REVIEW

Regulations for Biosolids Land Application in U.S. and European Union

R. IRANPOUR[1,*], H. H. J. COX[1], R. J. KEARNEY[1], J. H. CLARK[2], A. B. PINCINCE[3] and G. T. DAIGGER[4]

[1]*City of Los Angeles, Bureau of Sanitation, Hyperion Treatment Plant/TSF, 12000 Vista Del Mar, Playa Del Rey, California 90293*

[2]*Black & Veatch, Los Angeles, California*

[3]*Camp Dresser & McKee, Cambridge, Massachusetts*

[4]*CH2M Hill, Englewood, Colorado*

ABSTRACT: Land application of biosolids allows the nutritional value of treated sewage sludge to be used beneficially in agriculture. Biosolids are also useful as amendments in soil reclamation projects. Wastewater treatment plants in the U.S. and European Union (EU), however, are facing increasing public opposition to land application due to concerns about human and animal health and the environment from the presence of pollutants and pathogenic organisms in biosolids. This review discusses how present and proposed legislation on biosolids land application in the U.S. and Europe will affect land application as a management option for biosolids. Understanding the regulations is necessary as they guide biosolids research recently in progress at many wastewater treatment plants and institutions. Regulations in the U.S. and EU share the same objective of controlling pathogens and pollutants in biosolids, although differences exist in specific requirements. Future regulations on both continents are likely to become more stringent and more similar to each other. The presence of persistent pollutants in biosolids is of particular concern because: i) concentration limits for pollutants in biosolids are likely to be reduced; ii) newly introduced chemicals may find their way to wastewater treatment plants and accumulate in biosolids; and iii) current metal concentrations in biosolids seem to be the lowest attainable with current pretreatment technologies. These factors as well as future pathogen reduction requirements will put more pressure on wastewater treatment plants seeking to ensure that land application will remain a viable option for biosolids management. In addition, critical studies of the U.S. EPA 40 CFR Part 503 regulations and a Congressional hearing have questioned the scientific basis of this rule as well as policy decisions and monitoring by the U.S. EPA. Odor emissions, emergent pathogens, radionuclides, and certain pharmaceutical products such as antibiotics and endocrine disruptors are perceived as the main issues that may eventually revise the Part 503 rule. Despite these concerns, no scientific evidence exists that the current practice of biosolids land application would be harmful either to human health or to the environment.

INTRODUCTION

RESEARCH in the area of wastewater treatment is ultimately driven by regulations that protect human health and the environment. The purpose of this contribution is to review the biosolids regulations, which are the driving force behind much of the biosolids research and development recently in progress. Beneficially using biosolids that result from processing municipal wastewater sludge is a complex challenge for governmental and private organizations. Land application is an attractive option for beneficial use of biosolids because it uses its nutritional value as a fertilizer to enhance growth of agricultural crops. On the other hand, biosolids can contain pathogenic organisms and pollutants, which are causes of concern about human health and the accumulation of toxic substances in soils.

Government agencies in both the U.S. and European Union (EU) have issued regulations on the land application of biosolids, seeking to limit the risks from the pathogens and pollutants [1,2]. Despite these regulations, public opposition to biosolids land application is growing on both continents, and wastewater treatment facilities and biosolids producers face increasing difficulty in marketing biosolids. This is particularly important as the amount of sewage is projected to significantly increase over the next few years due to a growing population, more treatment plants transforming to full

*Author to whom correspondence should be addressed. E-mail: riz@san.lacity.org.

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secondary treatment in EU, and U.S. requirements for higher levels of treatment that go beyond that of secondary treatment [3,4]. At the same time, regulations on biosolids land application are likely to become more complex and stringent, hence putting more pressure on wastewater treatment plants to ensure compliance.

In the present review, the existing regulations in the U.S. and Europe are compared, differences and inconsistencies identified, and future developments in regulatory issues related to biosolids land application discussed. Any change in regulations regarding sludge processing and biosolids land application potentially has a tremendous impact on the daily operation of wastewater treatment plants, and on wastewater treatment and biosolids management in general. It is therefore imperative not only to comply with existing regulations, but also to anticipate future regulations to produce the highest quality biosolids over the long term.

Table 1. Geographic and demographic statistics.

Parameter	Year	U.S.	EU
Population[a]	2000	283,230,000	376,722,000
Land area (km^2)[a]		9,629,090	3,242,690
Population density (people/km^2)	2000	29	116
Agricultural area (km^2)[a]	1999	4,182,500	1,420,840
Sludge production (dry metric ton/annum)	1992		7,387,000[d] 5,511,000[e]
	1997	6,900, 000[b]	
	1998	6,900, 000[c]	6,588,000[e]
	2005	7,600,000[c]	8,331,000[e]
	2010	8,200,000[c]	
Sludge for beneficial use (% of total)	1998	60[c]	42[d], 52[e]
	2005	66[c]	54[e]
	2010	70[c]	
Sludge density (dry metric ton/annum.km^2 of agricultural land)	1998	1.6	4.6

[a][53];
[b][54];
[c][3];
[d][44];
[e][47], excluding Italy and Sweden (approximately 11 and 3% of total).

BACKGROUND

Both the EU and U.S. regulatory authorities emphasize the beneficial effect of recycling the nutritional value of biosolids, and thus they seek to find the best balance of applying biosolids to the land and the cost of reducing the risks from pathogens and contaminants in biosolids. There are significant differences between the U.S. and the EU in biosolids management, not only in specific regulations but also in the philosophies behind the regulations [5].

