



GUIDE TO BIOSOLIDS QUALITY

GUIDE TO BIOSOLIDS QUALITY

By

Dr. Shannon M. Mitchell, Assistant Professor, University of South Alabama,
Georgine Yorgey, Assistant Director, Center for Sustaining Agriculture and
Natural Resources, Washington State University, **Chad Kruger**, Director,
Center for Sustaining Agriculture and Natural Resources, Washington State
University

Abstract

Biosolids are the material produced from digestion of sewage at city wastewater treatment plants. Biosolids may be spread over land for plant fertilization and soil conditioning.

This publication summarizes the benefits of land-applied biosolids, describes and discusses major categories of contaminants, and explains what is currently known about emerging contaminants in biosolids. While this publication does not include a comprehensive list of individual contaminants, it does discuss the more relevant classes of contaminants.

Table of Contents

Introduction	3
Biosolids Quality: Crop Production Benefits	4
Organic Carbon	5
Macronutrients	5
Micronutrients	6
Biosolids Quality: Contaminants	6
Metals	6
Pathogens	6
Antibiotics and Antibiotic-Resistant Bacteria	7
Industrial and Household Chemicals	8
Odorants	9
Aerosols	9
Summary	9
For More Information	9
Acknowledgments	9
Guide to Biosolids Quality—	
Appendix A	10
Part I: Organic Contaminants	10
Part II: Biological Contaminants	11
Glossary	13
References	17

Guide to Biosolids Quality

Introduction

Biosolids are the **biomass** material produced following **aerobic and anaerobic digestion** at **municipal wastewater treatment facilities**. **Sewage sludge**, food particles, feces, and other organic solids are converted biologically, within engineered systems, to produce a completely transformed biosolids product. Biosolids are comprised of living and dead wastewater treatment **microorganisms**, small **inorganic** particles, and **insoluble** compounds. In Washington State, biosolids are most often land applied for plant fertilization and soil conditioning as part of a **sustainable practice** to manage municipal **wastewater residuals** (Figure 1).

Like animal manures, biosolids are a source of plant nutrients and stable **carbon compounds**. When biosolids are land applied for crop production, plant nutrients and **organic matter** improve crop production, allowing for recycling of nutrients, and reducing the amount of **synthetic** fertilizers needed. For example, approximately 5,000 tons of nitrogen (N) and 2,000 tons of phosphorus (P) were recycled in Washington State in 2012 by land-applying biosolids (WA Dept. of Ecology 2014a; Sullivan et al. 2015).

Land-applying biosolids keeps valuable organic carbon and plant nutrients from being disposed of in landfills or incinerated. In Washington State, approximately 81% of biosolids are land applied, 18.5% are incinerated, and 0.5% is disposed of in landfills (Figure 2). Of the portion that is approved for land application, 70% is used in agriculture, 25% is used in residential or commercial settings, and 5% is used in forestry (Figure 2).

Class A biosolids can be used as a fertilizer in residential or commercial areas. The Washington State University (WSU) publication [Using Biosolids in Gardens and Landscapes](#) (Cogger 2014) provides information on Class A biosolids use. **Class B biosolids** are used as a fertilizer in Washington State for wheat, alfalfa, and timber production (WA Dept. of Ecology 2014a). The WSU publication [Fertilizing with Biosolids](#) (Sullivan et al. 2015) provides information on Class B biosolids use in agriculture.

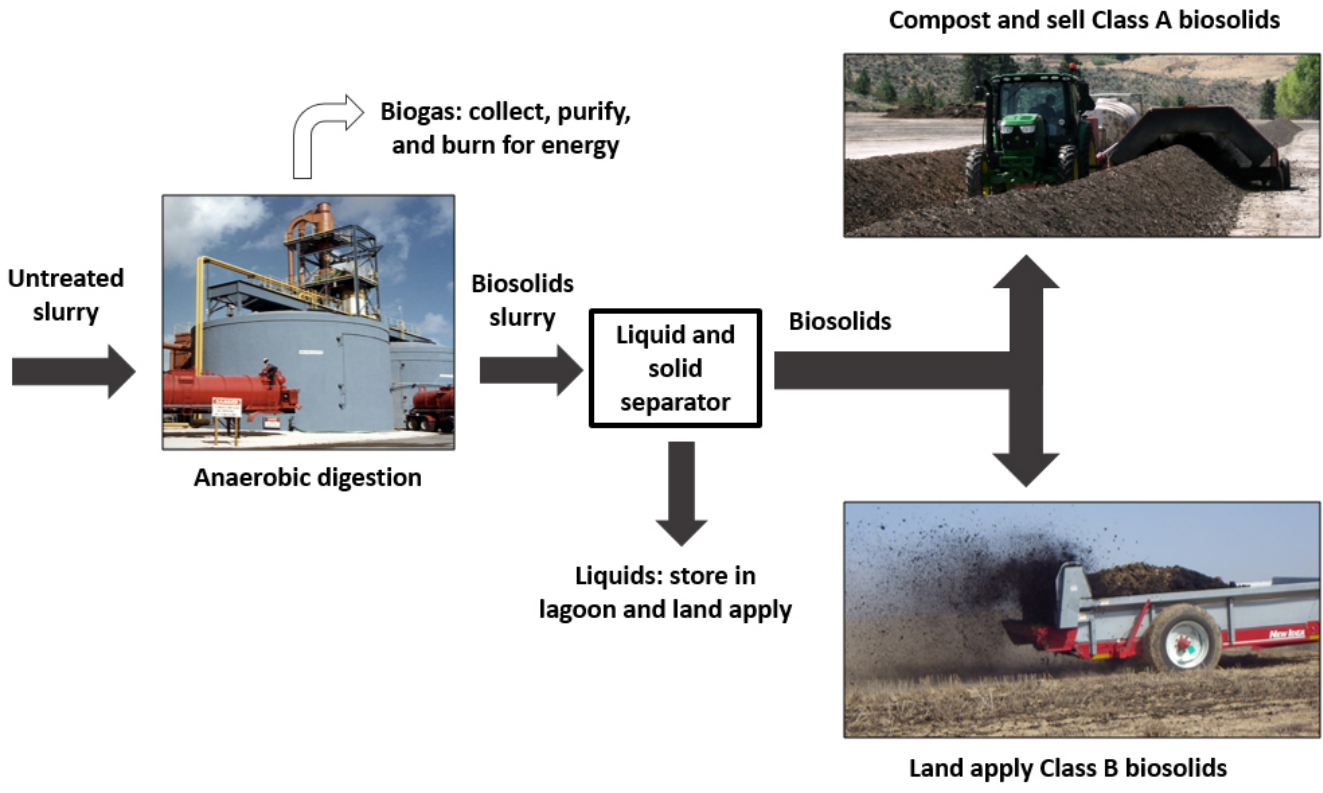


Figure 1. Treatment of sewage slurry using anaerobic digestion. Adapted from: Slurry, Options for slurry treatment by anaerobic digestion. Department of Environment, Food and Rural Affairs (Defra) 2011. (Land application photo by Andy Bary, WSU; anaerobic digestion photo from [Energy.gov Flickr page](#) and compost photo from [Food and Drug Administration Flickr page](#) per [USA.gov U.S. Government Works.](#))

