Chapter 1

Biosolids Management Practices and Regulatory Requirements

1.0 Introduction

In 1948, the U.S. Congress enacted the original Federal Water Pollution Control Act (FWPCA). Since its passage, the FWPCA has been amended many times. Two of the most important amendments were (1) the 1972 FWPCA Amendments and (2) the 1977 Clean Water Act Amendments [10]. These amendments define the basic national framework for water quality and water pollution control in the United States. Today, the comprehensive federal law is simply referred to as the U.S. Clean Water Act (CWA).

The primary objective of the CWA is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. To prevent contamination and deterioration of water quality, wastewater from industrial, commercial, and residential activities is treated at wastewater treatment plants (WWTPs) before it is discharged to surface water or groundwater (Fig. 1.1).

At present, there are more than 15,000 municipal wastewater treatment plants or publicly owned treatment works (POTWs) in the United States that process over 34 billion gallons of domestic sewage and other wastewater each day [21]. Sewage sludge represents the largest source of residual solids generated during the treatment of municipal wastewater by POTWs as well as by privately and federally

Figure 1.1 Aerial view of typical municipal wastewater treatment plant (WWTP). (*Courtesy of Waterlink, Inc.*)

owned wastewater treatment works. The annual amount of sewage sludge (i.e., biosolids) generated during the treatment of domestic sewage is estimated at approximately 47 pounds for every individual in the United States. Figure 1.2 illustrates the collection and treatment of domestic and industrial wastewater resulting in the production, treatment, use, and disposal of sewage sludge.

In the United States, the use or disposal of sewage sludge has been regulated under various federal environmental statutes. Land disposal and reuse of sewage sludge were regulated initially under the solid waste disposal regulations of 40 Code of Federal Regulations (CFR) Part 257, which was jointly promulgated under the 1976 Resource Conservation and Recovery Act (RCRA) and Sections 405 and 307 of the 1977 CWA Amendments. RCRA (PL 94-580) required that solid wastes be used or disposed in a safe and environmentally acceptable manner. Sewage sludge was included by definition in the RCRA provisions relating to solid waste management. The 1977 CWA Amendments (PL 95-217) contained two major provisions affecting sewage sludge use and disposal. First, Section 405 of the 1977 CWA Amendments required that the U.S. Environmental Protection Agency (USEPA) issue guidelines and regulations for the disposal and reuse of sewage sludge. Second, Section 307 of the CWA Amendments required pretreatment of industrial wastes if such wastes, when discharged

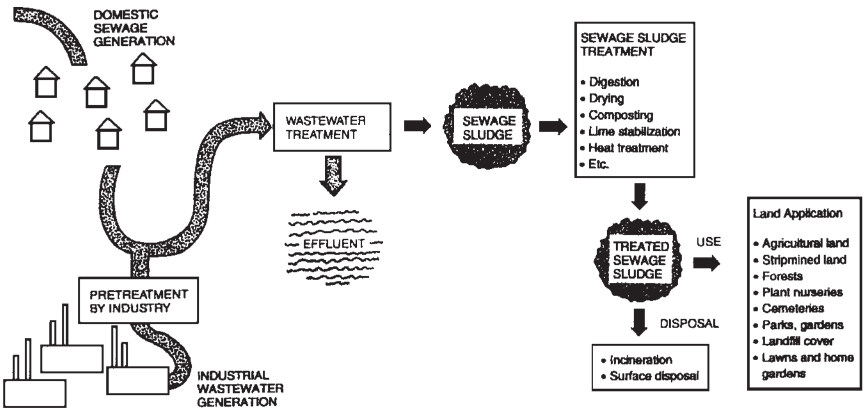

Figure 1.2 Schematic illustration of the generation, treatment, use, and disposal of sewage sludge.

into municipal sewage collection systems, inhibited wastewater treatment or the beneficial use of sewage sludge. In addition to RCRA and the CWA Amendments, the 1972 Marine Protection, Research and Sanctuaries Act (MPRSA) regulated the discharging of sewage sludge to oceans and estuaries until the Ocean Dumping Ban Act of 1988 prohibited this disposal practice [10].

In 1987, Section 405(d) of the CWA was amended to require the USEPA to establish sewage sludge pollutant standards that adequately protected public health and the environment from any reasonably anticipated adverse effects of pollutants in sewage sludge that is used or disposed [21]. These regulations were to include identification of the various beneficial uses for sludge while specifying factors to be taken into account in developing management practices for each type of reuse or disposal option. The 1987 CWA Amendments also required that any CWA Section 402 (National Pollutant Discharge Elimination System, NPDES) permit include sewage sludge use or disposal standards unless these requirements were included in another permit. The 1987 CWA Amendments expanded the regulated universe to include all treatment works treating domestic sewage (TWTDS), even those not requiring an NPDES permit. TWTDS include all sewage sludge or wastewater treatment systems used to store, treat, recycle, and reclaim municipal or domestic sewage.

In summary, to maintain regulatory compliance with the CWA requirements, POTWs must adopt and implement federally mandated procedures ensuring the proper treatment, use, and disposal of sewage sludge. Furthermore, as a result of Section 405 of the 1977 and 1987 CWA Amendments, increased use of sewage sludge recycling has become a clear objective of U.S. environmental policy.