Currently, the EU consists of 15 member countries, mostly located in Western Europe. Expansion to a total of 21 states is likely to occur in the near future, while other countries, mostly from the Eastern region, are considering membership. The land area presently occupied by the EU is smaller than that of the U.S., but its population is larger (Table 1), so that the average population density is four times as high in the EU. Consequently, the table shows that estimated past and projected future overall sludge production is higher in the EU than in the U.S. On the other hand, the total area for agriculture in the EU is about one third of what is now occupied by U.S. agriculture and the ratio of sludge produced to available agriculture area is about 2.5 times as high in the EU as in the U.S. Hence, biosolids management is generally considered a more urgent issue in the EU, with more sludge being produced and less agricultural area available for beneficial use.

The EU was first to regulate land application of biosolids. In 1986, a brief sludge directive (86/278/EEC) was issued that set low limits for several heavy metals from a "precautionary principle" to guarantee sustainability [1]. Although many definitions for sustainability have been formulated, and perhaps even more ways to promote it [6], heavy metals in biosolids form a special class of pollutants as they are biologically and chemically stable, and therefore tend to accumulate in soil. The 1986 directive did not set limits for pathogens, and included only a few requirements for sludge treatment processes.

Disposal of wastewater residuals is governed in the U.S. by two federal regulations: biosolids or residuals to be landfilled are regulated by 40 CFR Part 258; biosolids to be surface disposed, land applied and/or incinerated are regulated by 40 CFR Part 503 (known as Part 503 Biosolids Rule) [2]. The Part 503 Biosolids Rule not only regulates heavy metals, but also sets limits for pathogens and vector attraction. This rule was based on extensive environmental risk assessments and the results of an extensive survey of sludge production in the U.S. (1988 National Sewage Sludge Survey) [7].

U.S. EPA PART 503 BIOSOLIDS RULE

"The Standards for the Use or Disposal of Sewage Sludge" (Title 40 of the Code of Federal Regulations, Part 503) were published in the Federal Register on February 19, 1993, and became effective on March 22, 1993. This document established standards, which con-

Table 2. U.S.: Analytical procedures (§503.8).

Parameter	Method
Fecal coliform	9221-E or 9222-D in [55]
Salmonella sp.	Part 9260-D in [55]; or the method Kenner and Clark [56]
Helminth ova	[57]
Enteric viruses	D 4994-89 in [58]
Specific oxygen uptake rate	Part 2710-B in [55]
Inorganic pollutants	[59]
Total, fixed, and volatile solids	Part 2540-G in [55]
Percent volatile solids reduction	[60]

sist of general requirements, pollutant limits, management practices, and operational standards, for the final use (land application) or disposal (surface disposal and incineration) of sewage sludge generated during the treatment of domestic sewage in a treatment works. This review focuses on the application of biosolids to land, being described in subparts A, B and D of the rule. Whenever applicable, we specifically refer to paragraphs and (sub)-sections, such as §503.10 (b)(1), which would be paragraph 503.10 of the document, section (b)(1).

Sewage sludge is defined as a solid, semi-solid or liquid residue generated during treatment of domestic sewage in a treatment work, and includes the solids removed in primary, secondary, or advanced wastewater treatment processes and the products derived from these solids (§503.9(w)). The rule applies to POTWs with a design flow of 1 mgd or greater, POTWs serving a population of 10,000 people or greater, and POTWs that are Class 1 Biosolids management facilities (§503.1(a)). The Part 503 Biosolids Rule does not use the term biosolids, which was first introduced in the plain English guide to the Part 503 Rule [8] to emphasize the nutritional value of sewage sludge in land applications.

For application of biosolids to land, standards have been developed in three categories: pollutant concentrations, pathogen density, and the attraction of potential pathogen vectors (e.g., insects and scavenging mammals and birds). Analytical procedures (§503.8) for pollutant concentrations and pathogen densities as well as other parameters are summarized in Table 2.

Pollutant Concentrations

Pollutant standards have only been established for toxic metals, as specified in §503.13. Although it was originally intended to also include organic pollutants, it was decided that standards for this class would be deleted because concentrations in biosolids were at a level that do not pose significant risks to public health or the environment [9]. Furthermore, subsequent evaluations of dioxin-like compounds, the most toxic of all organic compounds, showed their concentrations in biosolids pose no risk. Table 3 lists the standards for ten metals. Biosolids can not be applied to the land if any one of the ceiling concentrations is exceeded (§503.13(a)). Land application as any other fertilizer is allowed when all pollutant concentration limits are met. If one or more of the latter are not met (but less than the ceiling concentration), the cumulative pollutant loading rate limits restrict the total amount of biosolids that can be land applied.

Pathogen Densities

The pathogen standards recognize two major levels of biosolids disinfection: Class A and Class B biosolids. Class A biosolids in general require reduction of fecal coliform to less than 1000 MPN/g dry weight or reduction of *Salmonella* sp. bacteria to

Table 3. U.S.: Pollutant limits (§503.13).

Metal	Ceiling Concentration Limit (mg/kg DS) Table 1, §503.13	Pollutant Contration Limit (mg/kg DS) Table 3, §503.13	Cumulative Pollutant Loading Rate Limit (kg/ha) Table 2, §503.13	Annual Pollutant Loading Rate Limit (kg/ha/y) Table 4, §503.13
Arsenic	75	41	41	2
Cadmium	85	39	39	1.9
Copper	4300	1500	1500	75
Lead	840	300	300	15
Mercury	57	17	17	0.85
Molybdenum	75			
Nickel	420	420	420	21
Selenium	100	100[a]	100	5
Zinc	7500	2800	2800	140

[a]Increased from 36 to 100 mg/kg as of 10/95.

Table 4. U.S.: Treatment alternatives and requirements for meeting indicator and pathogen reductions (§503.32).