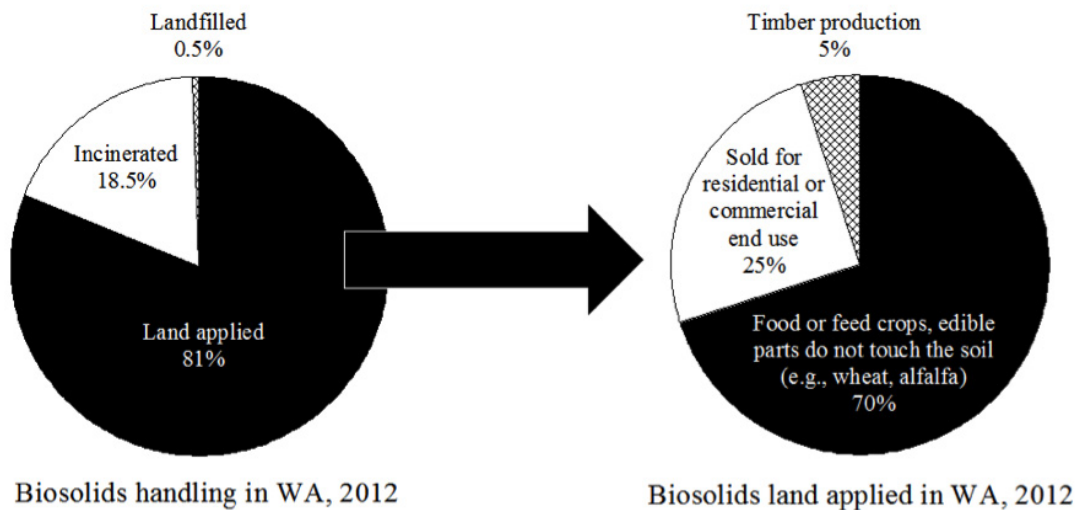


Figure 2. Biosolids use data for 2012, by percentage, for Washington State. Approximately 110,000 dry tons of biosolids were handled in Washington in 2012 (WA Dept. of Ecology 2014a). (Illustration by Shannon M. Mitchell, USA)

*Class A biosolids are used as a soil amendment and plant fertilizer in gardens and landscapes. They meet EPA standards for regulated **contaminants**, and they have been treated to reduce **biological contaminants** to very low levels.*

Class B biosolids are used as a soil amendment and plant fertilizer for agricultural land, timberland, rangeland, and land reclamation sites. They meet the criteria for regulated contaminants, and the level of biological contaminants has been substantially reduced. Plants whose edible parts do not make contact with the soil when harvested, such as wheat, barley, and alfalfa, can be harvested 30 days after the last biosolids application.

Recycling biosolids means that they are used for a useful purpose, instead of being disposed of in landfills or incinerated. Recycling biosolids through land application as a soil amendment and fertilizer is highly regulated. Only biosolids that meet the criteria for maximum allowable concentrations of potentially toxic **trace elements** and **pathogens** are land applied. There are also required setback distances from water sources to limit the potential for contamination of surface water and **groundwater** (WA Dept. of Ecology 2014a).

Scientific research shows that there are many **agronomic** benefits and minimal environmental or human health risks from biosolids when land application follows federal regulations (Cogger et al. 2013; EPA 2014a; Sullivan et al. 2015). Nevertheless, the public has many questions regarding biosolids recycling, and some are apprehensive about supporting biosolids land application because some contaminants can be found in biosolids.

This Washington State University (WSU) publication summarizes the benefits of land-applied biosolids, describes and discusses major categories of contaminants, and explains what is currently known about **emerging contaminants** in biosolids. This publication does not include a comprehensive list of individual contaminants, but rather, discusses the more relevant classes of contaminants. The WSU publication [Fertilizing with Biosolids](#) (Sullivan et al. 2015) provides more information on plant nutrients in biosolids, application guidelines, and soil quality benefits.

Biosolids Quality: Crop Production Benefits

The major benefit of using biosolids as a fertilizer and **soil conditioner** for crop production is that it can be an inexpensive method for providing nitrogen and improving soil quality. Class B biosolids are less expensive for farmers to use than synthetic fertilizers, and agricultural operations using biosolids have the same or increased crop yield and crop quality as crops grown with synthetic fertilizers (Epstein 2003; Cogger et al. 2013). The desirable aspects of biosolids for crop producers are summarized below.



Figure 3. Biosolids being spread on agricultural fields (left), and biosolids covering agricultural soil prior to incorporation (right). (Photos by Andy Bary, WSU)

Organic Carbon

The organic carbon (organic C) content in biosolids ranges from 5% to 54%, with a mean value of 24% (Girovich 1996; Gilmour et al. 2003). Adding organic C to soils low in organic matter improves soil quality. Physical improvements include higher **soil porosity**, **soil aggregation**, **water-holding capacity**, and lower **bulk density** (Epstein 2003). Plants grown in biosolids-amended soils exhibit improved root to shoot ratios as a result of decreased resistance to root penetration. Organic C is also a source of food for soil microorganisms and **macrofauna**.

Macronutrients

Organic nitrogen (organic N) is the primary nutrient in biosolids. Biosolids are a slow-release N fertilizer compared to synthetic fertilizers (e.g., anhydrous ammonia). Other plant **macronutrients** that are abundant in biosolids include phosphorus (P), magnesium (Mg), and calcium (Ca). However, there are only low levels of potassium (K), so supplements may be needed if soil analysis shows that concentrations of this element are below optimal levels (Epstein 2003).

In Washington State, the amount of biosolids land applied to a given site is calculated as part of the Washington Department of Ecology biosolids land-application program (WA Dept. of Ecology 2014b), so maximum crop yield can be targeted, while reducing the risk of **nitrate leaching**. Typically from 2 to 10 dry tons per acre (5–20 metric ton/hectare) of biosolids are applied to agricultural fields every 1 to 5 years (Girovich 1996). They can be applied in liquid slurry or solid form. The solid form is typically applied to fields with a spreader and then incorporated into the soil by tilling or disking (Figure 3).

