA, 1992a.

Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. *EPA SW-846*, second edition, with Updates I and II, and third edition, with Revision I, 1982.

APPENDIXES

Technical Aspects of Soil Morphology

Field Determination of Soil Texture

Moisten the soil and knead it between your thumb and fingers. If the sample sticks to your fingers, it's too wet. Continue kneading it, or add a little dry soil, just until it is no longer sticky.

Estimate the amount of sand the soil contains by the grittiness of the sample. If there is more than 50% sand, the soil is coarse-textured (sandy loam, loamy sand, or sand). If there is between 20 and 50% sand, you'll notice the sand, but there's enough silt and clay present to give the sample good body. Loam and clay loam are the most likely textures. If there is less than 20% sand, you'll have difficulty feeling it, and the texture will be silt loam, silty clay loam, or clay.

Push the sample upward between your thumb and finger to form a ribbon. The longer the ribbon is, the more the clay. If the sample contains less than 27% clay, you can form only a short, broken ribbon. The textural name contains the word loam, but not clay. If the sample has 27 to 40% clay, you should get a ribbon 1 to 2½ inches long. Textural names contain both the words clay and loam. If the sample has more than 40% clay, you should get a long ribbon. The texture is either clay or silty clay.

If the soil contains coarse fragments, you may need to add the appropriate modifier to the textural class name. Estimate the volume of coarse fragments present by looking at the vertical face of exposed soil. The proportion of the area occupied by coarse fragments equates to the percent of coarse fragments in the soil. Select the correct modifier from Key 1 on page 60.

Field Evaluation of Soil Structure

Soil structure is described in terms of the grade, size, and shape of soil peds. Criteria for evaluating size and grade are given in Keys 2 and 3 on page 60. Shapes of soil peds are illustrated in figure 3, page 10.

Soil structure is determined in the field by observing both an undisturbed vertical cut and the way the soil breaks out into your hand. The easier it breaks out, the stronger the grade. Weak and moderate structures will not break out of the cut face into individual peds. You'll have a large mass of soil in your hand, and you need to gently break this mass apart by applying gentle pressure. If the soil breaks easily along a natural plane of weakness, that plane separates structural units. If the soil merely fractures, you don't have structure.

Continue breaking the soil apart until you can't subdivide it any further without fracturing it. Then observe the size and shape of the peds in your hand. The grade is determined according to the way the soil breaks out of the face, the ease with which it separates under gentle pressure, and the amount of unaggregated material left in your hand. Record your observations, such as moderate fine granular or weak medium subangular blocky.

Technical Method for Determining Soil Color

Technical descriptions of soil profiles use Munsell color notations to describe soil colors. Each color is characterized by its hue, value, and chroma. A symbol, such as 10YR 4/3, is used to record these color characteristics.

Hue represents the spectral wavelength of the color. A hue of 10R represents a pure red color. A hue of 10Y has a pure yellow color. In soils, a very common hue is 10YR, which represents a color exactly half way between pure red and pure yellow. Other common soil hues are 5YR (3 parts red and 1 part yellow) and 7.5YR (5 parts red and 3 parts yellow).

Value represents the amount of light reflected back to the eye. Value is measured on a scale of 0 to 10, from no reflection to complete reflection. Low numbers represent dark soil colors, as most of the incident light is absorbed. High numbers represent light colors, as most of the light is reflected. Common values for soil colors are 3 and 4, representing 30% and 40% of the light reflected. Value is shown in the color symbol as the numerator of the fraction that follows the hue.

Chroma represents the amount of dilution with white light. On a scale of 0 to 20, 20 represents the pure color, and 0 represents infinite dilution with white light. Chromas of soil colors range between 0 and 8 and are commonly between 1 and 4. The lower chromas are black or gray colors, whereas the higher chromas are the bright yellowish or reddish colors. Chroma is shown as the denominator of the fraction in the color symbol.

The Munsell Color Company makes small color chips for each combination of hue, value, and chroma. Chips of those colors that are most frequently found in soils are arranged in special books of soil color charts. To determine soil color in the field, match the color of a soil aggregate with a chip of the same color. Then record the corresponding symbol for that chip's hue, value, and chroma.

Key 1.—Coarse fragment modifiers of textural class names

% by vol.	Gravel 2mm-3 in.	Cobbles 3-10 in.	Channers 2mm-6 in.
<15	----------------no modifier-----------------		
15-35	Gravelly	Cobbly	Channery
35-60	Very grav.	Very cob.	Very chan.
>60	Extremely grav.	Extremely cob.	Extremely chan.

Key 2.—Size ranges for soil peds (all sizes are in millimeters)

	Granular, Platy	Blocky	Prismatic, Columnar
Very fine	0 - 1	0 - 5	0 - 10
Fine	1 - 2	5 - 10	10 - 20
Medium	2 - 5	10 - 20	20 - 50
Coarse	5 - 10	20 - 50	50 - 100
Very coarse	>10	>50	>100

Key 3.—Grades of soil structure

Strong	The soil mass is well divided into distinct, easily recognizable peds that are obvious on the face of a soil pit. When dug out of the pit face, the soil falls into your hands as distinct, stable peds that resist further breakdown. Little or no soil remains as unaggregated loose grains.
Moderate	Peds can be seen in a pit face, and they are easily detected when you gently break apart a mass of soil held in your hands. Grains of soil that are not part of any aggregate are apparent. Peds are stable against weak forces, but may break down under stronger pressure.
Weak	Peds are difficult to detect, even when you break soil apart in your hands. Many grains are not part of any aggregate. Peds easily break down when small forces are applied.
Structureless	The grade applied to massive and single grain soils.

Criteria for Describing Soil Mottles

Soil mottles are described in terms of their abundance, size, contrast, and color. These terms are defined below.