Alternatives[a]	Class A Biosolids: Treatment Requirements	Class A Biosolids: Pathogen Reduction Requirements	Class B Biosolids: Treatment Requirements	Class B Biosolids: Pathogen Reduction Requirements
	General Requirements		*General Requirements*	
All		Fecal coliform <1000 MPN/g DS or *Salmonella* sp. MPN/4 g DS	None	
	Treatment-Specific Requirements		*Treatment-Specific Requirements*	
1	One of four time-temperature regimens (§503.32(a)(3))		None (§503.32(b)(2))	Fecal coliform $<2 \times 10^6$ MPN/g DS or $<2 \times 10^6$ CFU/g DS[d]
2	High pH – high temperature process (§503.32(a)(4))		Processes to Significantly Reduce Pathogens (PSRP) (§503.32(b)(3))	
3[b]	Process monitoring (§503.32(a)(5))	Helminth ova <1 ovum/4 g DS Enteric viruses <1 PFU/4 g DS	Processes equivalent to PSRP (§503.32(b)(4)	
4[c]	Undefined process (§503.32(a)(6))	Helminth ova <1 ovum/4 g DS Enteric viruses <1 PFU/4 g DS		
5	Processes to Further Reduce Pathogens (PFRP) (§503.32(a)(7))			
6	Processes equivalent to PFRP (§503.32(a)(8))			

[a]Class A alternatives 1 to 6 correspond to sections §532.32(a)3 to (a)8, respectively. Class B alternatives 1 to 3 correspond to sections §532.32(b)2 to (b)4, respectively.
[b]Helminth ova and enteric viruses to be determined before or after pathogen treatment.
[c]Helminth ova and enteric viruses to be determined for each batch leaving plant.
[d]Geometric mean of seven samples.

non-detectable levels, while using one of six treatment alternatives (Table 4). The six alternatives include treatment processes for pathogen reduction, and demonstration of reduction of enteric viruses and viable helminth ova (Table 4). Thermophilic anaerobic digestion is not listed as a Process to Further Reduce Pathogens (PFRP, alternative 5), but could qualify under one of four time-temperature treatments as specified in alternative 1, provided that the time segment was in pure batch environment, or could qualify as equivalent to a PFRP (alternative 6). Additional requirements include that the pathogen reductions must be met before or at the time of meeting the vector attraction reduction standard (§503.32(a)(2)), as well as at the time of use or disposal of the biosolids (§503.32(a)(3) to (a)(7)). This has the practical consequence that pathogen reduction should be achieved before vector attraction reduction, and that care should be taken in preventing recontamination of the biosolids and/or pathogen regrowth. It should be emphasized that only one of the two bacteria reduction requirements needs to be met for biosolids to qualify as Class A (§503.32(a)).

The regulations for Class B biosolids require that either the treatment processes or the fecal coliform limits in Table 4 be provided. Class B biosolids require a significant reduction of pathogen densities as compared to densities in untreated biosolids (§503.32(b)), but direct human exposure to Class B biosolids would still pose a significant health risk. Consequently, whereas Class A biosolids can be land applied without site restriction (e.g., agriculture, forest, home garden, lawn), application of Class B biosolids is restricted as summarized in Table 5. In addition, Class B biosolids are not allowed for use on lawns and in home gardens, as it is not practical to impose site restrictions for these areas.

Vector Attraction

Irrespective of the class of pathogen reduction, all biosolids to be land applied must meet one of the vector attraction reduction options as summarized in Table 6. These options are designed to reduce the attractiveness of biosolids to vectors by biological stabilization (options 1 to 8), or to prevent vectors from coming into contact with biosolids (options 9 to 11). Thermophilic anaerobic digestion processes often easily meet the minimum of 38% volatile solids reduction (option 1), hence the pollutant concentration limits and pathogen reductions are requirements of more immediate concern for biosolids produced from these processes.

Table 5. U.S.: Site restrictions for Class B biosolids (§503.32(b)(5)).

Harvesting/Land Use	Restriction
• Food and other crops with harvested parts that do not touch the soil surface (e.g., apples, oranges, cotton)	No harvesting for 30 days
• Food crops with harvested parts that are totally above ground but touch the soil surface (e.g., tomatoes, strawberries)	No harvesting for 14 months
• Food crops with harvested parts that are below the land surface and where the biosolids remain on the land for longer than 4 months before incorporation into the soil	No harvesting for 20 months
• Food crops with harvested parts that are below the land surface and where the biosolids remain on the land for shorter than 4 months before incorporation into the soil	No harvesting for 38 months
• Turf used for land with a high potential for public exposure or lawn	No harvesting for 12 months
• Grazing land	No grazing for 30 days
• Land with high potential for public exposure (e.g., park or ballfield)	Access restricted for 12 months
• Land with low potential for public exposure (e.g., private farm land)	Access restricted for 30 days

Exceptional Quality Biosolids

The term "Exceptional Quality (EQ) biosolids" has been introduced to describe biosolids that simultaneously meet the Class A pathogen reduction requirements in Table 4, the pollutant concentration limits in Table 3, and one of options 1 to 8 for vector attraction reduction in Table 6. This term was not defined in the Part 503 Biosolids Rule, but has become generally accepted as a convenient way to describe biosolids that meet all of these conditions. EQ biosolids can freely be applied to the land without general requirements and management practices as required for biosolids of lesser quality, although the application rate should not exceed the agronomic rate (i.e., should conform to the nutrient needs for plant growth) [8]. Like any other type of biosolids, EQ biosolids are subject to monitoring (§503.16(a)), recordkeeping (§503.17(a)) and reporting (§503.18) requirements. The monitoring frequency increases with the amount of biosolids produced (Table 7).