Cogger et al. (2013) compared biosolids and anhydrous ammonia fertilizers in a dryland wheat–fallow rotation. Biosolids were applied at 2, 3, and 4 dry tons per acre (5, 7, and 9 metric ton/hectare). Biosolids treatments were applied once every 4 years for 16 years. Standard anhydrous ammonia application was done once every 2 years for 16 years for the synthetic fertilizer treatment. On average, over the eight harvests from the wheat–fallow rotation, the biosolids-amended fields produced equal or greater wheat yields compared to the fields fertilized with anhydrous ammonia. Wheat harvesting and sample collection in fields where biosolids were applied is shown in Figure 4.



Figure 4. Wheat harvesting and sample collection from fields where Class B biosolids were land applied. (Photo by Andy Bary, WSU)

Micronutrients

Plant **micronutrients** in biosolids include boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (M), molybdenum (Mo), zinc (Zn), and nickel (Ni). Other chemical elements in biosolids, such as cobalt (Co), sodium (Na), selenium (Se), and silicon (Si), can also be beneficial to plants at low concentrations (Girovich 1996; Epstein 2003; Goodman 2004). If farmers are supplementing micronutrients, biosolids can reduce or eliminate the need for these supplements. Some farmers might not find it cost effective to apply micronutrients (e.g., not enough yield benefits to justify the cost); however, soils will receive these nutrients as an added benefit when biosolids are applied.

Biosolids Quality: Contaminants

Municipal wastewater treatment facilities treat wastewater from industrial and household sources that may contain various contaminants. Those contaminants that bind to organic or inorganic particles and are not degraded normally remain in the wastewater solids, which are eventually converted into biosolids (Girovich 1996; Epstein 2003). Contaminants can include metals, pathogens, **antibiotics**, some industrial and household chemicals, **odorants**, and **aerosols**.

A representative biosolids sample is tested for regulated contaminants and plant nutrients as part of the biosolids land-application program. In addition, many researchers and the **Environmental Protection Agency (EPA)** have surveyed numerous biosolids throughout the United States for a multitude of regulated and non-regulated contaminants, so the approximate contaminant concentration range is known. The types of contaminants that can be found in biosolids are summarized below and are discussed further in Appendix A.

Metals

Trace elements, including **heavy metals**, can be found in biosolids. Trace elements exist naturally in the environment and in agricultural soils and many are beneficial to living organisms. However, trace element concentrations in excess of beneficial levels can be toxic. Plants can uptake soluble or available trace elements into their roots and leaves. They are taken up to a lesser extent in fruits, seeds, and flowers (Epstein 2003).

Potentially toxic trace elements in biosolids are regulated and monitored in biosolids land-application programs. Concentrations of metals in biosolids have fallen sharply over the last 40 years since the passage of the **Clean Water Act** of 1972. Metals are no longer present in biosolids at concentrations that could cause human, animal, or environmental health issues (Cogger et al. 2000).

Metals bind to soils and have limited solubility in soils with a neutral pH, which lowers the risk of exposure to these metals.

There are several reasons why metal concentrations in biosolids should not be a concern when biosolids are applied to agricultural soils, but two major reasons are metal **sorption** characteristics and soil **pH**. Some metals bind to **hydrous oxide** surfaces and organic matter in soils, significantly lowering the amount that is plant-available (Epstein 2003). Metals are soluble at acidic pH levels, but most metals have drastically reduced **solubility** in the typical crop soil pH range of 5.5 to 7.5. When metal solubility decreases, it limits their transport and **bioavailability** (Epstein 2003). For example, aluminum is insoluble in soils above pH 5.5, so only a small fraction of the total aluminum is available for plant uptake in agricultural soils with a pH greater than 5.5.

Pathogens

Pathogens are disease-causing agents, and some pathogens are present in Class B biosolids. Pathogens are a universal problem in waste-derived soil amendments and even in yard debris with residual pet or animal waste (Table 1; WA Dept. of Ecology 2009; Gerba et al. 2011). Levels of **pathogenic bacteria** are lower in biosolids than in manure, but the number of **viruses** is higher in biosolids (Table 1). Free-range animals, such as deer and birds, living on agricultural lands also contribute to pathogen levels in soils.

The fate of pathogens in soils and crops is dependent on several factors, including climate and soil characteristics. Pathogen levels decrease in soil-crop systems over time due to pathogen sensitivity to heat, sunlight, drying, and competing **microbes**. Pathogens can live in soils and on plants, but plants do not uptake pathogens. Some **bacterial pathogens** and viruses survive for as long as several months (Gerba and Smith 2005). Pathogens do not leach through soil, but they can be transported by **surface runoff**.

There is the potential for pathogens to regrow in biosolids if climate and soil conditions are not harsh enough to kill them off, such as under moist and cool conditions. However, biosolids-amended soil is not a **reservoir for pathogens** following the end of the pathogen life-cycle (Epstein 2003). A review of pathogen **risk assessment** research confirms that current biosolids land-application guidelines are appropriate for protecting public health (Oun et al. 2014).

Table 1. Approximate concentrations of selected pathogenic bacteria and viruses in Class B biosolids, manure, and pet feces.

Pathogenic organism	Concentration (organism/g, dry weight)		
	Biosolids ^a	Manure ^a	Pet feces ^b
Bacteria			
<i>Campylobacter jejuni</i>	2	1400	
<i>E. coli</i> O157:H7	< 1	110	
<i>Listeria monocytogenes</i>	20	210	
<i>Salmonella</i>	50	180	1,000,000
Viruses			
Adenoviruses	20	Not detected	
Enteroviruses	< 1 to 30	Not detected	501,000

^aBacteria reported in colony-forming units per gram and viruses reported in plaque-forming units per gram (King et al. 2011).

^bValues reported in organisms per gram (Gerba et al. 2011).

Hot, dry soils exposed to sunlight create conditions that kill pathogenic bacteria and viruses. After pathogens die, they can no longer cause illness. The risk of pathogen or viral infection to the general public are low because plants do not uptake pathogens, and fresh crops whose harvested parts come into contact with the soil are not grown using Class B biosolids.

Table 2. Maximum concentrations of selected antibiotics in biosolids and cattle manure.

Antibiotic class	Maximum concentration (mg/kg, dry weight)	
	Biosolids	Cattle manure
Macrolide	6.5 ^a	8.1 ^b
Sulfonamide	0.65 ^a	0.36 ^c
Tetracycline	8.7 ^a	6.6 ^b

^aEPA (2009)

^bMassé et al. (2014)

^cZhao et al. (2010)

Antibiotics and Antibiotic-Resistant Bacteria

Antibiotics can be found in biosolids or manure because many of them are not completely metabolized before being excreted in urine and feces. Maximum levels of some antibiotics in biosolids and cattle manure are similar (Table 2). Antibiotic concentrations in swine manure are higher, ranging from 4 to 59 mg/kg and from 7 to 760 mg/L (Heuer et al. 2011; Massé et al. 2014).