1.0.1 Summary statistics for sewage sludge use and disposal in the United States

In 1988, the USEPA collected information on the use or disposal of sewage sludge through a two-part National Sewage Sludge Survey (NSSS). In Part I, a questionnaire survey was used to obtain both technical and financial information on the sewage sludge use or disposal practices employed by POTWs. In Part II, information on the quality of sewage sludge was obtained by analyzing sewage sludge from several POTWs for specific pollutants. Results from the NSSS were used as the basis for establishing several of the sewage sludge pollutant limits found in the 40 CFR Part 503 sludge rule (see Sec. 1.1). The number of POTWs and the magnitude of sewage sludge generated (dry-mass basis) as reported in the 1988 NSSS are sumarized in Table 1.1.

In 1988, POTWs with a design flow rate of over 100 million gallons per day (MGD) accounted for 30.1 percent of the sewage sludge used or disposed by POTWs. POTWs with a design flow rate of between 10 and 100 MGD used or disposed 38.4 percent of the total annual amount of sewage sludge generated in the United States, while POTWs with a flow rate of between 1 and 10 MGD used or disposed 24.0 percent of the sewage sludge. In contrast, while they account for more than half of all POTWs in the United States, POTWs with a flow rate of less than 1 MGD generated only 7.5 percent of the annual amount of sewage sludge used or disposed.

The 1988 NSSS identified four principal categories of practices employed by POTWs for the reuse and or disposal of sewage sludge. Table 1.2 illustrates that, in 1988, the most prevalent sludge reuse/disposal practice was land application (34.6 percent), followed by sewage sludge codisposal in municipal solid waste landfills. With respect to the total mass of sewage sludge generated, codisposal in municipal landfills was the preferred disposal practice in 1988, accounting for 33.7 percent of the total amount of sludge generated.

TABLE 1.1 Number of Publicly Owned Treatment Works (POTWs), Actual Flow, and Estimated Sewage Sludge Quantities in the United States*

POTW flow rate (MGD)†	No. of POTWs	Quantity of sewage sludge (dmt)‡	Percent
>100	35	2,120,512	30.1
10–100	459	2,709,604	38.4
1–10	2,666	1,692,086	24.0
<1	9,588	530,339	7.5
TOTAL	12,748	7,052,540	100.0

*Adapted from ref. [18].
†MGD, million gallons per day.
‡dmt, dry metric ton (1000 kg) = 0.9072 · U.S. ton. (kg = 2.2 lb.)

TABLE 1.2 Use and Disposal Practices of Sewage Sludge in the United States*

Use/disposal practice	Percentage of POTWs using a particular practice	Percentage of total sewage sludge generated
Land application	34.6	33.5
Codisposal landfill	22.2	33.7
Incineration	2.8	16.1
Surface disposal	10.1	10.4
Unknown transfers	30.3	6.3†

*Adapted from refs. [21,23].
†Ocean disposal—banned in 1988.

Due to the increased level to which municipal wastewater is now required to be treated, it is anticipated that the sewage sludge volumes have increased significantly since 1988. Some of the regulatory requirements that have mandated higher levels of wastewater treatment include (1) the reduction in permissible levels of nitrogen and phosphorus in wastewater discharges to surface waters and (2) the conversion of primary treatment-only facilities to full secondary treatment [21]. In addition to the increased stringency in federal and local water quality discharge standards, industrial pretreatment programs have had a significant impact on sewage sludge management. With the overall improvement in sewage sludge quality as a result of implementation of industrial pretreatment programs, a large volume of sewage sludge can now be directed toward beneficial use, such as land application and the production and sale of sewage sludge amendment products (e.g., compost, heat-dried pellets, alkaline-stabilized soil additives, and soil substitute products). To document the impact of changing water quality standards on sewage sludge quality and generation rates, the USEPA is currently developing the scope for a second national sewage sludge survey [2,3].

Although regulatory compliance issues have led to consideration of new approaches to sewage sludge recycling, in some cases, rising transportation and labor costs have stimulated changes in sewage sludge management. For example, wastewater treatment authorities recently have been faced with dramatic increases in sewage sludge disposal costs. In the 1970s, costs for sewage sludge disposal generally were less than $100 per dry ton, whereas recent short-term private contracts to implement land-based sewage sludge disposal alternatives have been reported to be as high as $800 per dry ton [23]. Such increases in disposal costs, along with the difficulties in siting sewage sludge disposal facilities, have led to situations where long-distance sewage sludge transport becomes necessary (e.g., New York City sewage sludge transported to Arizona for reuse/disposal). With such high sewage sludge management costs, more attention is being paid to the development and implementation of innovative approaches to sewage sludge recycling.

1.0.2 Institutional barriers and liability issues

Although the technological feasibility of innovative methods for recycling sewage sludge can be demonstrated repeatedly, in many cases, achieving public acceptance of new sludge management methods becomes insurmountable. The reluctance to accept the results of technological innovation directly influences the numerous political, regulatory, and financial policy barriers that wastewater treatment authorities must address in developing sludge management programs. The skepticism recorded about the proposed changes in current sludge disposal/recycling practices and policies included legitimate public concerns over protecting public health, the environment, and tax revenue. In recent years, potential liability associated with the beneficial use of sewage sludge has become a concern to both proponents and opponents of sewage sludge recycling [30].

Under federal law, anyone responsible for a hazardous substance release that is not federally permitted is liable for the costs of cleaning up the release under the 1980 Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, or Superfund). Potential Superfund liability has created concerns over the potential for future liability associated with sewage sludge use/disposal practices for both sludge generators and landowners. In addition, groups such as the Farm Credit Bank and various food processing organizations also have raised concerns over potential liabilities [21]. The potential for litigation brought on behalf of food processors and/or the public has created significant psychological and financial barriers to farmers who would otherwise use sewage sludge as either a low-cost fertilizer or soil amendment.