ISSUES FROM THE U.S. EPA PART 503 BIOSOLIDS RULE

Like probably every other federal regulation, the Part 503 Biosolids Rule has been scrutinized for inconsistencies and difficulties in implementing the regulations:

Sandino *et al.* [10] and Stukenberg *et al.* [11] noted that the two analytical procedures specified for fecal coliform determination did not provide the same outcome. The multiple tube fermentation procedure (reported as MPN/g DS) generally produced higher fecal coliform densities than the membrane filter technique (reported as CFU/g DS). This, for instance, raised uncertainty concerning the compliance of four wastewater treatment plants in meeting the Class B biosolids standard for pathogens, in which case the criteria were met using the membrane filter technique but not by using the multiple tube fermentation technique [10].

Concern has also been expressed about the ceiling concentrations for heavy metals. Whereas pollutant

Table 6. U.S.: Vector attraction reduction options (§503.33(b)).

Option[a]	Requirement
1	Minimum of 38% mass reduction of volatile solids.
2	For anaerobically digested biosolids not meeting option 1, demonstrate vector attraction reduction by bench-scale anaerobic digestion (less than 17% reduction of volatile solids over 40 days at 30–37°C)
3	For aerobically digested biosolids not meeting option 1, demonstrate vector attraction reduction by bench-scale aerobic digestion (less than 15% reduction of volatile solids over 30 days at 20°C)
4	For aerobically treated biosolids, the specific oxygen uptake rate should be equal or less than 1.5 mg/h/g DS at 20°C
5	Aerobic treatment of biosolids at temperatures greater than 40°C (average of 45°C) for 14 days or longer
6	Increase of the pH to above 12, followed by maintaining the pH at 12 or higher for 2 hours and at 11.5 or higher for an additional 22 hours
7	Reduce moisture content of biosolids that do not contain unstabilized solids to at least 75% solids.
8	Reduce moisture content of biosolids that do contain unstabilized solids to at least 90% solids.
9	Injection of biosolids beneath the land surface
10	Incorporation of biosolids into the soil

[a]Options 11 and 12 not included as they only apply for surface disposal and domestic septage, respectively.

Table 7. U.S.: Frequency of monitoring for pathogen densities, pollutants, and vector attraction reduction (§503.16(a)).

Amount of Biosolids (metric tons/year)	Frequency
<320	Once per year
320 to <1650	4 times per year
1650 to <16500	6 times per year
≥16500	12 times per year

concentration limits in Table 3 are determined as monthly averages, a single measurement exceeding the ceiling concentration would disqualify the biosolids for land application [12].

Many facilities produce and recycle or dispose of biosolids continuously. Therefore, since a number of laboratory procedures that are needed to verify compliance to the regulations require several hours or even a few weeks for completion, the results are often available only after the biosolids have been applied to the land. Noncompliance can result in enforcement actions by U.S. EPA. Risks of noncompliance can be eliminated by storing biosolids until the laboratory results are in. However, this might be an expensive solution for facilities that do not already have the needed storage capacity [13].

Although the Part 503 Biosolids Rule does not specify a method for calculation of volatile solids reduction, three methods or equations are recommended [14]. Sloan *et al.* [13] demonstrated that these equations gave different calculations of the volatile solids reduction, resulting in the same data set either complying or not complying with option 1 of the vector attraction reduction requirements (Table 6). Switzenbaum *et al.* [15] evaluated the relationship between two of the methods (the Van Kleeck equation and the mass-balance method).

Sloan *et al.* [13] also discusses the effect of various stabilization processes on pollutant concentrations. Processes that reduce volatile solids, such as anaerobic digestion, may cause an increase of the pollutant concentration, to the extent that while the concentration in untreated sludge was below the limit, exceedance was observed for biosolids.

DEVELOPMENTS IN THE U.S.

Studies of the Part 503 Biosolids Rule conducted by U.S. EPA and other organizations concluded that: i) although the Part 503 Biosolids Rule restricts public access to treated lands, the rule does not apply to farm workers [16]; ii) EPA would need to expand its resources to ensure compliance with the land application requirements [17]. These studies, a Congressional hearing entitled "EPA Sludge Rule: Closed Minds or Open Debates", as well as other official calls prompted U.S. EPA to request the National Academy of Sciences to review the scientific basis for 40 CFR 503 for a second time in 2000. These and other developments are discussed in the next sections.

Public Acceptance

There is growing opposition from various stakeholders in the U.S. to the land application of biosolids. Although the U.S. EPA states that all types of biosolids produced under the Part 503 Biosolids Rule are equally safe considering the additional requirements and restrictions for "lower quality" biosolids [8], state and local authorities are entitled to impose additional requirements (§503.5(b)). Local regulations can greatly differ from state to state, and in the BioCycle 2000 survey it was noted that sixteen states had one or more towns and/or counties that issued restrictions, bans or ordinances on biosolids land application [18]. The controversy between producers and end-users of biosolids on the one hand and political and activist groups on the other hand has sparked a vivid discussion in the national media and the scientific literature. Whereas the public opinion is mainly concerned about the possible negative impact of land application of biosolids, advocates of biosolids try to emphasize the nutritional and economical value of biosolids and the lack of scientific evidence for harmful effects of biosolids use [e.g., 19,20,21]. It is generally accepted that only an open policy through outreach and education can bridge opposing views and ensure land application as a long-term solution for biosolids management [e.g., 3]. An example is the National Biosolids Partnership, an alliance of the Association of Metropolitan Sewerage Agencies, Water Environment Federation, and U.S. EPA, with its development of the Environmental Management System (EMS). The EMS (http://www.biosolids.org) is a set of standard procedures or steps to emphasize the total quality management concepts. Biosolids producers and applicators can use EMS as a tool to demonstrate to their communities that they are committed to going beyond meeting regulatory requirements for biosolids management, and to explain how they are working to improve their environmental performance. The U.S. EPA is also implementing the Biosolids Database Management System (BDMS) that contains information on virtually all aspects of biosolids generation and management.