Abundance—the percentage of exposed surface area occupied by mottles:

Few—less than 2%
Common—2-20%
Many—more than 20%

Size—the approximate diameter of individual mottles:

Fine—< 5 mm
Medium—5-15 mm
Coarse—> 15 mm

Contrast—the relative difference between the mottle color and the matrix color:

Faint—Mottles are evident only upon close scrutiny. Mottle color and matrix color are nearly the same.
Distinct —Mottles are readily seen though not striking. Mottle color and matrix color are different, though not widely so.
Prominent—Mottles are so conspicuous that they are the outstanding visible feature of the horizon. Mottle color and matrix color are widely different.

Color—The hue, value, and chroma of the mottles, as described using a Munsell book of soil colors.

Horizon Definitions

Master Horizons. The six master horizons (O, A, E, B, C, R) are defined below.

O Horizon—The O stands for organic. O horizons don't have to be 100% organic material, but most are nearly so. Wet soils in bogs and swamps often have O horizons of peat and muck. Forest soils usually have thin, surficial O horizons that consist of leaves and twigs in various stages of decay.

A Horizon—This is the surface horizon of a mineral soil. Its unique characteristic is a dark color formed by the accumulation of organic matter. Granular or fine blocky structures are typical.

E horizon—E horizons have light gray or white colors. Where present, they usually occur immediately beneath an O or an A horizon. They are common in sandy soils that formed under coniferous forests and in medium to fine textured soils that formed under deciduous forests. They also occur immediately above very slowly permeable claypans or fragipans in situations that indicate wetness.

B horizon —B horizons are subsoil horizons of maximum alteration due to soil-forming processes. In some soils, the B has the brightest yellowish-brown or reddish brown color. In others, it has the best developed blocky or prismatic structure. Many B horizons are distinguished by accumulations of clay, iron and aluminum oxides, or carbonates.

C Horizon—The C horizon is weathered geologic material below the A or B horizon. Anything you can dig with a spade but that has not been changed very much by soil forming processes is considered a C horizon.

R Horizon—R stands for rock. It refers to hard bedrock that you cannot dig with a spade. Depending on the depth to bedrock, it may occur directly beneath any of the other master horizons.

Transition Horizons. Master horizons rarely change abruptly from one to another. In some cases, we can describe the nature of the transition as a characteristic of the boundary between two horizons. But if the transition zone is more than 5 inches thick, we usually describe it as a transition horizon.

AB Horizon —This horizon occurs between the A and the B. It's dominated by properties of the A, but some properties of the B are evident. Dark colors associated with organic matter are fading as organic matter decreases, and the structure often changes from granular to blocky.

BA Horizon—This horizon also occurs between the A and the B, but it's more like the B than the A. Structure is the same shape as in the B, but the grade is a little weaker. The color may be a little darker than the B, or the clay content may be a little less than the maximum in lower horizons.

BC Horizon—This is a transition from B to C. Properties of the B are dominant, but some influence of the C is evident. Often the clay content will be less than the maximum in the B, or the color will be fading. If the C is massive the BC has structure, but the peds are larger and the grade is weaker than in the B.

Special Kinds of A, B, and C Horizons. Many horizons are the result of unique processes that leave a distinct mark on the horizon. These horizons are identified with a lower case letter immediately following the master horizon symbol. There are over 25 such horizons. Only the more common ones are defined below.

Ap Horizon—This is the *plow* layer of the soil. Cultivation thoroughly mixes the upper 8 to 12 inches of soil and destroys any natural horizons that may have been present. Even if all of the original A horizon has been lost by erosion, plowing the exposed B or C horizon automatically makes the surface horizon an Ap.

Bt Horizon—This is a *textural* B horizon, or argillic horizon, formed by accumulation of silicate clays. Some of the clay comes from weathering of minerals within the Bt. Most of it comes from translocation of clay from horizons higher in the profile. Deposition of clay platelets on the surfaces of peds in the Bt creates waxy coatings called clay skins. Bt horizons are quite common, and they usually have moderate or strong blocky and prismatic structures.

Bg Horizon —This horizon is *gleyed.* The soil is so wet for so long that most of the iron is reduced and leached away. Gleyed horizons are gray, and they may or may not be mottled. Gleying is not restricted to the Bg. Other gleyed horizons include Ag, BAg, BCg, Cg.

Bk Horizon—This horizon is enriched with calcium *carbonate* leached from horizons above. It is common in soils of dry regions that receive limited rainfall. Usually you can see white streaks or nodules of lime, and the soil effervesces strongly when a drop of HCl is placed on it. Bk horizons contain more calcium carbonate than the C horizons beneath them.

Bkm Horizon—This horizon is called a *petrocalcic* horizon. It is enriched with calcium carbonate (k) and is strongly cemented (m). Petrocalcic horizons occur only in the southwestern United States in environments that have had enough moisture to leach carbonates part way down, but not entirely out of, the soil. Subsequently these carbonate deposits have crystallized to completely cement the horizon.

Bkqm Horizon—This horizon is called a *duripan.* It is enriched with calcium carbonate (k) and silica (q), and it is strongly cemented (m). Duripans are most common in soils that contain some volcanic ash in regions of limited rainfall that have distinct rainy and dry seasons. Lime and silica leached from the upper 10 to 20 inches are deposited in the Bkqm, cementing the soil grains so firmly that it's just like rock. The duripan is usually only 6 to 10 inches thick, but it is cemented so strongly that neither roots nor water can go through it.

Bs Horizon—This horizon is called a *spodic* horizon. It's common in sandy soils developed under coniferous vegetation in cool, moist climates. The leachate from the litter at the soil surface is very acid, causing iron, aluminum, and organic matter to be removed from upper horizons and deposited in the Bs horizon. The color is usually bright yellowish-brown or reddish-brown, and it fades with depth. Sometimes there is a thin black horizon at the top of the Bs, and often a white E horizon is above it.