To ease some of the liability concerns, the 40 CFR Part 503 sludge rule clarifies that Superfund liability does not apply to the beneficial use of sewage sludge [21]. Moreover, the Farm Credit Bank in conjunction with the USEPA has developed an indemnification statement that is currently being employed by several companies to clarify the legal responsibilities of the sludge preparer, land applier, and farmer when sewage sludge reuse/disposal projects are in compliance with applicable standards and management practices of the 40 CFR Part 503 rule [21].

Finally, overcoming the nontechnical issues such as public perception and legal liability fears may prove to be the greatest barrier facing sewage sludge management authorities in the future. Studies of public acceptance and institutional barriers to changes in sewage sludge management practices suggest that techniques such as (1) providing adequate public involvement in the decision-making process, (2) addressing public nuisance concerns early, (3) use of stakeholder advisory groups, and (4) aggressive education programs may minimize opposition to implementation of innovative sludge management practices.

1.1 Regulatory Aspects to Biosolids Management

In compliance with the requirements of Section 405(d) of the 1987 CWA Amendments, on February 19, 1993, the final version of 40 CFR Part 503, "Standards for the Use or Disposal of Biosolids," was published in the *Federal Register* [22]. In the 40 CFR Part 503 rule, the term *biosolids* was introduced as a replacement for the term *sewage sludge.* The new term was designed to reflect the beneficial characteristics of the residual solids generated from municipal wastewater treatment. The 40 CFR Part 503 rule defines *biosolids* as the final solid, semisolid, or liquid residue generated during the treatment of domestic sewage in a municipal wastewater treatment plant [19]. The 40 CFR Part 503 rule applies to biosolids generated from the treatment of domestic wastewater as well as domestic septage.

Biosolids permitting requirements apply to all TWTDS, i.e., facilities that generate, treat, or provide disposal of biosolids, including nondischarging and biosolids-only (i.e., sludge) facilities. A TWTDS facility must apply for a federal biosolids permit from the USEPA or an approved state biosolids program if it manages biosolids that are ultimately subject to the 40 CFR Part 503 rule. In other words, if the biosolids are applied to land, placed in a surface disposal site, incinerated, or sent to a municipal solid waste monofill, the TWTDS facility requires a permit under the 40 CFR Part 503 rule.

The 40 CFR Part 503 rule does not apply to materials such as grease trap residues or other nondomestic wastewater residues pumped from commercial facilities such as solids produced by industrial wastewater treatment facilities or grit and screenings from publicly owned treatment works (POTWs). Wastewater biosolids disposed in municipal solid waste landfills or used as landfill cover material are regulated by federal and local solid waste regulations [21].

The 40 CFR Part 503 rule was designed to protect public health and the environment from any reasonably anticipated adverse effects of pollutants that may be present in biosolids. A schematic diagram illustrating the various components of the 40 CFR Part 503 rule is provided in Fig. 1.3. The provisions of the 40 CFR Part 503 rule are consistent with USEPA's policy of promoting beneficial uses of biosolids. Most of the requirements contained in the 40 CFR Part 503 rule were generated based on results from extensive multimedia risk-assessment studies conducted by the USEPA [28].

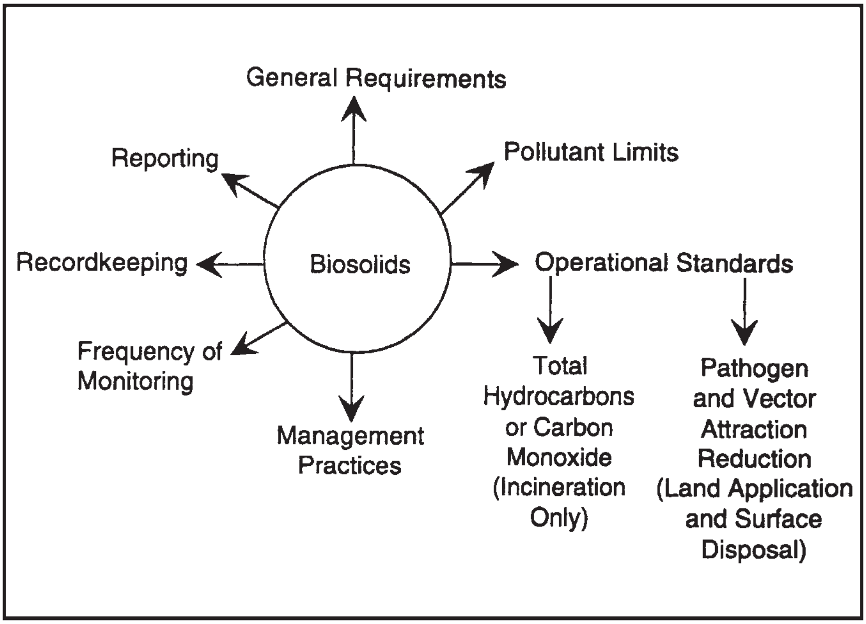

Figure 1.3 Various components of the 40 CFR Part 503 sludge rule.

1.1.1 Risk-assessment basis for the 40 CFR Part 503 rule

The Part 503 rule was developed with the realization that the use or disposal of biosolids may result in measurable changes in the environment. The biosolids risk-assessment process provided a scientific basis for determining acceptable environmental change when biosolids were used or disposed. *Acceptable environmental change* has been defined by the USEPA as any measurable change that still maintains adequate protection for public health and the environment. The risk-assessment procedures used in developing the sludge rule (40 CFR Part 503) were based on the methodology formulated by the National Academy of Science, which included the following four steps: (1) hazard identification, (2) exposure assessment, (3) dose-response evaluation, and (4) risk characterization [28].