Federal Commitment

Concern has arisen about the commitment of the U.S. EPA to the biosolids program [23]. Indeed, the number of U.S. EPA staff assigned to the program has been declining over the past years, although little progress has been made with delegation of the biosolids program to individual States. In response, U.S. EPA stated that resources were limited, but well balanced against competing priorities [22]. Nevertheless, State Biosolids Coordinators expressed concern about the commitment of EPA to the biosolids program.

Radioactivity in Biosolids

The U.S. EPA and USNRC (United States Nuclear Regulatory Commission) have been collaborating for several years on assessing the implications and concentration of radioactivity in biosolids [23]. In November 2003, the USNRC made three reports available, which indicate that exposure to radiation from biosolids (including from land application of biosolids) is very low and consequently, is not likely to be a concern [24].

Dioxins in Biosolids

There is also concern about the release to the environment of dioxins and related compounds through biosolids [24], but there have been changing ideas about the importance of the problem and about how to address it. It has been noted that human exposure to these compounds from biosolids is expected to occur through the food chain, but that this exposure is expected to be well within background levels [25]. In 1999, the EPA proposed to limit the concentration of dioxins in biosolids to 300 ppt toxic equivalent (TEQ) [26]. However, after collecting new data and revising the risk assessments [27], the U.S. EPA made in October 2003 the final decision not to regulate dioxins because dioxins from biosolids do not pose a significant risk to human health or the environment [28].

Class A Biosolids

It has been acknowledged that public acceptance can be increased by upgrading biosolids processing standards from Class B to Class A and/or Exceptional Quality. Some local and county agencies, for example in Southern California, have now prohibited land application of Class B biosolids and only accept Class A biosolids. The Part 503 Biosolids Rule specifies several alternatives for production of Class A biosolids; nevertheless, the vast majority of biosolids applied to land in 2000 were still of Class B quality [18]. In a 1999 guidance document, the U.S. EPA provided additional information on the Pathogen Equivalency Committee (PEC) and approved processes for Class A biosolids production [14]. Two-phase thermo-meso anaerobic digestion with intermittent feeding to each digester four times per day was recommended as equivalent to a PFRP (Table 4). Thermophilic anaerobic digestion is an attractive treatment because it may be less expensive than most other options for Class A biosolids production and can relatively easily be implemented by conversion of mesophilic digesters to thermophilic operation [e.g., 29,30,31,32,33,34,35,36,37]. One of the alternatives is composting, which has been promoted by the U.S. EPA as a "highly effective way of stabilizing and reducing pathogens in biosolids, resulting in a valuable soil conditioning product that often has many useful properties" [3]. Another option for producing Class A biosolids is thermal drying, which may be attractive from the perspective of public acceptability in that the biosolids volume is significantly reduced and odors are mitigated.

Pathogen Regrowth

Regrowth of pathogens or indicator bacteria has sometimes been observed during post-treatment and storage of Class A biosolids [38,39]. Pathogen regrowth during in-plant storage is particularly important, because biosolids are often stored for a few hours or overnight before being loaded for transport, and Class A pathogen requirements need to be met at the last point of control by the plant. This point usually is when biosolids are prepared for transport to the land.

Pathogen regrowth in Class A biosolids has recently been selected as one of the research areas sponsored by the Water Environment Research Foundation.

Ongoing Research

WERF, U.S. EPA and other organizations are currently sponsoring research that addresses the negative issues of biosolids land application. These issues are mainly focused on odor emissions and pathogens. Odor studies are focused on: i) investigating the mechanism by which polymers used for biosolids conditioning may generate foul odor during application of biosolids to land by either the release of amines from certain polymer types [40] or by degradation of protein captured within polymer flocks [41]; ii) defining an "odor index" that will help to evaluate odor emissions from existing biosolids processes with the aim of minimizing odors [42]; iii) characterizing odorous as well as biosolids air and odor emission risk assessment. Pathogen studies are focused on: i) screening, identifying, and selecting an appropriate surrogate human parasite(s) as well as the development of related laboratory procedures; ii) assessing the fate of emerging pathogens in biosolids; iii) assessing the bioassay procedures for biosolids to address concerns about human health and environmental impacts from biosolids use.

Recently, the U.S. EPA announced its action plan [43] in response to recommendations made by the National Research Council after reviewing the technical basis of the chemical and microbial regulations regarding biosolids land application [44]. This action plan contains 14 specific projects, to be initiated between 2004 and 2007, and which address several areas for research and outreach.

Table 8. EU: Additional national regulations over the 1986 Directive [44].

Additional Regulation	Country
Lower heavy metal limits	Belgium, Denmark, Finland, the Netherlands, Sweden
Pathogen limits	France, Italy, Luxembourg
Organic compounds limits	Austria, Belgium, Denmark, France, Germany, Sweden
Regulations similar to as in EU	UK

EU REGULATIONS

Regulations regarding the agricultural use of biosolids in the EU have been described in a 1986 Directive containing 18 articles [1]. Individual member states are allowed to adopt standards more stringent than those established by the EU. As summarized in Table 8, some individual states have adopted lower heavy metal limits, or have included limits for pathogens and/or organic pollutants [44]. In a recent working document [45], additional regulations and revisions to the 1986 Directive have been proposed, which include requirements for organic pollutants, pathogens, and treatment processes. These are not likely to take effect until 2005 [44].