In addition to relatively low antibiotic concentrations in biosolids, those antibiotics that are found in biosolids tend to bind tightly to soil particles, which reduce their **biological activity**. Research on antibiotics in biosolids continues; however, to date, antibiotics have not been found to accumulate in soils or have adverse effects on microorganisms at concentrations found in land-applied biosolids. To date, the scientific literature shows that bioavailable antibiotic concentrations in biosolids are not high enough to influence **antibiotic resistance**.

Antibiotic-resistant bacteria are found in biosolids, manure, and even pristine soils (Minur et al. 2011; Brooks et al. 2015). The main concern with levels of resistant bacteria and antibiotics in biosolids or manure is that they may increase the risk of pathogenic bacteria acquiring antibiotic-resistance traits. Research shows that land-applied manure containing antibiotics and resistance genes can significantly influence resistant bacterial populations in soils (Heuer and Smalla 2007; Heuer et al. 2011).

In contrast, levels of resistant bacteria in soils amended with biosolids were not significantly different from unamended soils or soils fertilized with a synthetic fertilizer (Zerzghi et al. 2010). Research in the area of bacterial resistance continues, but currently the public health risk from resistant bacteria in biosolids is considered to be low. Risks are minimized by restrictions on public access to biosolids and by rules that limit the types of crops that can be grown using Class B biosolids (NRC 2002; Brooks et al. 2007; King et al. 2011).

Industrial and Household Chemicals

There can be numerous types of **persistent chemicals** in biosolids because biosolids are derived from industrial and household wastewater. Chemicals in biosolids can include **surfactants, plasticizers, pharmaceuticals, flame retardants,** and chemicals from **personal care products**—for example, **triclosan**, which is found in some hand soaps (Figure 5). These substances are not regulated by the EPA because risk assessments have so far shown that organic chemicals pose minimal risk to human health and the environment at the concentrations commonly found in land-applied biosolids.

Supplementing EPA risk assessments, Smith (2009) performed risk assessments for surfactants, **dioxins**, pharmaceuticals, **estrogenic compounds**, and other **organic contaminants** found in biosolids, concluding that they pose minimal risk to human health if the biosolids are land-applied on agricultural soils at normal agronomic rates. Additionally, Rocarro et al. (2014) performed risk assessments for pharmaceuticals and personal care products and found low risk for human health problems from land-applied biosolids.

Three primary factors govern the assessment that industrial and household chemicals in biosolids are not likely to endanger human health or the environment when land-applied. First, **degradation** and sorption effectively lower bioavailable contaminant levels. Second, plants do not uptake significant levels of organic contaminants. Third, the required setback distances for land-applied biosolids limit contaminant transport to water sources (Sullivan et al. 2015).

Many contaminants found in biosolids are also found in household dust, personal hygiene products, and manufactured foods. For example, median concentrations of a flame retardant, plasticizer, and perfluorinated chemical are at similar levels for biosolids and household dust (Table 3). Although these levels are similar, the general population is exposed to a substantially greater amount of household dust than biosolids.

Another example is the **antibacterial** ingredient triclosan, which is found in some hand soaps. This contaminant concentration was greater in biosolids than in household dust; however, the general population can be exposed to high concentrations of triclosan (1,000 mg/kg) when using some hand soaps (Figure 5).

Concentrations of the plasticizer **di(2-ethylhexyl) phthalate (DEHP)** in both biosolids and household dust are relatively high in comparison to the other chemicals listed in Table 3. DEHP is found in some **polyvinyl chloride (PVC) resin** (Figure 6), and small amounts of DEHP can leach from these plastic resins. For example, up to 24 mg/kg of DEHP was found in olive oil stored in plastic containers (EHHI 2008). Consequently, it appears that the public is exposed to DEHP in many products they use daily.

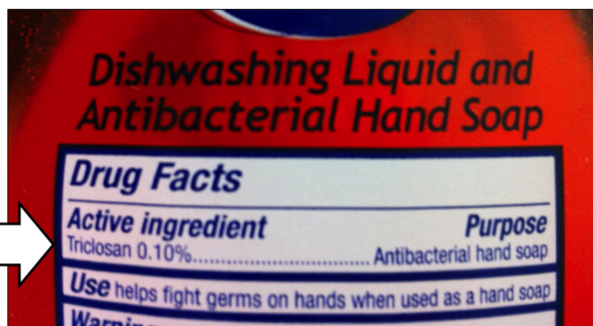


Figure 5. The antibacterial compound triclosan is found in some hand soaps. (Photo by Shannon M. Mitchell, USA)

Table 3. Median concentrations of selected contaminants in biosolids and household dust.

Category	Compound	Median concentration (mg/kg, dry weight)	
		Biosolids	Household dust
Flame retardant	PBDE 99	0.58 ^a	0.30 ^c
Plasticizer	BPA	1.00 ^a	1.46 ^d
Perfluorinated chemical	PFOS	1.02 ^a	0.48 ^e
Antibacterial	Triclosan	3.86 ^a	0.22 ^d
Plasticizer	DEHP	310.00 ^b	340.00 ^c

^aHiggins et al. (2010)

^bMaximum reported value from EPA (2009)

^cRudel et al. (2003)

^dGreens et al. (2009)

^eKato et al. (2009)








Symbol	Type of plastic	Example
	Polyethylene Terephthalate PETE	Beverage bottles
	High Density Polyethylene HDPE	Milk jugs
	Polyvinyl Chloride PVC with DEHP	Cooking oil bottles
	Low Density Polyethylene LDPE	Zip-lock bags
	Polypropylene PP	Yogurt containers
	Polystyrene PS	Styrofoam containers
	Other e.g., Polycarbonate with BPA	Canned foods

Figure 6. Plastic resin materials in plastic products. DEHP is found in some PVC resin (symbol #3), and bisphenol A (BPA), shown in the category of Other, can be found in the lacquer lining of canned foods (symbol #7). Adapted from: Plastics that may be harmful to children and reproductive health. Environment & Human Health, Inc. Report (2008).

Certain chemicals, such as triclosan, dioxins, persistent pharmaceuticals, and some surfactants might be more of an environmental concern than others. For example, triclosan has been found to **bioaccumulate** in earthworms; some pharmaceuticals are persistent and can leach through the soil and into groundwater; some surfactants are toxic to aquatic species.

Recently, the EPA identified safer and more environmentally friendly surfactant alternatives for industrial use, replacing common surfactants like **nonylphenol ethoxylates (NPE)**. The EPA now evaluates manufacturing processes that use surfactants to assess potential environmental and human health risks (EPA 2012; 2014b). Because emerging contaminants have been studied for a shorter period of time relative to metals, less information is available. Thus, continued research is needed to supply the information necessary for new or improved risk assessments.