Bw Horizon —This is a *weathered* horizon, also called a cambic horizon. It is altered enough to have structure, more intense color, or to have been leached, but it does not have enough accumulation of secondary minerals to be a Bt, Bs, or Bk horizon. Bw horizons are common in cool region mountain soils under high rainfall, in arid soils, and in relatively young soils.

Bx Horizon—This refers to a special feature called a *fragipan.* It is a massive, dense, but not cemented soil horizon. It is often mottled and has gray streaks of silt scattered throughout. The density is so high that neither roots nor water can penetrate effectively, except in some of the silt streaks.

Cr Horizon—Weathered bedrock, or rock that is soft enough to slice with a knife or a spade, is called Cr. It's rock material, and you can often see original rock structure, but it's not hard enough to be designated R.

Estimating AWHC

Calculation of AWHC from Soil Properties and Estimated Values

Steps in the procedure for calculating estimated AWHC are as follows:

1. Identify the horizons present in the soil profile.
2. Measure the thickness of each horizon.
3. Determine the depth to a root-limiting layer.
4. Determine the texture and the coarse fragment content for each horizon.
5. Find the AWHC rate that corresponds to the texture of each horizon (see Key 4).
6. Multiply AWHC x Depth x Percent fine earth for each horizon.
7. Total the products from Step 6 for all horizons within the depth of rooting (see Key 5).

Key 4.—AWHC rates

Sand, Loamy sand	.06 in./in.
Sandy loam	.12 in./in.
Clay, Silty clay, Sandy clay, Sandy clay loam	.15 in./in.
Loam, Silt loam, Clay loam, Silty clay loam	.20 in./in.

Key 5.—Sample calculations of AWHC

Horizon	Depth	Texture	% coarse fragments	AWHC		Thickness		Fraction fine earth		AWHC
A	0 - 12	Silt loam	0	.2	x	12	x	1.0	=	2.4
BA	12 - 20	Silt loam	0	.2	x	8	x	1.0	=	1.6
Bt	20 - 36	Silty clay loam	0	.2	x	16	x	1.0	=	3.2
BC	36 - 48	Silty clay loam	0	.2	x	12	x	1.0	=	2.4
C	48 - 60	Silt loam	0	.2	x	12	x	1.0	=	2.4
								Total soil AWHC	**=**	**12.0**
A	0 - 4	Loam	0	.2	x	4	x	1.0	=	0.8
BA	4 - 10	Clay loam	0	.2	x	6	x	1.0	=	1.2
Bw	10 - 18	Grav. clay loam	30	.2	x	8	x	.7	=	1.1
Bkqm	18 - 28	(Duripan)	100	---		---		---		0
Ck	28 - 40	Loam	10	---		---		---		0
								Total soil AWHC	**=**	**3.1**

Sample Clauses for Use in Permits

The following clauses are examples of the kind of information that can be included in permits. Underlined words or phrases indicate places where the permit writer needs to substitute information specific to a given application.

This permit is issued in accordance with an application submitted by the City of Central Point for Gary Jones (site owner) at Tax Lots 403 and 405, Sections 12 and 13, Township 24 S., Range 53 E., Missouri Meridian, dated March 17, 1990, and is subject to the following conditions:

1. This permit applies only to those areas (Fields 1 through 9) mapped by the USDA Natural Resources Conservation Service as belonging to the Hillsboro soil series (approximately 620 acres) highlighted on the site map submitted under that application.
2. Biosolids volatile solids shall be reduced by 38% or more by the anaerobic digestion process prior to land spreading.
3. Prior to land spreading, biosolids quality shall be assessed to determine percent total and volatile solids, nitrate nitrogen, ammonia nitrogen, TKN, phosphorus, potassium, and metals (arsenic, cadmium, copper, chromium, lead, mercury, nickel, and zinc).
4. Land spreading of biosolids shall be via pressurized distribution plate application.
5. Biosolids shall be transported by tank trailers equipped with valves adequate to prevent leakage. Each tank trailer shall have a current Department wastewater biosolids permit number posted at all times on the doors of the "motorized vehicle" as defined by United States Department of Transportation Regulations, Title 49, U.S.C.
6. Immediately following land spreading, biosolids tankers shall be cleaned on-site to prevent drag-out of biosolids onto public roadways.
7. Central Point's annual biosolids land spreading rates specifically delineated for each crop are indicated below. Application rates shall not exceed those indicated in Key 6.

Key 6.—Biosolids from lagoon

		Gallons per acre	Dry tons per acre	Limited by
Crop:	Dry wheat	21,760	3.4	Nitrogen, 40 lb/acre
	Dry barley	16,000	2.5	Nitrogen, 30 lb/acre
	Dry pasture	26,880	4.2	Nitrogen, 50 lb/acre
	Field corn*	107,820	16.8	Nitrogen, 200 lb/acre
	Irrigated pasture*	75,265	11.8	Nitrogen, 140 lb/acre
*Reclamation***		512,000	80	Organic matter, 3-4% added to the acre furrow slice

*To prevent runoff, biosolids land application would have to occur in four or more separate installments followed by a sufficient period of time to enable solids to dry between applications. In many instances, it may be more practical to grow field corn followed by a cover crop such as alfalfa or clover to decrease the need for biosolids nitrogen, or to supplement biosolids nitrogen with commercial fertilizer.

**Due to the high quantity of water associated with liquid biosolids, land application of lagoon solids at rates sufficient to supply 4% organic matter would be impractical unless solids were dewatered first.