To evaluate both the human health and environmental risks associated with biosolids reuse and disposal practices, the USEPA analyzed the health impacts on humans, animals, plants, and soil organisms resulting from exposure to pollutants found in biosolids. The USEPA evaluated 14 various exposure pathways in which human beings and the environment may be exposed to pollutants contained in land-applied biosolids. Similarly, the USEPA evaluated two exposure pathways through which human beings and the environment may be affected by the surface disposal of biosolids, while the impact of biosolids incineration on human health was modeled assuming one principal exposure pathway [25]. Figure 1.4 summarizes the various exposure pathways evaluated by the USEPA in the development of the 40 CFR Part 503 rule.

Employing human health and environmental risk assessments to establish permissible biosolids use and disposal standards represents a paradigm shift away from the policy-driven methodology employed by many European countries and Canadian provinces.

Summary of Exposure Pathways Used in Risk Assessment for Land Application of Biosolids

Pathway	Description of HEI[a]
1. Biosolids → Soil → Plant → Human	Human (except home gardener) lifetime ingestion of plants grown in biosolids-amended soil
2. Biosolids → Soil → Plant → Human	Human (home gardener) lifetime ingestion of plants grown in biosolids-amended soil
3. Biosolids → Human	Human (child) ingesting biosolids
4. Biosolids → Soil → Plant → Animal → Human	Human lifetime ingestion of animal products (animals raised on forage grown on biosolids-amended soil)
5. Biosolids → Soil → Animal → Human	Human lifetime ingestion of animal products (animals ingest biosolids directly)
6. Biosolids → Soil → Plant → Animal	Animal lifetime ingestion of plants grown on biosolids-amended soil
7. Biosolids → Soil → Animal	Animal lifetime ingestion of biosolids
8. Biosolids → Soil → Plant	Plant toxicity due to taking up biosolids pollutants when grown in biosolids-amended soils
9. Biosolids → Soil → Soil → Organism	Soil organism ingesting biosolids/soil mixture
10. Biosolids → Soil → Soil → Organism → Soil → Organism → Predator	Predator of soil organisms that have been exposed to biosolids-amended soils
11. Biosolids → Soil → Airborne Dust → Human	Adult human lifetime inhalation of particles (dust) (e.g., tractor driver tilling a field)
12. Biosolids → Soil → Surface Water → Human	Human lifetime drinking surface water and ingesting fish containing pollutants in biosolids
13. Biosolids → Soil → Air → Human	Human lifetime inhalation of pollutants in biosolids that volatilized to air
14. Biosolids → Soil → Ground Water → Human	Human lifetime drinking well water containing pollutants from biosolids that leached from soil to ground water

[a] HEI = highly exposed individual

(a)

Summary of Exposure Pathways Used in Risk Assessments for Surface Disposal and Incineration of Biosolids

Pathway	Description of HEI[a] Exposure for a 70-Year Lifetime
Surface Disposal	
1. Biosolids → Soil → Air → Human	Adult human breathing volatile pollutants from biosolids disposed at a surface disposal site
2. Biosolids → Soil → Ground Water → Human	Adult human drinking water obtained from ground water beneath a surface disposal site
Incineration	
1. Biosolids → Incineration → Particulate → Air → Human	Adult human breathing pollutants in the emissions from a biosolids incinerator

[a]HEI = highly exposed individual

(b)

Figure 1.4 Various exposure pathways evaluated by the USEPA in developing the 40 CFR Part 503 rule: (*a*) exposure pathways for land-applied biosolids; (*b*) exposure pathways for surface disposal and incineration of biosolids.

Policy-driven approaches used to establish biosolids quality standards allow only small, incremental increases of pollutants into the environment. A typical example of a policy-driven biosolids land-application standard might include a mandate requiring that the soil metal concentrations resulting from biosolids land application shall not be permitted to exceed the 95th percentile of background soil concentrations. Unfortunately, these policy-driven approaches to establishing environmental standards not only result in overly conservative pollutant limits but often have neither a scientific nor technical basis.

In most cases, the USEPA determined that risk-based pollutant limits could be calculated to achieve the goal of protecting public health and the environment. However, in three cases, risk-assessment methodologies were not sufficiently developed to provide a reasonable estimate of risk. These cases included establishing (1) pathogen reduction criteria for land-applied biosolids, (2) vector attraction reduction criteria for land-applied biosolids, and (3) total hydrocarbon (THC) limits in biosolids incineration emissions. In lieu of developing a risk-based pollutant limit for these cases, the USEPA adopted technology-based biosolids management requirements to ensure an adequate margin of protection for human health and the environment [19,25].

Once risk assessments were completed, the basic approach adopted by the USEPA to establish the permissible pollutant concentrations was to use the lower of either (1) the risk-derived concentration or (2) the 99th percentile concentration derived from the 1988 USEPA NSSS [18]. The NSSS summarized pollutant concentration data in biosolids generated from 186 statistically representative POTWs. In the case of the pollutants chromium and selenium, the 99th percentile concentration found in the 1988 NSSS was lower than the concentration derived from risk assessments. Therefore, the initial limiting concentration specified for both metals for land-applied biosolids was the 99th percentile concentration found in the 1988 NSSS.