Pollutant Concentrations

Table 9 compares pollutant standards from the U.S., the EU and the Netherlands. Generally, the standards from the Netherlands are the strictest ones. The relative values of the standards can be visualized in Figure 1, in which the standards for each metal are normalized with respect to the U.S. pollution concentration limit. Nor-

Table 9. EU: Comparison of pollutant (metal) limits for the EU, the Netherlands and the U.S.

	EU limits [45]						U.S. EPA limits [7]	
Pollutant	Current Upper	Current Lower	Short-term	Medium-term	Long-term	Netherlands limit [6]	Ceiling Concentration	Limit Concentration
Arsenic						15	75	41
Cadmium	40	20	10	5	2	1.25	83	39
Chromium			1,000	800	600	75		
Copper	1,750	1,000	1,000	800	600	75	4,300	1,500
Lead	1,200	750	750	500	200	100	840	300
Mercury	25	16	10	5	2	0.75	57	17
Molybdenum							75	
Nickel	400	300	300	200	100	30	420	420
Selenium							100	100
Zinc	4,000	2,500	2,500	2,000	1,500	300	7,500	2,800

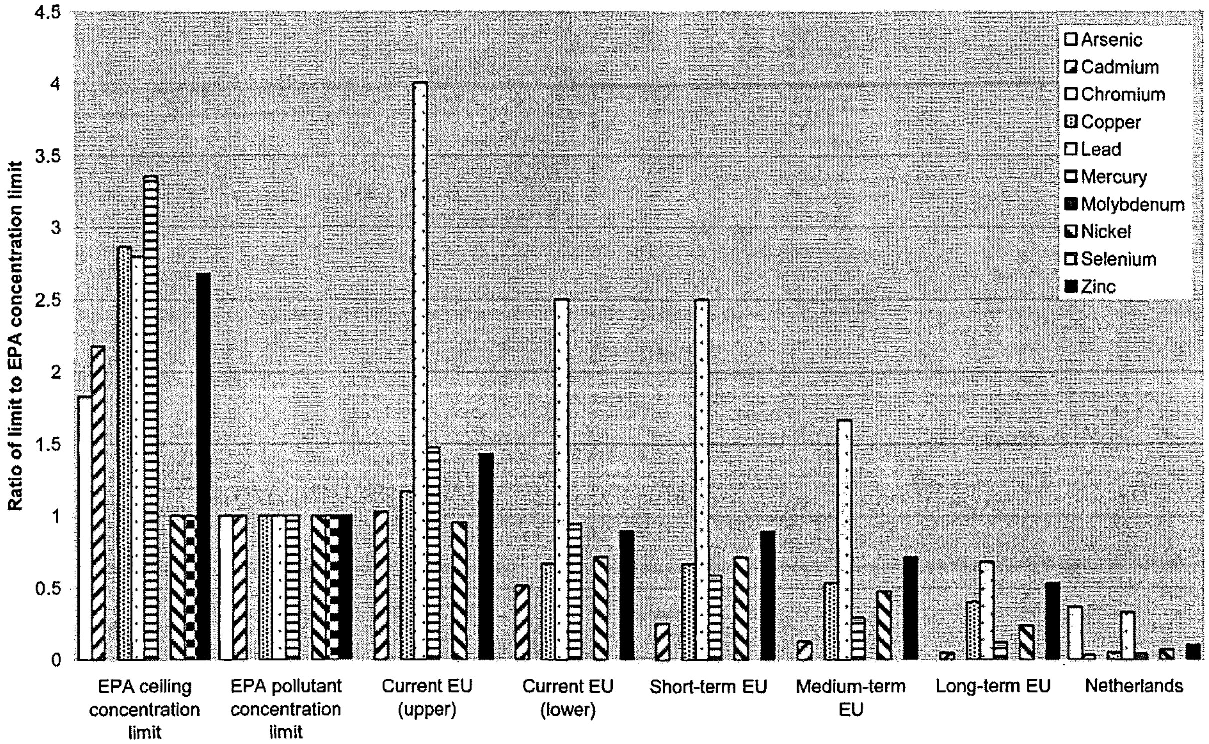

Figure 1. *Comparison of heavy metal concentrations allowed in biosolids [6,7,46].*

malization is obtained by dividing the limits for each metal by the U.S. pollution concentration limit. In Figure 1, two values are shown for the current EU limits. The values represent normalized upper and lower values of the range in Table 9. Clearly, the limits set by the Netherlands are stricter than any of the other limits. Also, the limits for lead in all the EU standards are less stringent than limits from the U.S. and from the Netherlands. It can further be seen that limit concentrations in the EU are expected to decrease significantly over the long-term. In addition to heavy metals, the EU is considering setting limits to the concentrations of certain groups of organic pollutants (Table 10).

Table 10. EU: Proposed limit concentrations of organic pollutants in biosolids [45].

Organic Pollutant	Limit Concentration (mg/kg DS)
Halogenated organic compounds	500
Linear alkylbenzene sulphonates	2600
Di(2-ethylhexyl)phthalate	100
Nonylphenol and nonylphenolethoxylates	50
Polycyclic aromatic hydrocarbons	6
Polychlorinated biphenyls	0.8
Polychlorinated dibenzodioxins/dibenzofurans	0.0001 (total equivalents)

Pathogen Densities

Whereas metal limits are in general lower in the EU than in the U.S., the opposite is the case for pathogen limits although legislation in both continents shares common features [6]. The EU 1986 Directive does not specify limits for pathogen densities, but requires treatment of biosolids prior to land application in order to reduce pathogen densities unless the biosolids are injected or incorporated into the soil (Article 6(a)). Requirements for biosolids treatment are the responsibility of individual member states. For instance, the treatment processes adopted by the UK are comparable to the U.S. processes to significantly reduce pathogens (PSRPs) for biosolids Class B production [6]. These include such processes as aerobic digestion, composting and lime stabilization. Site restrictions on the application of biosolids on farmland exist, depending on the purpose of the land and/or the agricultural crop. The proposed regulations in the 2000 working document developed by the EU are more specific towards pathogen reductions, treatment processes and site restrictions in land application (Table 11 and 12). The document distinguishes between advanced treatment (comparable to Processes to Further Reduce Pathogens, PFRPs, in the Part 503 Biosolids Rule for Class A biosolids)

Table 11. EU: Proposed advanced and conventional treatments for biosolids, and pathogen density limits [45].