8. Based on Central Point's biosolids analysis data, the Jones Site has an ultimate loading of 435 dry tons per acre. Copper is the pollutant which limits loading. Should future analyses show substantial changes in the characteristics of Central Point's biosolids pollutant content, the ultimate loading rate and allowable accumulation period may have to be adjusted.
9. No land spreading of biosolids shall occur within the 100 year flood plain of Eagle Creek.
10. A 100 foot (minimum) setback shall be maintained between Buckhorn Creek and the nearest point of biosolids land application.
11. A 50 foot (minimum) setback shall be maintained from all seasonal streams and points of biosolids land application.
12. A 300 foot (minimum) setback shall be maintained between the Crestline Recreation Trail and the nearest point of biosolids land application.
13. A 600 foot (minimum) setback shall be maintained between areas of biosolids land application and the Oak Grove Elementary School.
14. No land spreading of biosolids shall occur within 100 feet of the shoreline of the Beaver Flat Marsh.
15. No land spreading of biosolids shall occur in areas where slopes exceed 20%.
16. Land spreading of biosolids shall cease when precipitation exceeds 1/4 inch per hour.
17. Depth to groundwater shall be measured from Piezometers 1, 2, 3, and 4 in Fields 4, 8 and 9 prior to land spreading of biosolids. No biosolids shall be applied when permanent groundwater is within 4 feet of ground surface.
18. Application of biosolids is not permitted from November 15 to April 15 due to frozen soil conditions.
19. No land spreading of biosolids shall occur on the site annually between November 1 and April 15 without separate case-by-case written authorization from the Department.
20. Areas where biosolids have been applied shall be clearly marked by flag pins or stakes noting the date of application immediately following application.
21. No food crops (for direct human consumption) whose harvested parts are grown below ground shall be planted on any biosolids-amended field for at least 38 months following land spreading of biosolids.
22. No food chain crops for direct human consumption whose harvested parts are grown above ground (e.g., tomatoes) shall be grown on fields authorized to receive biosolids for at least 14 months following land spreading of biosolids.
23. The western perimeter of the biosolids land application site shall be posted by signs at 150 foot (maximum) intervals and enclosed by a fence. Access to the biosolids land spreading area shall be via locked gate.
24. Public access to the site shall be restricted for at least 12 months after land spreading of biosolids has ceased.
25. There shall be no storage or stockpiling of wastewater biosolids at the Jones Site without separate written authorization from the Department.
26. In the event an odor problem is reported to the Department after biosolids have been spread on land at the Jones Site, immediate steps, such as, but not limited to, the addition of liming materials, must be taken to counteract that condition.
27. Central Point WWTP shall keep site records adequate to quantify the date, location and amount of biosolids applied, segments of each field that received biosolids, pounds of arsenic, cadmium, copper, chromium, lead, mercury, nickel, and zinc applied to each segment receiving biosolids, and the type of crop grown. These data shall be submitted to the Department on a monthly basis through the life of the permit.

28. The Department shall have the right to, at reasonable times, and upon presentation of credentials: enter Central Point WWTP's place of recordkeeping to review biosolids management operations and records; have access to and obtain copies of any records required to be kept under the terms of this permit; inspect any monitoring equipment required under this permit; inspect any collection, transport, or land spreading vehicles acknowledged under Central Point's biosolids management plan; sample any ground or surface water, soils, or vegetation from the Jones Site and obtain any photographic documentation or evidence deemed appropriate.
29. The Department shall be notified within one hour of any spills or other threats to the environment that may occur as a result of biosolids handling. Failure to provide notification within one hour may be considered cause for taking enforcement action against Central Point. Spills that occur after normal working hours shall be reported to the Emergency Management Division (EMD) within one hour. The telephone number for EMD is 1-800-452-1103.
30. The Department may impose any additional restrictions or conditions deemed necessary to assure adequate biosolids management. Any variations from the approved biosolids application plan for the Jones Site must be approved in writing in advance by the Department.
31. This permit is subject to revocation should health hazards, environmental degradation, or nuisance conditions develop as a result of inadequate biosolids treatment or site management. If operations are not conducted in accordance with terms specified under this permit, the Department shall initiate necessary remedial action.

GLOSSARY

Absorption
Filling up of soil pores with water, much as a sponge soaks up water.

Adsorption
Retention of water in soil by attraction between water molecules and the surfaces of soil particles. Also, retention of cations in soil by attraction between their positive charges and the negatively charged surfaces of clay and organic matter particles.

Aeration
The movement of air back and forth between the atmosphere and the pores of a soil. See **Well-aerated soil.**

Aerobic
Having oxygen gas as part of the environment, or occurring only in the presence of oxygen gas.

Aerobic digestion
The biochemical decomposition of organic matter in domestic wastewater biosolids into carbon dioxide and water by microorganisms in the presence of air.

Agricultural land
Land on which a food crop, a feed crop, or a fiber crop is grown. This includes range land and land used as pasture.

Agronomic loading rate
The amount of biosolids that would need to be applied to a site in order to supply the recommended amount of nitrogen or phosphorus for a growing crop.

Agronomic rate
The whole sludge application rate, on a dry weight basis, that is designed to 1) provide the amount of nitrogen needed by the food crop, feed crop, fiber crop, cover crop, or vegetation grown on the land; and 2) minimize the amount of nitrogen in the wastewater biosolids that passes below the root zone of the crop or the vegetation grown on the land to the groundwater.

Allowable accumulation period
The number of years that biosolids can be applied on a particular site. The allowable accumulation period depends on the amount of inorganic pollutants contained in the biosolids and the amount of biosolids applied each year.

Anaerobic digestion
The biochemical decomposition of organic matter in domestic wastewater biosolids into methane gas and carbon dioxide by microorganisms in the absence of air.

Annual pollutant loading rate
The maximum amount of a pollutant that can be applied to a unit area of land during a 365-day period.

Annual whole sludge application rate
The maximum amount of wastewater biosolids, on a dry weight basis, that can be applied to a unit area of land during a 365-day period.

AWHC
Available Water Holding Capacity. The maximum amount of water a soil can store for plant use. A good soil can provide 9 to 12 inches of available water. A poor soil might provide only 2 or 3 inches of available water.

Beneficial use
Taking advantage of the nutrient content and soil conditioning properties of a biosolids product to supply some or all of the fertilizer needs of an agronomic crop or stabilizing vegetative cover.