The USEPA received many comments from both the regulated community and the public after the initial promulgation of the 40 CFR Part 503 rule [30]. In addition to public comments, several industry groups and POTWs initiated lawsuits against the USEPA contending that the land-application pollutant limits set for chromium and selenium in the rule were overly stringent [30]. In these particular lawsuits, the District of Columbia Circuit Court concluded that Section 405 of the CWA mandated that only risk-based pollutant concentrations could be promulgated in the 40 CFR Part 503 rule. Since the maximum chromium level reported in the 1988 NSSS and subsequently investigated in the USEPA risk assessments did not pose a significant risk to human health and the environment, the USEPA decided to delete all chromium limits for land-applied biosolids from the 40 CFR Part 503 rule. Moreover, the USEPA revised the selenium pollutant concentration limits, concluding that it could not legally adopt a more stringent concentration limit for selenium in land-applied biosolids than the risk-assessment-based concentration of 100 mg/kg (dry solids basis).

1.2 Land Application of Biosolids

Land application of biosolids includes all forms of applying bulk or bagged biosolids to land for beneficial use. Beneficial uses include biosolids application to (1) agricultural land for food production, (2) agricultural land for production of feed and fiber crops, (3) pasture and range land, (4) nonagricultural land (e.g., forests), (5) disturbed lands (e.g., highway embankments, mine reclamation, etc.), (6) construction sites and gravel pits, (7) public contact sites (e.g., parks and golf courses), and (8) home lawns and gardens. Figure 1.5 presents photographs depicting the land application of various types of biosolids for agricultural production.

The 40 CFR Part 503 rule requires that any person applying biosolids to land or any person who prepares biosolids for beneficial use must obtain a permit. The 40 CFR Part 503 rule defines a *person* as an individual, association, partnership, corporation, municipality, state or federal agency, or any individual working on behalf of one of these entities. The self-implementing nature of the 40 CFR Part 503 rule requires that biosolids land appliers comply with the rule even if they have not applied for and/or have not been issued a permit covering biosolids use. Similarly, USEPA (or an approved state regulatory agency) can take enforcement actions directly against persons who violate the 40 CFR Part 503 requirements regardless of whether or not they have been issued a biosolids permit [21,30].

Regardless of the land-application end use (i.e., agricultural or nonagricultural), seven types of requirements must be met to legally apply biosolids to land: (1) general requirements, (2) pollutant limits, (3) management practices, (4) operational standards covering pathogen and vector attraction reduction requirements, (5) frequency of monitoring requirements, (6) recordkeeping requirements, and (7) reporting requirements. Each of these requirements is discussed in further detail in the following sections.

1.2.1 General requirements for land-applied biosolids

Subpart B of the 40 CFR Part 503 rule specifies the legal requirements for land applying biosolids and/or any material derived from biosolids (e.g., land application of biosolids composted with yard wastes). General requirements mandate that the preparer of bulk biosolids provide any subsequent preparer and any land applier of biosolids with the appropriate "notice and information" certification necessary to

(a)

(b)

Figure 1.5 Biosolids land application for agricultural production: (*a*) subsurface injection of liquid biosolids; (*b*) surface application of dewatered biosolids. (*Courtesy of Ag-Chem Equipment Company, Inc.*)

comply with Subpart B. Subpart B requirements (i.e., pollutant limits, class of pathogen control, and vector attraction reduction) are designed to ensure that all preparers of biosolids that do not meet specific quality requirements have written agreement with any biosolids land applier before land application of biosolids commences.

In addition to having a written contract with the land applier, the preparers of land-applied biosolids must provide the state regulatory authority with information pertaining to the site location, time period of application, and the name, address, telephone numbers, and NPDES permit number of the biosolids applier. The regulation also requires all land appliers of bulk biosolids that are subject to the cumulative pollutant limits to provide written notification to the permitting authority for the state in which the bulk biosolids are applied.

If, for any reason, bulk biosolids subject to cumulative limits have been applied to the site but the cumulative amount of pollutants applied is unknown, no further amount of biosolids can be applied to the site unless it can meet the more stringent pollutant concentration limits (see Sec. 1.2.2).

In addition to the general requirements, the 40 CFR Part 503 rule requires that biosolids meet two levels of quality with respect to pollutant limits, i.e., pollutant ceiling concentrations and any one of the following: (1) pollutant concentration limits, (2) cumulative loading rate limits, or (3) annual pollutant loading rate limits. The 40 CFR Part 503 rule also has created two levels of biosolids quality with respect to pathogen concentrations, i.e., Class A and Class B biosolids. Finally, the 40 CFR Part 503 rule permits two types of approaches for meeting vector attraction reduction, namely, (1) biosolids processing or (2) use of physical barriers. The following sections describe each of these requirements and their impact on the suitability of biosolids to be applied to land.

1.2.2 Pollutant limits

A central feature of the biosolids land-application requirements is pollutant limits. It should be noted that at the time of this writing, the only regulated pollutants for land-applied biosolids were heavy metals. It should be noted that the USEPA recently promulgated a proposed limit of 300 parts per trillion (300 ppt) for dioxin in land-applied biosolids (dry-mass basis), but this standard has not yet been codified into law [33]. The heavy metal pollutant limits are divided into two types: (1) concentration limits (i.e., limits on the concentrations of pollutants in biosolids) and (2) loading rate limits (i.e., limits on the rate at which pollutants may be applied to land). Concentration limits are further divided into two types: (1) ceiling concentration limits, which govern whether a biosolids can be applied to land at all, and (2) pollutant concentration limits, which define biosolids that are exempted from meeting pollutant loading rate limits, certain recordkeeping requirements, etc.