Odorants

Odors from biosolids come from a complex mixture of odorants. Unpleasant odors are the main public complaint about land-applied biosolids (NRC 2002). Although odorants are a nuisance, they are not a public health threat (Girovich 1996). Biosolids produced at different facilities have different odors because the wastewater treatment processes used are not always the same.

Aerosols

Aerosols are comprised of very small airborne particles that may contain contaminants, such as pathogens or chemicals. They travel through the air, but they do not travel very far (usually less than 541 ft), and they do not remain airborne for very long (usually less than one hour) (Low et al. 2007; King et al. 2011).

*The fate of industrial and household chemicals in soils results in low **effective concentrations**. Most chemicals in biosolids tend to bind to soils, and they also degrade in biosolids-amended soils. Risks to the general public are minimal because plants do not uptake significant amounts of organic chemicals into their edible parts.*

To minimize human contact with significant concentrations of aerosols, there are public access restrictions for biosolids-application sites. Authorized individuals who come in contact with biosolids should follow basic hygiene precautions and wear appropriate personal protective equipment (CDC 2002).

Summary

Biosolids are land applied as a sustainable way to manage municipal wastewater residuals. There are many benefits to land-applying Class B biosolids on agricultural fields because biosolids are rich in organic carbon, nitrogen, phosphorus, and other plant nutrients. Equal or greater crop yields are obtained using biosolids compared to synthetic fertilizer. Incorporating biosolids into the soil improves soil porosity and water-holding capacity, among other soil characteristics, and biosolids can help improve soil quality for more effective crop production.

Land-applying biosolids is highly regulated by state environmental protection departments and the EPA because, along with the organic carbon and plant nutrients in biosolids, there are low levels of contaminants derived from industrial and household wastewater. To date, research indicates that contaminants in Class B biosolids pose minimal risk to human, animal, or environmental health. Ongoing research on biosolids continues to investigate contaminants and measure potential impacts. New research findings are reviewed periodically and risk assessments conducted to reevaluate the effectiveness of existing biosolids land-application regulations.

For More Information

For more information on biosolids, visit the Washington State University Biosolids Management [website](#).

Acknowledgments

The information in this publication is based on work supported by the National Institute of Food and Agriculture, the U.S. Department of Agriculture, under award number 2011-68002-30191, and the WSU Agricultural Research Center through the Biomass Research Funds. The authors would like to thank Dr. Craig G. Cogger, Washington State University Soil Scientist and Extension Specialist, for his expert review during the early stages of manuscript preparation.

Guide to Biosolids Quality— Appendix A

This appendix describes and discusses the major categories of contaminants that may be found in biosolids. Part I of this section covers the categories of organic contaminants, and Part II covers the categories of biological contaminants. When interpreting the information provided here, it is important to understand that exposure to contaminants through biosolids may be minimal compared to exposure through other pathways, such as household dust, personal hygiene products, uncontrolled burning, and animal manures.

Many contaminants degrade in the soil or are neutralized when they bind tightly to soil particles, so potential negative effects in the terrestrial environment may be short-lived. However, some contaminants persist in the environment and can be potentially harmful. If risk assessments show that significant risk exists from an organic contaminant, use of the chemical may be restricted or banned. Risk assessments are periodically updated as new information becomes available in order to accurately evaluate potential environmental and human health risks from land-applied biosolids.

Part I: Organic Contaminants

Personal care products

Some personal care products, like lotions, soaps, fragrances, and cosmetics, contain chemicals that may be of environmental concern. Antibacterials such as triclosan and fragrances such as synthetic **musks** are of particular concern. Triclosan may negatively impact soil or aquatic microorganisms because of its antibacterial properties, which allow it to kill bacteria. However, overall, the effects of triclosan in the soil may be short-lived because it binds to soil particles and its **half-life** ranges from 17 to 35 days (Smith 2009).

Pharmaceuticals

Allowing pharmaceuticals into the environment is a concern because of their unknown effects on the aquatic or terrestrial ecosystems and their potential for groundwater contamination. There are hundreds of pharmaceuticals released into municipal wastewater treatment facilities every day because many medicines are not completely metabolized. Some pharmaceuticals, such as **carbamazepine**, are persistent and can leach through soils.

Not all pharmaceuticals are potentially harmful to the environment, but antibiotics are a unique group because they kill or inhibit certain bacteria when they are at effective concentrations. With antibiotics, there is the potential for soil microbial effects, including antibiotic-resistance selection, if relatively high antibiotic concentrations reach soils. However, most antibiotics found in biosolids are not bioavailable because they tend to bind tightly to soil particles, which neutralize them.

Surfactants

Surfactants are used in many industrial applications and consumer products and can end up in biosolids from industrial and municipal wastes. Some surfactants, including nonylphenol ethoxylates (NPEs) and **nonylphenol (NP)**, can cause environmental and human health problems. The use of these chemicals is being more closely monitored, regulated, restricted, or banned (EPCEU 2006; EPA 2014) because NPEs are toxic to some aquatic species and NP has endocrine-disrupting properties (Smith 2009), which can cause **endocrine disruption** in fish by mimicking estrogen compounds, thereby disrupting the natural balance of hormones. It can also bioaccumulate in fish and birds; however, currently there is inconsistent evidence that it bioaccumulates in humans.

Fish consumption may lead to higher levels of NP in breast milk, which may in turn negatively affect newborns (e.g., abnormal neurological development, growth, and memory function). However, drinking water with low levels of NP is not a significant source of exposure. In **terrestrial systems**, the effects of NPE and NP contamination may be short-lived because they tend to bind to soil particles and the half-life for each is less than 20 days (Smith 2009; González et al. 2010).

Plasticizers

Plasticizers (such as **bisphenol A [BPA]** and **phthalates**) are used to make soft plastics. One commonly used plasticizer is DEHP. DEHP has relatively low toxicity for aquatic species (Defra 1991), although it can bioaccumulate in aquatic organisms. Some evidence links DEHP to changing levels of male sex steroid hormones, potentially affecting fertility (Mendiola et al. 2012). The European Union has restricted the use of DEHP and other phthalates in order to lower the public's exposure to these plastic materials and to limit children's potential exposure to phthalates contained in children's toys (EPCEU 2006).

DEHP that ends up in biosolids comes from plastic pipes, industrial waste, and products stored in plastic materials (e.g., foods and soaps). DEHP exposure from biosolids is less concerning than DEHP inhalation and ingestion. In terrestrial systems, the effects of DEHP may be short-lived because it binds strongly to soils, and its half-life is less than 50 days (Smith 2009).

Perfluorinated chemicals

Perfluorinated chemicals (PFCs) are used to make non-stick, waterproof, stain-resistant, or fire-resistant surfaces. They are persistent and can leach through soil. Toxicity studies are limited at this time; however, these chemicals do not bioaccumulate. There is uncertainty about the effects of long term low levels of perfluorinated chemicals in the environment, such as **perfluorooctanoic acid (PFOA)**, and how they may affect human and animal health (NIH 2012).