Biosolids
Solids derived from primary, secondary, or advanced treatment of domestic wastewater which have been treated through one or more controlled processes that significantly reduce pathogens and reduce volatile solids or chemically stabilize solids to the extent that they do not attract vectors. This term refers to domestic wastewater treatment facility solids that have undergone adequate treatment to permit their land application.

Biosolids derived products
Materials derived from composting domestic wastewater treatment facility solids or other processes, such as thermal drying, which result in a material that meets pollutant concentrations in 503.13(b)(3), the Class A pathogen requirements in 503.32(a), and one of the vector attraction reduction requirements in 503.33(b)(1) to 503.33(b)(8). Biosolids derived products also include any soil amendments which, in part, contain biosolids meeting these criteria. Biosolids derived products are acceptable for distribution to the general public for immediate use.

Bulk wastewater biosolids
Domestic wastewater biosolids that are not sold or given away in a bag or other container for application to the land.

Cation
A positively charged ion in the soil solution.

CEC
Cation Exchange Capacity. The amount of positively charged cations such as calcium, potassium, copper, and nickel that can be retained in the soil by attraction to the negatively charged surfaces of soil clays and organic matter. CEC is expressed in terms of milliequivalents per 100 grams of soil.

Channers
Small, flat, oblong coarse fragments in soils, ranging in length of the longest dimension from 2 mm to 6 inches.

Claypan
A restrictive layer that consists of a horizon of clayey soil that is dense and massive, but not cemented. Claypans usually lie directly beneath a horizon of medium-textured soil, and the change from that horizon to the claypan is abrupt.

Coarse fragments
Rock fragments larger than 2 mm in diameter. Gravel, cobbles, and channers are the most common kinds of coarse fragments in soils.

Coarse-grained materials
Soils that consist of loamy sand or sand textures and often contain large amounts of gravel or cobbles. These soils have high rates of saturated hydraulic conductivity and rapid or very rapid permeability.

Coarse-textured soil
A soil whose texture is sand or loamy sand.

Cobbles
Large, rounded coarse fragments in soils, ranging in diameter from 3 to 10 inches.

Contour cropping
Planting crops in rows that run across slopes and around hills, rather than up and down slopes. Contour crop rows slow down runoff and help conserve soil.

Cover crop
A small grain crop, such as oats, wheat, or barley, not grown for harvest.

Crop rotation
The sequence of crops grown on a field over a number of years. Crop rotation cycles may run from as few as 3 years to as many as 9 or 10 years.

Cross-slope farming
See **Contour cropping.**

Cumulative pollutant loading rate
The maximum amount of an inorganic pollutant that can be applied to an area of land.

Deep soil
Soil that is more than 40 inches deep to hard bedrock (R horizon), soft or weathered bedrock (Cr horizon), or a cemented horizon such as a duripan (Bkqm horizon) or petrocalcic (Bkm) horizon.

Denitrification
Loss of nitrogen from soil by conversion of nitrate (NO_3^-) to nitrogen gas (N_2). Denitrification occurs when parts of the soil become reduced by exclusion of oxygen, either under saturated or near-saturated conditions, or as oxygen demand is created during decomposition.

Diversion terrace
A raised berm of earth constructed horizontally across a slope in order to intercept runoff and divert it laterally to a grassed waterway that can conduct the water safely downslope without eroding the soil.

Domestic wastewater biosolids
Solid, semisolid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Wastewater biosolids include, but are not limited to, domestic septage; scum or solids removed in primary, secondary, or advanced wastewater treatment processes; and a material derived from wastewater biosolids. Wastewater biosolids do not include ash generated during the firing of biosolids in an incinerator, or grit and screening generated during preliminary treatment of domestic wastewater biosolids in a treatment works.

Domestic wastewater treatment facility solids
The accumulated suspended and settleable solids of domestic wastewater, deposited in tanks or basins mixed with water to form a semiliquid mass.

Drainage class
The degree of wetness of a soil, as determined by the depth to a water table and the length of time the soil remains saturated. Common drainage classes include excessively drained, well drained, moderately well drained, somewhat poorly drained, and poorly drained.

Droughty
Incapable of storing much water in the soil for plant use. Sandy soils, shallow soils, and sloping soils on southerly aspects are likely to be droughty unless they are resupplied with rainfall or irrigation water at short intervals.

Dry weight basis
Calculated on the basis of having been dried at 105°C until reaching a constant mass (i.e., essentially 100% solids content)

Duripan
A restrictive layer, also denoted as a Bkqm horizon, that is so thoroughly cemented with silica, with or without calcium carbonate, that it resembles a layer of rock in the soil.

Exempt biosolids
Domestic wastewater treatment facility solids containing trace pollutant concentrations that are below federal alternative pollutant limits recognized under 503.13(b)(3) that have been treated by a Class A pathogen reduction process recognized under 503.32(a) and one of the vector attraction reduction procedures established under 503.33(b)(1) to (8). These solids are recognized as soil amendments that are acceptable for distribution and marketing to the public.

Equivalent
The number of grams of any particular chemical (calcium, copper, potassium) that is equal in reacting power to 1 gram of hydrogen.

Feed crops
Crops produced primarily for consumption by animals.

Fiber crops
Crops such as flax and cotton.

Field capacity
The moisture content of a soil when free drainage immediately after a rain or an irrigation has virtually ceased. It represents the maximum amount of water a soil can retain against the force of gravity.

Fine earth
All soil material that is smaller than 2 mm in diameter. Fine earth includes sand (.05-2.0 mm), silt (.002-.05 mm), and clay (<.002 mm).

Fine-textured soil
A soil whose texture is silty clay, sandy clay, or clay.

Floodplain
The nearly level surface next to a river that is covered with water when the river floods.

Food crops
Crops consumed by humans. These include, but are not limited to, fruits, vegetables, and tobacco.

Fragipan
A restrictive layer, also denoted as a Bx horizon, that is extremely dense and compact but is not cemented and is not very high in clay content.