All land-applied biosolids must meet the ceiling concentration limits for heavy metals. The ceiling concentrations are the maximum concentration limits for nine heavy metals typically found in biosolids (Table 1.3).

If the concentration limit for any one of the heavy metals exceeds the level given in Table 1.3, the biosolids cannot be applied to land. The ceiling concentration limits for heavy metals were included in 40 CFR Part 503 to encourage industrial pretreatment efforts and to prevent the introduction of heavily contaminated materials into the environment.

Depending on the effectiveness of industrial pretreatment programs and wastewater treatment operation, the heavy metal concentrations in biosolids may be reduced to the pollutant concentration limits (see Table 1.3). POTWs whose biosolids meet pollutant concentration limits are offered two important advantages with regard to biosolids land application, namely, (1) there are no limits on the lifetime quantity of pollutants that can be applied to a site, and (2) the biosolids application rate depends only on the agronomic rate (see Sec. 1.3.2.1).

Like concentration limits, loading rate limits are also divided into two types: (1) cumulative pollutant loading rates (CPLRs) and (2) annual pollutant loading rates (APLRs) (Table 1.4). Bulk biosolids that meet ceiling concentration limits but do not meet pollutant concentration limits must meet cumulative pollutant loading rates, which specify the total lifetime quantity of pollutants that can be applied to a site (see Table 1.4). Once the cumulative pollutant loading rate has been reached, no more biosolids of this quality may be applied to a site.

In contrast to biosolids that are applied in bulk, biosolids that are sold or given away in bags or other containers meeting ceiling limits but not meeting pollutant concentration limits must meet APLRs, which specify the total amount of pollutant that can be applied to a site in any one year. The following sections provide additional information specific to the land application of bulk and bagged biosolids.

1.2.2.1 Land application of bulk biosolids. The 40 CFR Part 503 rule mandates that bulk biosolids cannot be applied to agricultural land, forest land, or a public contact site at a rate greater than the agronomic rate. The *agronomic rate* is defined as the biosolids application rate that provides nitrogen (or phosphorus) at a rate that just satisfies the crop nutrient requirements. Figure 1.6 is a photograph depicting

TABLE 1.3 Concentration Limits for Biosolids Applied to Land*

Heavy metal	Ceiling concentration limits (mg/kg)†	Pollution concentration limits‡ (mg/kg)†
Arsenic	75	41
Cadmium	85	39
Copper	4300	1500
Lead	840	300
Mercury	57	17
Molybdenum	75	—
Nickel	420	420
Selenium	100	36
Zinc	7500	280

*Adapted from ref. [31].
†Dry-weight basis.
‡Monthly average concentration.

TABLE 1.4 Loading Rate Limits for Land-Applied Biosolids*

Pollutant	Cumulative pollutant loading rate limits (kg/ha)†	Annual pollutant loading rate limits (kg/ha)†
Arsenic	41	2.00
Cadmium	39	1.90
Copper	1500	75.00
Lead	300	15.00
Mercury	17	0.85
Nickel	420	21.00
Selenium	100	5.00
Zinc	2800	140.00

lb/acre = 0.8922 · kg/ha.
*Taken from refs. [24,31].
†To qualify as exceptional quality biosolids, none of the heavy metal concentration can exceed the pollutant concentration limits.

Figure 1.6 Photograph of biosolids being applied to land in bulk at a forest site.

the land application of biosolids in bulk at a forest site. Bulk biosolids can be applied to land at a reclamation site at a rate greater than the agronomic rate if authorized by the permitting agency [31].

In all cases, when bulk biosolids that do not meet pollutant concentration limits are applied to land, the application rate and site life must be determined as part of the overall land-application design. Preparers or appliers of bulk biosolids have the option of using the CPLR values to estimate either (1) a maximum site life based on a given biosolids application rate or (2) a maximum annual whole sludge application rate (AWSAR) in terms of dry metric tons (dmt) per hectare (or U.S. tons per acre) given a design site life. In most cases, POTWs will use their existing biosolids land-application rate (i.e., AWSAR) to estimate site life if their biosolids application rate is at or below the agronomic rate. However, the latter approach to biosolids land-application design is sometimes used in cases where it is necessary for the POTW to adjust the AWSAR downward to extend site life.

To estimate site life, an APLR must be estimated for each regulated pollutant given the existing biosolids land-application rate. The APLR is obtained by multiplying the concentration of each pollutant by the AWSAR, as illustrated by Eq. (1.1).

$$\text{APLR}\left(\frac{\text{kg}}{\text{ha}\cdot\text{yr}}\right) = \text{biosolids pollutant concentration}\left(\frac{\text{mg}}{\text{kg}}\right) \cdot \text{AWSAR}\left(\frac{10^3\ \text{kg}}{\text{ha}\cdot\text{yr}}\right)\cdot\frac{\text{kg}}{10^6\ \text{mg}} \qquad (1.1)$$

Once the APLR is estimated, the site life can be obtained by dividing the CPLR by the derived APLR [Eq. (1.2)].

$$\text{Site life (years)} = \frac{\text{CPLR}\left(\frac{\text{kg}}{\text{ha}}\right)}{\text{APLR}\left(\frac{\text{kg}}{\text{ha}\cdot\text{yr}}\right)} \qquad (1.2)$$

When site life is calculated for each regulated pollutant, the shortest time duration becomes the design site life for the biosolids land-application program. Example 1.0 illustrates the use of Eqs. (1.1) and (1.2) in estimating site life for a biosolids land-application system.