Since 2000, the EPA has been working with manufacturers to phase out some perfluorinated chemicals. A review of emerging organic contaminants in biosolids by Clarke and Smith (2011) determined that the potential effects of perfluorinated chemicals in biosolids should be researched further since they are present at higher concentrations compared to other chemicals.

Flame retardants

Flame retardants are used in many materials and products to make them fire resistant. **Polybrominated diphenyl ethers (PBDEs)** are commonly used in building materials, electronics, furnishings, motor vehicles, plastics, polyurethane foams, and textiles (EPA 2009). PBDEs can end up in biosolids depending on how much is released into the sewer system. Toxicity is not well understood, but PBDEs may be endocrine disruptors or **neurotoxins**. The EPA states that PBDEs may be toxic to the liver and thyroid in humans.

The use of PBDEs was restricted in Washington State in 2008, and the Washington Department of Ecology released a report in January 2015 recommending restrictions on products and furniture that contain PBDEs as well as requirements for having manufacturers report PBDE use in their consumer products (WA Dept. of Ecology 2014a). Other states have or are in the process of phasing out or banning their use. PBDEs bind tightly to soil particles; they are very persistent, and they can bioaccumulate (EPA 2015c).

Polychlorinated biphenyls

Polychlorinated biphenyls (PCBs), also called **Aroclors**, were widely used in numerous materials and products (similar to PBDEs) prior to 1979. They were banned in 1979 because they were found to be **carcinogenic**. They can still be found in items that pre-date the ban, including electrical equipment, oil, thermal insulation, cable insulation, adhesives, paint, caulking, plastics, and floor finishes. PCBs can end up in biosolids depending on how much is released into the sewer system from these old materials. PCBs bind tightly to soil particles; they are very persistent, and they can bioaccumulate (EPA 2013a).

Dioxins and furans

Dioxins and **furans** are byproducts of certain industrial processes, incineration, and uncontrolled burning. Dioxins and furans are mainly released into the atmosphere and are eventually deposited on the Earth's surface. They can also be released into sewer systems from industrial and household wastewater, and because they are very persistent, they can end up in wastewater effluent and biosolids. Some dioxins cause adverse health effects at high enough levels, including cancer (EPA 2015b); **2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD)** is the most toxic dioxin (EPA 2015b).

TCDD is a priority pollutant, and 16 other dioxins and furans may have endocrine-disrupting properties (WHO 2014). They are regulated as **nonconventional pollutants** in many **National Pollutant Discharge Elimination System (NPDES) permits**. Dioxins and furans are regulated in wastewater **effluents** to limit the amount discharged to the environment. They are not regulated in biosolids because an extensive risk assessment by the EPA concluded that these compounds are present in biosolids at levels that are too low to warrant regulation (EPA 2003). In the terrestrial system, dioxins and furans are persistent and tend to bind to soils since they are insoluble in water. They can also bioaccumulate because they concentrate in the fatty tissue of **biota** (Fiedler 2003).

Part II: Biological Contaminants

The primary pathogens of concern in sewage sludge and biosolids are listed in Table A-1. They fall under the following four categories: **enteric viruses**, bacterial pathogens, **protozoan parasites**, and **helminth parasites**. Many of these pathogens may not be detected in biosolids frequently, or they may be present at low concentrations; however, it is important to continue to monitor biosolids for pathogens so the public health risks from land-applied biosolids remain low.

Table A-1. Pathogens of concern in biosolids.

Enteric viruses	Bacterial pathogens	Protozoan parasites	Helminth parasites
Adenoviruses	<i>Aeromonas</i>	<i>Balantidium coli</i>	<i>Ascaris lumbricoides</i>
Astroviruses	<i>Burkholderia</i>	<i>Cryptosporidium</i> spp.	<i>Ascaris sum</i>
Caliciviruses	<i>Campylobacter jejuni</i>	<i>Cyclospora</i>	<i>Hymenolepis nana</i>
Coxsackieviruses	Enteropathogenic <i>E. coli</i>	<i>Entamoeba histolytica</i>	<i>Necator americanus</i>
Echoviruses	<i>E. coli</i> O157:H7	<i>Giardia lamblia</i>	<i>Taenia</i> spp.
Enteroviruses	<i>Helicobacter pylori</i>	<i>Microsporidia</i>	<i>Toxocara canis</i>
Hepatitis virus A/E	<i>Legionella</i> spp.	<i>Toxoplasma gondii</i>	<i>Trichuris trichirua</i>
Norovirus	<i>Leptospira</i>		
Norwalk virus	<i>Listeria monocytogenes</i>		
Polioviruses	<i>Salmonella</i> spp.		
Reoviruses	<i>Vibrio cholera</i>		
Rotaviruses	<i>Yersinia</i> spp.		

Adapted from: NRC (2002) and EPA (2011)

Table A-2. Pathogen/indicator maximum allowable levels in Class B and Class A biosolids.^a

Pathogen or indicator	Class B	Class A
Fecal coliform	< 2×10 ⁶ CFU ^b or MPN ^c per gram	< 1×10 ³ MPN per gram
<i>Salmonella</i> spp.	Reduced by a factor of 10	< 3 MPN per 4 grams
Enteric viruses	Reduced by a factor of 10	< 1 PFU ^d per 4 grams
Viable helminth ova	Not applicable	< 1 viable ova per 4 grams

Adapted from: EPA 2015a

^aTotal solids on dry weight basis

^bCFU = colony-forming units

^cMPN = **most probable number**

^dPFU = plaque-forming units

Regulated pathogens or indicators

Currently, four types of pathogens or **indicators** are measured in biosolids to determine Class B and Class A equivalency. These four types are **fecal coliform**, ***Salmonella* spp.**, enteric viruses, and viable helminth **ova** (Table A-2). Testing for some pathogens or indicators is less expensive than testing for all pathogens that can be found in biosolids. However, some researchers believe that this traditional method of testing pathogen contamination in biosolids may be inadequate for estimating emerging pathogen concentrations. New molecular genetic methods for quantifying pathogen levels are advancing, and they may prove to be more accurate and reliable methods of testing in the future (EPA 2011).

Protozoan Parasites

The two most common protozoan parasites associated with biosolids are ***Cryptosporidium*** and ***Giardia***. Although these protozoa die within days of Class B biosolids treatment, more research concerning ***Cryptosporidium* oocyst** viability is needed for improved risk assessment evaluations (EPA 2011). In soils, ***Giardia*** can persist for less than a day or up to 28 days, and ***Cryptosporidium*** can persist from 28 days to over a year.