Conventional	Advanced
General Requirements	
• >2 $\log_{10}$ reduction of *Escherichia coli*	• >6 $\log_{10}$ reduction of *Escherichia coli* to less than 500 CFU/g WS • Initial validation of process through 6 $\log_{10}$ reduction of test organism such as *Salmonella Senftenberg* W775
Treatment Options	
• Thermophilic aerobic stabilization at ≥55°C at a mean retention period of 20 days • Thermophilic anaerobic digestion at ≥53°C with a mean retention period of 20 days • Conditioning with lime to pH ≥ 12 for at least 24 hours • Mesophilic anaerobic digestion at 350C with a mean retention period of 15 days • Extended aeration at ambient temperature as a batch (time dependent on prevailing climatic conditions) • Simultaneous aerobic stabilisation at ambient temperature (time dependent on prevailing climatic conditions) • Storage in liquid form at ambient temperature as a batch (time dependent on prevailing climatic conditions)	• Thermal drying at ≥80°C to water content ≤10% while maintaining a water activity of ≥0.90 during the first hour • Thermophilic aerobic stabilisation at ≥55°C for 20 hours as batch • Thermophilic anaerobic digestion at ≥53°C for 20 hours as batch • Thermal treatment of liquid sludge at 70°C for ≥30 minutes, followed by mesophilic digestion at 35°C at a mean retention period of 12 days • Conditioning with lime to pH ≥12 while maintaining ≥55°C for 2 hours • Conditioning with lime to pH ≥12 for >3 months

and conventional treatment (comparable to PSRPs in the Part 503 Biosolids Rule for Class B biosolids). Limits are also defined for the densities of *Escherichia coli* and *Salmonella* sp. According to the proposed regulations, thermophilic anaerobic digestion is an advanced treatment if a temperature of at least 53°C is maintained for 20 hours as a batch. Biosolids produced in an advanced treatment have basically no restrictions in land application, whereas conventional treatments produce biosolids with a much more limited applicability (Table 12).

Sampling and Monitoring

Under the present regulations the member states decide on the required frequency of sampling of biosolids and soil, and the required analyses. The 2000 working document specifies the frequency of sampling, based on the quantity of biosolids produced, as summarized in Table 13.

FUTURE DEVELOPMENTS IN THE EU

Public Acceptance

Debates on biosolids use differ in intensity and outcome in the member states [44,46]. In some countries the debate is over, resulting either in a general acceptance (e.g., Denmark, UK) or in restrictions that in effect prevent the land application of biosolids (Belgium,

Table 12. EU: Biosolids uses produced from advanced and conventional treatment [45].

Application	Advanced Treatment	Conventional Treatment
Pasture land	Yes	Yes, deep injection and no grazing in following six weeks
Forage crops	Yes	Yes, no harvesting in six weeks following spreading
Arable land	Yes	Yes, deep injection or immediate ploughing down
Fruit and vegetable crops in contact with ground	Yes	No. No harvest for 12 months following application
Fruit and vegetable crops in contact with ground and eaten raw	Yes	No. No harvest for 30 months following application
Fruit trees, vineyards, tree plantations and re-forestation	Yes	Yes, deep injection and no access to public in 10 following months folowing spreading
Parks, green areas, city gardens, all urban areas where general public has access	Yes, only well-established and odorless biosolids	No
Forests	No	No
Land reclamation	Yes	Yes, no access to public in 10 months following spreading

Table 13. EU: Proposed sampling frequency [45].

Biosolids (tonnes DS per year)	Frequency (minimum number per year)				
	Agronomic Parameters[a]	Heavy Metals	Organic Compounds	Dioxins	Microorganisms
<250	2	2	–	–	2
250–1000	4	4	1	–	4
1000–2500	8	4	2	–	8
2500–4000	12	8	4	1	12
>4000	12	12	6	1	12

[a]Dry and organic matter, pH, primary nutrients (N, P, K), secondary nutrients (Ca, Mg, S), micro-nutrients (B, Co, Fe, Mn, Mo)

the Netherlands). In other countries, discussions have just started or biosolids land application is not a matter of major concern. Despite these differences, the EU is seeking to promote biosolids land application by reducing potential risks, by further research, and by increasing public confidence [47].

Pollutants

The 2000 Working Document proposes to include limits to certain groups of organic compounds (Table 10), although it has been recognized that metal contamination of biosolids is more important with respect to human health [48,49]. Only a few studies have been performed on organic compound concentrations in biosolids, and a full evaluation is further hampered by the fact that at present no universally accepted and validated analytical methods exist for analyzing most organic compounds [46]. Nevertheless, the few studies that were conducted seem to indicate that for certain organic compound classes the concentrations in biosolids often exceeded the limits proposed in the 2000 Working Document [46,48,49]. The costs for compliance, though difficult to estimate, are likely to be significant [46].