Example 1.0 The CPLR for arsenic is 41 kg/ha. If the concentration of arsenic in the biosolids is 10 mg/kg (dry weight), estimate the site life based on arsenic if the AWSAR is to be maintained at 15 dmt/ha ($15\cdot10^3$ kg/ha).

solution

Step 1. Estimate the APLR using Eq. (1.1).

$$\text{APLR}\left(\frac{\text{kg}}{\text{ha}\cdot\text{yr}}\right) = \text{biosolids pollutant concentration}\left(\frac{\text{mg}}{\text{kg}}\right) \cdot \text{AWSAR}\left(\frac{10^3\ \text{kg}}{\text{ha}\cdot\text{yr}}\right)\cdot\frac{\text{kg}}{10^6\ \text{mg}}$$

$$= \frac{10\ \text{mg}}{\text{kg}}\cdot\frac{15\cdot10^3\ \text{kg}}{\text{ha}\cdot\text{yr}}\cdot\frac{\text{kg}}{10^6\ \text{mg}}$$

$$= \frac{0.15\ \text{kg}}{\text{ha}\cdot\text{yr}}$$

Step 2. Estimate the site life using Eq. (1.2).

$$\text{Site life (years)} = \frac{\text{CPLR}\left(\dfrac{\text{kg}}{\text{ha}}\right)}{\text{APLR}\left(\dfrac{\text{kg}}{\text{ha}\cdot\text{yr}}\right)}$$

$$= \frac{\dfrac{41\ \text{kg}}{\text{ha}}}{\left(\dfrac{0.15\ \text{kg}}{\text{ha}\cdot\text{yr}}\right)} = 273\ \text{years}$$

NOTE: In the actual biosolids land-application design, similar calculations would be performed for each of the nine regulated heavy metals. The metal yielding the shortest site life would become the limiting pollutant.

1.2.2.2 Land application of bagged biosolids. When the biosolids preparer cannot control the number of biosolids applications made to a site directly (i.e., when biosolids in bags or other containers are given away or sold), APLRs must be met (see Table 1.4). In this case, as long as the annual limits are met, the total pollutant load to the site over time will not exceed levels identified through the USEPA risk assessments as protective of human health and the environment [28].

For the case of biosolids sold or given away in bags or other containers, only the AWSAR (in dry metric tons/hectare or dry U.S. tons/acre) needs to be determined. To estimate the AWSAR, Eq. (1.3) is used. It should be noted that Eq. (1.3) employs the APLR limits found in Table 1.4.

$$\text{AWSAR}\left(\frac{\text{dry metric tons}}{\text{hectare}}\right) =$$

$$\frac{\text{APLR}\left(\dfrac{\text{kg}}{\text{ha}\cdot\text{yr}}\right)}{\text{concentration of pollutant in biosolids}\left(\dfrac{\text{mg}}{\text{kg}}\right)\cdot\left(\dfrac{\text{kg}}{10^6\ \text{mg}}\cdot\dfrac{10^3\ \text{kg}}{\text{dmt}}\right)}$$

$$= \frac{\text{APLR}\left(\dfrac{\text{kg}}{\text{ha}\cdot\text{yr}}\right)}{\text{concentration of pollutant biosolids}\left(\dfrac{\text{mg}}{\text{kg}}\right)\cdot 0.001} \qquad (1.3)$$

When AWSARs for all nine regulated pollutants are calculated, the lowest AWSAR becomes the limiting application rate for those biosolids. Example 1.1 illustrates the use of Eq. (1.3) in estimating the biosolids application rate for bagged biosolids that ensures that the APLRs are not exceeded.

Example 1.1 The Little County Water Reclamation Facility is considering selling its biosolids to the general public in 100-pound sacks. What is the AWSAR in dry metric tons per hectare per year if the biosolids have the following average heavy metal concentrations?

Metal	Concentration in biosolids (mg/kg)
Arsenic	20.3
Cadmium	52.1
Copper	1133.1
Lead	723.1
Mercury	4.1
Nickel	321.7
Selenium	27.8
Zinc	2241.6

solution

Step 1. Calculate the AWSAR for each regulated pollutant using Eq. (1.3) and the APLRs from Table 1.2. For example, for arsenic, the APLR limit is 2.0 kg/ha·yr (see Table 1.4). Given this APLR, the AWSAR can be estimated as follows:

$$\text{AWSAR}\left(\frac{\text{dry metric tons}}{\text{ha}\cdot\text{yr}}\right) = \frac{\text{APLR}\left(\dfrac{\text{kg}}{\text{ha}\cdot\text{yr}}\right)}{\text{concentration of pollutant in biosolids}\left(\dfrac{\text{mg}}{\text{kg}}\right)\cdot\left(\dfrac{\text{kg}}{10^6\ \text{mg}}\cdot\dfrac{10^3\ \text{kg}}{\text{dmt}}\right)}$$

$$= \frac{\dfrac{2.0\ \text{kg}}{\text{ha}\cdot\text{yr}}}{\left(\dfrac{20.3\ \text{mg}}{\text{kg}}\right)\cdot\left(\dfrac{\text{kg}}{10^6\ \text{mg}}\cdot\dfrac{10^3\ \text{kg}}{\text{dmt}}\right)} = \frac{98.5\ \text{dmt}}{\text{ha}\cdot\text{yr}}$$

Step 2. The AWSAR can be calculated for each heavy metal using the same procedure. The results are given in the following table:

Metal	Concentration in biosolids (mg/kg)	APLR (kg/ha·yr)	AWSAR (metric tons/ha·yr)
Arsenic	20.3	2.0	98.5
Cadmium	52.1	1.9	36.5
Copper	1133.1	75.0	66.2
Lead	723.1	15.0	20.7
Mercury	4.1	0.9	207.3
Nickel	321.7	21.0	65.3
Selenium	27.8	5.0	179.9
Zinc	2241.6	140.0	62.5

Step 3. The limiting AWSAR is 20.7 metric tons/ha·yr, which was estimated for lead. Therefore, the maximum annual biosolids application rate for these biosolids is 20.7 metric tons/ha·yr.