Helminth Parasites

Biosolids-borne helminthes and ova (i.e., eggs) are rare in the U.S. because the public has access to clean water and has a high level of personal hygiene (EPA 2015b). Very few helminths entering the sewer system means very few can end up in biosolids. However, helminth ova can persist for several years in soil (Gerba and Smith 2005), so it is important to continue limiting helminth parasites in biosolids. This is especially true for Class A biosolids since the primary route of helminth infection is through consumption of contaminated foods.

Aerosolized Endotoxins

Endotoxins are poisonous substances that are released when the cell walls of **gram-negative bacteria** break down. Concentrations of endotoxins are similar for biosolids, animal manures, and compost (EPA 2011). Aerosolized endotoxins can form following mixing, tilling, or disking biosolids, animal manures, and compost. The effects of inhaling aerosolized endotoxins can include fever, coughing, breathlessness, flu-like symptoms, and inflammation (EPA 2011).

Authorized individuals who come in contact with biosolids during mixing, disking, or tilling should wear appropriate personal protective equipment (CDC 2002). Aerosols are not airborne for very long and they do not travel very far, only around 541 ft (Low et al. 2007; King et al. 2011), so they are unlikely to become a public health concern.

Glossary

adenoviruses. Viruses affecting adenoid tissue (tonsils), most of which cause respiratory diseases, and spread by respiratory secretions and fecal contamination. See also **viruses**.

aerosols. Small particles or liquid droplets in air.

agronomic. Relating to agronomy, the science and technology of producing and using plants for food, fuel, fiber, and land reclamation.

anaerobic digestion. A series of biological processes in which microorganisms break down biodegradable material (often wastes such as liquid manure or food-processing wastes) in the absence of oxygen, which generates biogas containing methane, a source of renewable energy.

antibacterial. Chemical or agent that interferes with the growth and reproduction of bacteria. Used specifically for disinfecting surfaces and eliminating potentially harmful bacteria. Unlike antibiotics, antibacterial agents are not used as medicines for humans or animals, but can be found in soaps, detergents, health and skincare products, and household cleaners.

antibiotic. A substance used in medicines for humans and animals that is capable of destroying or weakening certain microorganisms, especially bacteria or fungi that cause infections or infectious diseases.

antibiotic resistance. The ability of a microorganism to withstand the effects of an antibiotic.

Aroclors. Also called PCBs. Synthetic (man-made) organic chemicals banned in 1979 after they were found to cause cancer in animals.

bacterial pathogens. Also called pathogenic bacteria. Bacteria that can cause disease, in contrast to the majority of bacteria, which are harmless or beneficial. See also **pathogens**.

bioaccumulate. To accumulate substances within a biological organism in concentrations greater than the concentrations found in the environment.

bioavailability. Degree and rate at which a substance is absorbed into a living system or is made available at the site of physiological activity.

biological activity. Describes the effects, either beneficial or adverse, of a chemical or drug on living matter.

biological contaminants. Biological substances, such as parasites, bacteria, and viruses that may pose a threat to human and animal health. See also **contaminants**.

biomass. Organic matter derived from living or recently living organisms.

biosolids. Treated sewage sludge, particularly that which is intended for agricultural use as a soil conditioner.

biota. The animal and plant life of a particular region, habitat, or geological period.

bisphenol A (BPA). Synthetic organic chemical used since 1957 to manufacture certain plastics and epoxy resins, commonly used as coatings on the inside of food and beverage cans, that is currently being investigated for potentially harmful effects on both human and environmental health because it is an endocrine (hormone system) disruptor.

bulk density. The dry weight (often of soil) in a given volume.

Campylobacter. Gram-negative bacteria, most of which are pathogenic and can infect humans and animals and are one of the main causes of bacterial foodborne disease in many developed countries.

carbamazepine. Brand name Tegretol. A medication used to treat epilepsy and neuropathic pain as well as schizophrenia and bipolar disorder.

carbon compounds. Compounds consisting largely of carbon atoms, which are the basis of all organic, living matter.

carcinogenic. Having the potential to cause cancer.

Class A biosolids. Sewage sludge that has been treated to reduce biological contaminants to very low levels. Meets EPA standards for regulated contaminants. Can be used as a soil amendment and plant fertilizer in home gardens and landscapes.

Class B biosolids. Sewage sludge that has been treated to substantially reduce the level of biological contaminants. Meets the EPA criteria for regulated contaminants. Can be used as a soil amendment and plant fertilizer for agricultural land, timberland, rangeland, and land-reclamation sites.

Clean Water Act. The primary federal law in the United States governing water pollution.

colony-forming unit. A unit of measure used to estimate the number of viable bacterial cells in a sample.

compost. Organic matter that has been composted; that is, decomposed through a series of biological processes in which microorganisms break down biodegradable material in the presence of oxygen; it can then be recycled as a fertilizer and soil amendment.

contaminants. Undesirable biological or chemical elements or agents, foreign matter, or other substances that if present may be potentially harmful to humans and the environment. Unlike pollutants, contaminants are not always hazardous. See also **pollutants**.

***Cryptosporidium*.** Type of protozoan parasite that causes diarrheal gastrointestinal illness in humans. These parasites are able to form oocysts (i.e., a dormant and more resilient form of the organism) until favorable environmental conditions arise.

degradation. Breakdown of substances by chemical or biological reactions.

di(2-ethylhexyl) phthalate (DEHP). Synthetic organic chemical in the phthalate group, widely used as a plasticizer in the manufacture of some polyvinyl chloride (PVC) plastic materials.

dioxins. Highly toxic compounds produced as a by-product in some manufacturing processes, notably herbicide production and paper bleaching. They are a serious and persistent environmental contaminant.

effective concentrations. The amount of a substance needed to induce a response.

effluents. Outflowing liquid that is frequently wastewater or treated wastewater.

emerging contaminants. New, previously undetected, or poorly understood contaminants.

endocrine disruption. Interference with the human endocrine (hormonal) system. Any system in the body controlled by hormones can be derailed by a hormone disruptor, which can cause cancerous tumors, birth defects, and other developmental disorders.

endotoxins. Substances bound to the outer membrane of gram-negative bacteria that can be released when a bacterium ruptures or disintegrates, potentially eliciting a strong immune response in humans.

enteric viruses. Group of viruses that primarily infect the intestinal tract of humans through ingestion of food or water contaminated with viruses of fecal origin. This group includes adenoviruses and enteroviruses. See also **viruses**.

enteroviruses. Viruses found in feces and respiratory secretions that are spread through the fecal-oral route, potentially causing illnesses ranging from mild respiratory problems to meningitis. See also **viruses**.

Environmental Protection Agency (EPA). An agency of the U.S. federal government that was created for the purpose of protecting human health and the environment.