Glacial till
An unstratified, heterogeneous mixture of sand, silt, clay, coarse fragments, rocks and boulders that was deposited at the margins and beneath the ice of continental or alpine glaciers.

Gleyed
Soil that is very wet for long periods of time and is characterized by gray colors, with or without mottles.

Gravel
Small, rounded coarse fragments in soils, ranging in diameter from 2 mm to 3 inches.

Gravitational water
Water that fills large pores when soil is saturated and drains away freely under the influence of gravity. Gravitational water is not available for plant use.

Groundwater
Water below the land surface in the saturated zone.

Hardpan
A generic term for a very dense or cemented layer in soils. Very dense "hardpans" include fragipans, claypans, tillage pans, and compacted layers. Cemented "hardpans" include duripans and petrocalcic horizons.

Heavy texture
A general term that refers to soils that have a high clay content. The higher the clay content, the "heavier" the soil. Clays, silty clays, and some silty clay loams would all be considered heavy soils.

Humus
The relatively resistant fraction of soil organic matter that forms during biological decomposition of organic residues. Humus usually constitutes the major fraction of soil organic matter.

Hydraulic conductivity
A quantitative measure of the rate of water movement through soil. The most common laboratory measurement determines the rate of saturated flow in a vertical direction. Classes of vertical, saturated hydraulic conductivity are empirically related to classes of soil permeability.

Immobilization
Conversion of an element from the inorganic form to the organic form by microbes. Immobilized elements are not readily available for uptake by plants. Nitrogen and phosphorus are common elements immobilized in this way.

Inclusion
An area of soil that is too small to show separately on a soil map at the scale at which the map is being made. Inclusions are present only because of limitations of the scale of mapping, and they are normal parts of the definition of map units. Inclusions can be mapped separately only by making very detailed maps at very large scales.

Infiltration
The rate that water *enters* the soil. Infiltration depends on the size of pores and the stability of soil aggregates right at the soil surface. If water cannot infiltrate, then it either ponds on the surface or runs off over the surface.

Inorganic nitrogen
Nitrogen that is in the ammonium (NH_4^+) or nitrate (NO_3^-) form, either in biosolids or in the soil.

Internal drainage
The ability of free water to escape from a soil. Internal drainage is characterized by the depth to and duration of water tables in soils and classified in terms of drainage classes.

Internal drainage class
See **Drainage class.**

Lacustrine
A term that refers to sediments that were originally deposited at the bottom of a lake and are now exposed due to uplift of the land or lowering of the water level.

Land application
The spraying or spreading of domestic wastewater biosolids onto the land surface; the injection of domestic wastewater biosolids below the land surface; or the incorporation of domestic wastewater biosolids into the soil so that the biosolids can either condition the soil or fertilize crops or vegetation grown in the soil, or both.

Leaching
Removal of soluble minerals, nutrients, organic chemicals and pesticides from the soil by water passing through the soil.

Legume
A crop that forms a specific association with soil bacteria that are capable of fixing nitrogen, that is, transforming nitrogen gas to organically combined nitrogen. Common legumes include alfalfa, clovers, peas, and soybeans. Nitrogen fixation can provide most of the nitrogen nutrition of the legume crop, and it can provide large amounts of residual nitrogen for succeeding crops.

Light texture
A general term that refers to soils that have a very low clay content. The lower the clay content, the "lighter" the soil. Loamy sands, sandy loams, and some loams all would be considered light soils.

Loam
A specific class of soil texture that contains a balanced mixture of sand, silt, and clay. Generally the sand content is between 30 and 50%, the silt content is between 30 and 50%, and the clay content is between 10 and 27%.

Lodging
A process whereby cereal grains, upon taking up excess amounts of nitrogen, put on excess vegetative growth, lose strength in the stems, and tip over. Lodging reduces grain yields because grain lying flat is difficult to combine.

Map unit
A collection of all soil-landscape areas shown on a soil map that have the same name and the same kind or kinds of soils. Map units contain one or two dominant soils, plus small areas of other kinds of soils of minor extent. Map unit names identify the dominant soil or soils. The minor components collectively are called inclusions, and they are identified in the map unit description.

Map unit description
The part of the text of a soil survey report that describes the characteristics of the soil and landscape of the dominant soils in a map unit. The map unit description also tells the kind and amount of the inclusions in the map unit, and it gives general information on use and management of the map unit for agriculture, forestry, and urban development.

Matrix color
The dominant color in a variegated or mottled soil. The color that occupies a greater percentage of the exposed surface area than any other color.

Medium-textured soil
A soil whose texture is loam or silt loam.

Milliequivalent
One one-thousandth of an equivalent. In soil science milliequivalents are used to quantify the capacity of a soil to adsorb positively charged ions independently of the particular kind of substance.

Mineralization
Biochemical conversion of nitrogen in the organic matter of soils and biosolids to inorganic nitrogen. Mineralization produces nitrogen in the ammonium (NH_4^+) form, which is then converted to the nitrate (NO_3^-) form by the nitrification process.

Minimum tillage
Preparation of a seedbed for planting a crop without conventional moldboard plowing. Tillage operations range from disking or chisel plowing the soil before planting to planting directly into soil that has not been tilled since the harvest of the previous crop. Minimum tillage usually leaves enough plant residues on the soil surface to provide a measure of erosion protection.

Moderately coarse-textured soil
A soil whose texture is sandy loam.

Moderately deep soil
Soil that is 20 to 40 inches deep to hard bedrock (R horizon), soft or weathered bedrock (Cr horizon), or a cemented horizon such as a duripan (Bkqm horizon) or petrocalcic (Bkm) horizon.

Moderately fine-textured soil
A soil whose texture is silty clay loam, clay loam, or sandy clay loam.

Moderately well drained
A soil that has a temporary water table for short periods of time in the lower part of the subsoil. The soil is usually mottled somewhere between 24 and 40 inches.