Biosolids sold or given away in bags or other containers are required to have a label attached or a handout sheet provided. The information required on the label or handout sheet includes (1) the name and address of the preparer, (2) a statement prohibiting application except in accordance with the instructions on the label, and (3) the calculated AWSAR that does not cause the APLR to be exceeded (see Sec. 1.2.3.5). Finally, when metal concentrations limit the biosolids loading rate, the nutrient levels must be monitored to determine if supplemental fertilization is required. Example 1.2 illustrates the approach for estimating the level of supplemental fertilization required as a result of biosolids land application.

Example 1.2 The Little County Water Reclamation Facility (Example 1.1) has negotiated with a local nursery to deliver several hundred sacks of biosolids over the course of the growing season to supply nutrients to ornamental shrubbery. If the local nursery estimates that the crop nitrogen requirement is 150 pounds of nitrogen per acre-year, what would be the amount of nitrogen provided by the biosolids relative to the crop nutrient requirements during the first year? Assume that the nitrogen content of the biosolids is 1.5 percent and that 30 percent of the nitrogen (dry-mass basis) is available during the first year of application.

solution

Step 1. From Example 1.1, the AWSAR was estimated to be 20.7 dmt/ha·yr. Since the crop nutrient needs are given in pounds per acre-year, the AWSAR in metric tons per hectare-year must be converted to U.S. units.

$$\frac{9.22 \text{ tons biosolids}}{\text{acre} \cdot \text{yr}} = \frac{20.7 \text{ metric tons}}{\text{ha} \cdot \text{year}} \cdot \left(\frac{1000 \text{ kg}}{\text{metric tons}}\right) \cdot \left(\frac{2.2 \text{ lb}}{\text{kg}}\right) \cdot \left(\frac{\text{ton}}{2000 \text{ lb}}\right) \cdot \left(\frac{\text{ha}}{2.47 \text{ acre}}\right)$$

Step 2. Since nitrogen is only 1.5 percent of the total biosolids added and, of this, only 30 percent is available in the first year, the available nitrogen from biosolids (pounds of nitrogen per acre-year) is calculated as follows:

$$\frac{83.0 \text{ lb nitrogen}}{\text{acre} \cdot \text{yr}} = \frac{9.22 \text{ tons biosolids}}{\text{acre} \cdot \text{yr}} \cdot \left(\frac{2000 \text{ lb}}{\text{ton}}\right) \cdot \frac{0.015 \text{ lb N applied}}{\text{lb biosolids}} \cdot \frac{0.3 \text{ lb N available}}{\text{lb N applied}}$$

Step 3. Since the biosolids can only supply 83.0 pounds of the required nitrogen when applied at a AWSAR of 20.7 metric tons per hectare per year, an additional 67 pounds of nitrogen per acre must be added through supplemental fertilization during each growing season.

NOTE: This is only an approximate method for estimating the supplemental nutrient requirements. In most cases, there is both native nitrogen and nitrogen from previous biosolids application available for meeting crop nutrient requirements. To account for these other nitrogen sources in determining supplemental nitrogen requirements, see Chap. 7.

1.2.3 Management practices

In addition to heavy metal concentrations and loading limits, the 40 CFR Part 503 rule requires that certain management practices be met when biosolids are being applied to land. The only instance where a land applier is exempt from management practices is when exceptional-quality (EQ) biosolids are being applied (see Sec. 1.4).

Management practices were included in the 40 CFR Part 503 rule to (1) constrain risks when actual risks were not evaluated, (2) support risk-modeling assumptions, or (3) ensure proper handling of biosolids. A summary of the management practices for land application of biosolids is given in Table 1.5. Details on each of the land application management practices are provided in the following sections.

1.2.3.1 Endangered species. The 40 CFR Part 503 rule prohibits the land application of biosolids if they could have a negative impact on endangered or threatened species or their designated critical habitat. *Critical habitat* is defined as any environment where an endangered or threatened species lives and grows during its life cycle [24]. It is the responsibility of the land applier to determine if land application of biosolids will adversely affect the endangered species or their critical habitat. In addition to seeking advice from the permitting authority, land appliers can contact the U.S. Department of Interior's Fish and Wildlife Service (FWS), which publishes an annual list of endangered and threatened species [24,31].

1.2.3.2 Application to flooded, frozen, or snow-covered land. Application of biosolids to flooded, frozen, or snow-covered land is not prohibited by the 40 CFR Part 503 rule. However, biosolids applied to such land must not enter surface waters or wetlands unless specifically authorized by a permit issued under Sections 402 or 404 of the CWA. Some common runoff controls at biosolids land-application sites include slope restrictions, buffer zones/filter strips, berms, dikes, silt fences, diversions, siltation basins, and terraces [24,31].