DISCUSSION AND CONCLUSIONS

Beneficial biosolids use through land application is encouraged in the U.S. and Europe as a way to reduce the volume of waste sludge that would have to be landfilled, incinerated or otherwise disposed of. Legislation regarding biosolids land application on both continents shares the overall purpose of protecting the environment and human and animal health. This is done through regulations that set limits on the amount of pollutants and pathogens in biosolids, require management practices, and impose site restrictions on land application. Many differences exist in specific requirements, and, in general, current legislation in the U.S. focuses on reduction both of pathogens and of pollutants whereas European legislation is directed more towards the regulation of pollutants. Both the U.S. EPA and the EU are further developing legislation, and it is likely that differences will become less apparent after future revisions. From a practical point of view, however, additional state (U.S.) or national (EU) regulations are often the real challenge for wastewater treatment plants rather than the regulations from U.S. EPA or EU.

With respect to future regulations, it can be foreseen that limits for pollutants and pathogens will become more stringent. Pathogen standards are technology-based, but there is uncertainty about: i) the efficiency of accepted technologies in disinfecting biosolids; ii) the prevalence of "new" pathogens that were not considered in the present regulations; iii) the use and selection of indicator organisms for assessment of overall pathogen reduction; and iv) the stability of biosolids with respect to growth and/or reactivation of indicator and pathogenic bacteria. The NRC recommended a national survey of pathogen occurrence in biosolids as new information has become available on pathogens that were not considered for the Part 503 Biosolids Rule [44]. The use of *Clostridium perfringens* as an additional indicator for monitoring pathogens was also recommended. This species is present in biosolids at a relatively high density and its spores are relatively tolerant to high temperatures. A similar suggestion was recently made to the EU [50]. Finally, it has been recommended to improve and standardize biosolids sampling procedures and analytic techniques for enumeration of pathogens, and to validate current treatment processes for pathogen reduction [44,50].

Likewise, there is concern about meeting proposed

Table 14. Comparison of pollutant concentrations in US sewage sludges and biosolids and proposed limits in EU (mg/kg dry wt).

	Proposed Ceilings in EU		U.S. Sewage Sludges and Biosolids		
Pollutant	Year 2015	Year 2025	NSSS 1988 (mean)	Pennsylvania, 1996–97 (median / 95th percentile)	TITP, 2001, Los Angeles, CA (mean)
Arsenic	–	–	9.9	3.6/18.7	11.5
Cadmium	5	2	6.9	2.26/7.39	3.2
Chromium	800	600	119	35.1/314	–
Copper	800	600	741	511/1382	265
Lead	500	200	134.4	64.9/202	59
Mercury	5	2	5.2	1.54/6.01	3
Molybdenum	–	–	9.2	8.18/36	25
Nickel	200	100	42.7	22.6/84.5	46.5
Selenium	–	–	5.2	4.28/8.47	58
Zinc	2000	1500	1202	705/1985	964
Reference	[45]	[45]	[7]	[51]	[31]

limits for pollutants. The presence of pollutants in biosolids is related to domestic and industrial emissions and urban run-off. Sludge treatment at wastewater treatment plants may be able to remove biodegradable pollutants depending on actual treatment conditions; however, heavy metals and persistent organic compounds will remain in biosolids after treatment with present technologies.

In Table 14, proposed EU limits are compared to the metal pollutant concentrations found in biosolids in the U.S. in various studies and surveys. A generally declining trend of pollutant concentrations over the years can be discerned [51], which can probably be attributed to improved emission control at the source. Nevertheless, it can be seen, that if the U.S. EPA would adopt EU limits, U.S. wastewater treatment facilities with relatively high pollutant concentrations (e.g., 95th percentile of the 1996-1997 Pennsylvania survey) would face difficulties in meeting most of the future EU limits proposed for heavy metals. As current heavy metal concentrations in sewage sludge and biosolids seem to be the lowest attainable with current pretreatment technologies and standards [51], this would imply a need for development of new technologies for further reducing heavy metal concentrations, perhaps involving precipitation or adsorption to a suitable porous solid. It is also possible that new technologies will be needed to remove or decompose toxic compounds.

Regulatory agencies in U.S. and Europe have been advised to scientifically substantiate the selection and concentration limits of pollutants most critical to safe use of biosolids and the approved treatment processes for stabilization and disinfection of biosolids [44,46,49]. This is a difficult task because, for example, over 330 organic compounds with known or suspected toxic effects have been detected in sewage [48].

Decreasing the presence of these pollutants in biosolids has so far been accomplished almost entirely by emission reduction at the source. For example, emission control technologies and reduction of use have led to decreasing concentrations of e.g. phthalates, nonylphenol, polyaromatic hydrocarbons and dioxins in biosolids over the past years [48,49]. However, the introduction of new chemicals and increased use of others have resulted to their presence in biosolids. Brominated diphenyl ethers (flame retardants), nitro musks (synthetic perfumes), linear alkylbenzene sulfonates (detergents), pharmaceutical compounds, odorants (biosolids odor) and polyelectrolytes (biosolids dewatering) have been identified among others as emerging pollutants of potential significance in biosolids both in Europe and the US [44,49].

In conclusion, long term changes in the Part 503 Biosolids Rule that can be expected are [52]; i) odor may be eventually regulated if a relationship to public health is established; ii) Class B biosolids may no longer be acceptable for land application; iii) more pollutants and emerging pathogens may be included; and iv) certain pharmaceutical products, such as antibiotics and endocrine disruptors, may be further regulated. Although these issues have been raised, no scientific evidence exists that the current practice of biosolids land application is harmful either to human health or to the environment. The current standards for biosolids in the U.S. and in some EU member states are based on scientific risk assessments. Future U.S. and EU legislation on the land application of biosolids may become more complex with new scientific and technological advancements becoming available, however, future standards should continue to be based on science.

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