Montmorillonite
A type of soil clay that has a very high shrink-swell potential.

NH_4-N
The amount of nitrogen in the ammonium form. Each 100 pounds of ammonium-nitrogen contains 78 pounds of actual nitrogen.

Nitrification
The biological conversion of ammonium (NH_4^+) to nitrate (NO_3^-) in soil. As the nitrogen cycle operates in most soils, the nitrification step follows the mineralization step, in which organic nitrogen is converted to ammonium (NH_4^+).

NO_3-N
The amount of nitrogen in the nitrate form. Each 100 pounds of nitrate nitrogen contains 22 1/2 pounds of actual nitrogen.

Nutrient-supplying power
The ability of a soil to provide nutrients in amounts needed for plant growth. Medium-textured soils that are high in organic matter generally have a high nutrient-supplying power. Sandy soils that are low in organic matter generally have a low nutrient-supplying power.

Organic nitrogen
Nitrogen that is combined in the molecular structure of organic compounds. Most of the organic nitrogen in soils occurs as proteins and amino acids or amine groups.

Pasture
Land on which animals feed directly on feed crops such as legumes, grasses, grain stubble, or stover.

Pathogenic organisms
Disease-causing organisms. These include, but are not limited to, certain bacteria, protozoa, viruses, and viable helminth ova.

Ped
An aggregate of individual grains of sand, silt, and clay into a single unit of soil structure. Ped shapes include granular, platy, blocky, and prismatic. Ped sizes may vary from 1-mm granules to 40-cm prisms.

Permeability
The rate that water moves *through* the soil. Permeability depends on the amount, size, and interconnectedness of soil pores. These in turn are related to soil texture, soil structure, and soil density.

Petrocalcic horizon
A restrictive layer, also denoted as a Bkm horizon, that is enriched with calcium carbonate, and in which the calcium carbonate has cemented the horizon into a rocklike layer.

pH
A number that indicates the relative acidity or alkalinity of a soil. A pH of 7.0 indicates a neutral soil. Lower numbers indicate acid soils; higher numbers indicate alkaline soils.

Pollutant
An organic substance, an inorganic substance, a combination of organic and inorganic substances, or a pathogenic organism that, after discharge and upon exposure, ingestion, inhalation, or assimilation into an organism either directly

from the environment or indirectly by ingestion through the food chain, could, on the basis of information available to the Administrator of EPA, cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunction in reproduction), or physical deformations in either organisms or offspring of the organisms.

Pollutant limit

A numerical value that describes the amount of a pollutant allowed per unit amount of biosolids (e.g., milligrams per kilogram of total solids); the amount of a pollutant that can be applied to a unit area of land (e.g., kilograms per hectare); or the volume of a material that can be applied to a unit area of land (e.g., gallons per acre).

Poorly aerated

Soils in which air is not readily exchanged between the soil and the atmosphere. Wet soils are poorly aerated because air moves more slowly through water than through air-filled pores.

Poorly drained

A soil that is saturated at or near the surface for long periods of time. Poorly drained soils are usually gleyed, and they often have mottles in the A or Ap horizon.

Pores

Spaces, or voids, between mineral grains and aggregates in the soil. The amount, size, shape, and continuity of soil pores control the rates of air and water movement into and throughout the soil.

Public contact site

Land with a high potential for contact by the public. This includes, but is not limited to, public parks, ball fields, cemeteries, plant nurseries, turf farms, and golf courses.

Puddling

Formation of a dense, massive surface soil when medium- to fine-textured soils are tilled when they are too wet.

Range land

Open land with indigenous vegetation

Readily available nitrogen

Nitrogen that is in the soil in the ammonium (NH_4^+) or nitrate (NO_3^-) form. Ammonium and nitrate are dissolved in the soil solution and can be taken up and utilized by plants immediately.

Reclamation site

Drastically disturbed land that is reclaimed using domestic wastewater biosolids. This includes, but is not limited to, strip mines and construction sites.

Reduced tillage

See **Minimum tillage.**

Residual nitrogen

Nitrogen that remains in the soil after the harvest of a crop. Residual nitrogen is either immediately available or will become available to the succeeding crop. Sources of residual nitrogen include inorganic nitrate that is not leached from the soil, organic nitrogen in crop residues, and organic nitrogen in previous biosolids applications.

Restrictive layer

A general term for any soil horizon that is slowly or very slowly permeable and underlies more permeable soil horizons. Restrictive layers slow down or stop the downward movement of water in soils, and they impede plant root penetration.

Runoff

Water that flows over the surface of soil toward a stream or lake without sinking into the soil.

Saturated flow

Movement of water in soil when all the pores are completely full of water, that is, when the soil is saturated. Rates of saturated flow through large pores are relatively rapid, and the potential for contamination of groundwater with water-borne pollutants is high.

Shallow soil

Soil that is less than 20 inches deep to hard bedrock (R horizon), soft or weathered bedrock (Cr horizon), or a cemented horizon such as a duripan (Bkqm horizon) or petrocalcic (Bkm) horizon.

Shrink-swell potential

The tendency of a soil to change volume due to gain or loss of moisture. Soils with high shrink-swell potentials expand appreciably when they wet up and contract appreciably when they dry out.

Slaking

The breakdown of structural aggregates under the impact of falling droplets of water. Grains of silt and clay washed off peds clog soil pores, creating a thin surface crust that seals the soil, reduces infiltration, and increases runoff and erosion. Silty soils that are low in organic matter and have weak structure are particularly susceptible to slaking.

Slickensides

Polished, shiny surfaces on clayey soil aggregates, caused by the movement of two masses of soil past each other as soil expands upon wetting. Slickensides are evidence of high shrink-swell potential in soils that contain large amounts of montmorillonite clays.

Soil

A natural body that develops in profile form in response to forces of climate and organisms acting on a parent material in a specific landscape position over a long period of time. Soil covers the earth in a thin layer and supplies plants with air, water, nutrients, and mechanical support.

Soil amendment

Anything that is added to the soil to improve its physical or chemical condition for plant growth. Lime, gypsum, inorganic fertilizers, and organic materials, including wastewater biosolids, are all soil amendments.

Soil conditioner

Any material applied to improve aggregation and stability of structural soil aggregates. Domestic wastewater biosolids provide these benefits, and are therefore soil conditioners.

Soil drainage class

The degree of wetness of a soil, as determined by the depth to a water table in the soil and the length of time the soil remains saturated. Common drainage classes include excessively drained, well drained, moderately well drained, somewhat poorly drained, and poorly drained.

Soil horizon

A layer of soil that is approximately parallel to the earth's surface. Each horizon results from specific soil-forming processes, and each is distinguished from horizons above and below by a unique set of physical, chemical, and biological properties.

Soil profile

A vertical exposure that allows you to see all of the soil horizons that are present.

Soil profile description

A technical record of the soil properties that can be observed and measured in the field for each and every horizon in the entire soil profile.

Soil series

The set of all soils whose profiles are essentially alike, within narrowly defined ranges of variability. The soil series is the lowest unit of soil classification. Names of soil series are usually taken from geographic entities in areas where the soil was first described, for example, the Appling Series, the Tama Series, the Willamette Series.

Soil slope

The inclination of the land surface, expressed as percent. A 10% slope means that the elevation changes by 10 feet for every 100 feet of horizontal distance.

Soil structure

The arrangement of individual grains of sand, silt, and clay into larger units called aggregates, or peds. Plant roots, humus, and soil clays all help to hold soil peds together. Soil structure is characterized by the size, shape, and strength of the peds.

Soil survey

The process by which a soil map is made. Soil scientists walk over the land, observe soil and landscape properties, classify the soils, and locate soil boundaries in the field. They use air photo base maps to record the location of soil boundaries and label each delineation with a map unit symbol.

Soil survey report

A book in which the results of the soil survey of an area, often a county, are published. The soil survey report contains three related components: the soil maps, text that describes the properties and behavior of the soils and map units, and tables that give quantitative data and interpretations for soil use and management.

Soil texture

The amounts of sand, silt, and clay that make up a soil. Specific combinations of sand, silt, and clay form textural classes, each of which is named with a term such as silt loam, clay loam, or sandy loam.

Somewhat poorly drained

A soil that is saturated in the upper part of the subsoil for significant periods of time during rainy seasons. The soil is usually gray and mottled somewhere between 10 and 24 inches.

Starter fertilizer

Fertilizer applied to the soil at the time a crop is planted to provide a source of nutrients that will be readily available at the time the plants are beginning to grow vigorously. Starter fertilizers bridge the gap between planting and subsequent availability of nutrients from mineralization of organic matter.

Terrace
A landform consisting of a long, narrow, nearly level surface at or near the margin and above the level of a body of water. Stream terraces are above the level of the stream's floodplain, and they are usually marked by an escarpment that descends from the terrace to the floodplain.

Terracing
Construction of one or more diversion terraces across a slope.

Tillage pan
A compact, dense layer of soil at the base of the surface layer of a cultivated soil. Compaction occurs when the soil is plowed or disked when it is too wet.

Total solids
The materials in domestic wastewater biosolids that remain as residue when the biosolids are dried at 103 to 105°C.

Traffic pan
A compacted layer beneath the surface layer of a cultivated soil that occurs as the result of the cumulative effects over time of driving over the soil with heavy equipment.

Treatment of wastewater biosolids
The preparation of wastewater biosolids for final use or disposal. This includes, but is not limited to, thickening, stabilization, and dewatering. It does not include storage of biosolids.

Unsaturated flow
Movement of water through soil when some soil pores, particularly the larger ones, are filled with air. Unsaturated flow occurs as water moves through films of water around soil particles in response to an energy gradient from moist soil to dry soil. Rates of unsaturated flow are very slow.

Unstabilized solids
Organic materials in domestic wastewater biosolids that have not been treated in either an aerobic or an anaerobic treatment process.

Vector attraction
The characteristic of domestic wastewater biosolids that attracts rodents, flies, mosquitoes, or other organisms capable of transporting infectious agents.

Volatile solids
The amount of the total solids in domestic wastewater biosolids lost when the biosolids are combusted at 550°C in the presence of excess air.

Volatilization
Conversion of ammonium (NH_4^+) in the soil to ammonia gas (NH_3) and escape of ammonia into the atmosphere.

Water table
The top of a zone of saturated soil. Water tables in soils are classed as perched, apparent, or artesian. A perched water table refers to a zone of saturation that is underlain by unsaturated soil. Perched water tables are associated with restrictive layers. An apparent water table refers to a thick zone of saturated soil in which there is no evidence of restrictive layers. An artesian water table refers to water under pressure that is trapped beneath an impermeable layer. The water table rises when the impermeable layer is breached.

Weathering
The physical disintegration and chemical decomposition of rocks in place upon exposure to the atmosphere. Weathering produces earthy material that, upon further modification by chemical and biological processes, is transformed into soil.

Well-aerated
Soil that allows easy exchange of air between the soil and the atmosphere. Well-aerated soils have plenty of pores that are big enough and sufficiently interconnected to provide pathways for air movement. They usually have good structure and are well or moderately well drained.

Well drained
A soil that is rarely saturated above a depth of 40 inches. Well drained soils are well-aerated and have brown, yellowish brown, or reddish brown colors. They are not mottled above 40 inches or so.

Wetlands
Those areas that are inundated or saturated by surface water or ground water at a frequency and duration to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

Wilting point
The moisture content of a soil at which a plant can no longer extract water. Without addition of water, plants will wilt and ultimately die. Some soils, particularly clayey soils, contain relatively large amounts of water at the wilting point, but it is held so tightly in the very small pores of the clays that plants can't use it.

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