***Escherichia coli* O157:H7.** Distinct variation of the bacteria *E. coli* that is pathogenic and is typically passed to humans through consumption of contaminated food. It is infectious, causing diarrheal illness that if severe enough can lead to kidney failure.

estrogenic compounds. Substances having an action similar to that of estrogen, the primary female sex hormone that is responsible for development and regulation of the female reproductive system and secondary sex characteristics.

fecal coliform. Bacteria that live in the digestive tracts of warm-blooded animals, including humans, and are excreted in their feces. Most are not harmful, but some are pathogenic to humans and can cause disease.

flame retardants. Compounds added to a variety of manufactured materials to make them more fire resistant.

furans. Colorless, flammable, highly volatile liquids found in heat-treated commercial foods, such as roasted coffee and processed baby foods that are toxic and may be carcinogenic in humans.

Gram-negative bacteria. Bacteria that have an inner cell membrane and do not form spores (i.e., a more resilient form of the organism that allows for asexual reproduction), and are more resistant.

***Giardia*.** Type of protozoan parasite transmitted by the fecal-oral route that can cause diarrhea, gas, cramps, and nausea. These parasites are able to form oocysts (i.e., a dormant and more resilient form of the organism) until favorable environmental conditions arise.

groundwater. Water present in soil pore spaces beneath the soil surface or in rock crevices and pores.

half-life. The time required for any specified substance to decrease by half (e.g., the length of time in days it takes for half of a contaminant concentration to be degraded).

heavy metals. Any relatively dense metal, such as alkali and alkaline earth metals, transition and post-transition metals, lanthanides, and actinides. Sometimes arsenic and antimony are also considered heavy metals.

helminth parasites. Large, worm-like parasites that can cause a wide variety of infectious diseases by infecting the gastrointestinal tract of humans. Infection can occur when, for example, helminth eggs are swallowed after touching contaminated soil.

hydrous oxide. A class of minerals that is highly porous with large surface areas that show an affinity for organic and inorganic contaminants.

indicator organism. A group of organisms used as a proxy or substitute for pathogen contamination testing. See also **pathogens**.

inorganic. Of, relating to, or denoting non-living compounds (not containing more than one carbon atom).

insoluble. Substance incapable of being dissolved. Refers to solubility in water unless otherwise indicated.

leaching. Draining away substances from soil or similar materials by the action of liquids, especially rainwater.

macrofauna. Organisms greater than 2 mm in length that live part of their life in the soil. Some examples are earthworms, insects and their larvae, slugs, and snails.

macronutrients. Nutrients needed in relatively large amounts. For plants, the primary macronutrients are nitrogen, phosphorus, and potassium. Calcium, sulfur, and magnesium are secondary macronutrients.

microbes. Shorter term for microorganisms.

micronutrients. Nutrients only needed in very small amounts.

microorganisms. Diverse, microscopic living organisms that include fungi, viruses, all bacteria, and almost all protozoa.

most probable number. In microbiology, microbial cultures grown in the laboratory are assessed visually to determine growth or no growth, bypassing the difficult process of colony counting.

municipal wastewater. Wastewater derived from local households and sometimes industrial facilities.

musks. Perfume ingredient essential in modern perfumery.

National Pollutant Discharge Elimination System (NPDES)

permits. The permitting system used to regulate point source pollution (i.e., identifiable effluent discharge locations), such as municipal wastewater treatment facilities, industrial facilities, and some animal feedlots.

neurotoxins. Substances that are poisonous or destructive to nerve tissue.

nitrate. Chemical (NO_3^-) produced for use as a fertilizer in agriculture because of its high solubility and biodegradability characteristics.

nonconventional pollutants. Pollutants other than the conventional pollutants. Conventional pollutants are biochemical oxygen demand (BOD), fecal coliform bacteria, oil and grease, pH, and total suspended solids. Wastewater treatment facilities are designed to remove these conventional pollutants, but not nonconventional pollutants.

nonylphenol (NP). Synthetic organic compounds that are used in manufacturing antioxidants, lubricating oil, detergents, emulsifiers, and solubilizers (surfactants) that have been found to be an endocrine disruptor.

nonylphenol ethoxylates (NPE). Also called nonoxynols. Synthetic organic compounds used in detergents, emulsifiers, wetting agents, and defoaming agents (surfactants) that break down to nonylphenol in some cases and have mild to medium estrogenic function.

odorants. A chemical compound that has a smell or odor.

oocyst. A hardy, thick-walled spore that develops at a certain stage in the life cycle of coccidian parasites like *Cryptosporidium* and then is shed in the feces of infected individuals.

ova. For helminths, ova are the eggs produced by helminth worms for reproduction.

organic. Of, relating to, or derived from living matter.

organic contaminants. A class of chemical contaminants that has more than one carbon atom in its chemical makeup.

organic matter. Matter composed of organic (carbon-containing) compounds that have come from the remains of organisms such as plants and animals and their waste products.

organic solids. Solids made up of compounds with more than one carbon atom in their chemical makeup as opposed to inorganic solids which are made up of inorganic (non-carbon) compounds.

parasites. Organisms that live in or on a host in a non-mutual symbiotic relationship where they derive nourishment from the host while doing damage to it.

pathogenic bacteria. Single-celled microorganisms that cause disease.

pathogens. Agents that cause disease, especially living microorganisms such as bacteria, viruses, or fungi.

perfluorinated chemicals (PFCs). A group of fluorine-containing chemicals that have been used extensively in commercial applications to make products oil, stain, and water resistant such as stain-resistant carpeting and food packaging like microwavable popcorn bags.

perfluorooctanoic acid (PFOA). A type of PFC that is used in the process of making Teflon® and similar chemicals, although it is burned off during the process and is not present in significant amounts in the final Teflon products. It is a toxicant and carcinogen in animals.

persistent chemicals. Chemicals that are difficult to remove from the environment.

personal care products. Products used by individuals for personal hygiene and personal appearance, such as soaps, cosmetics, fragrances, and hair-styling products.

plasticizers. Additives that increase the plasticity or fluidity of plastic materials used to make soft plastics like some polyvinyl chlorides (PVCs). See **phthalates**.

plaque-forming unit. A unit of measure used to estimate the number of particles capable of forming plaques (e.g., virus particles) in a sample.

pH. A numeric scale used to specify the acidity or basicity of an aqueous (water-containing) solution.

pharmaceuticals. Compounds manufactured for use as medicinal drugs.

phthalates. A group of man-made chemicals used in a wide range of common products, and are often used as a plasticizer in plastics, especially in PVC resins.

pollutants. Undesirable biological or chemical elements or agents, foreign matter, or other substances or contaminants that are in high enough concentrations that they become hazardous to human or environmental health.

polybrominated diphenyl ethers (PBDEs). Organic chemicals, structurally similar to polychlorinated biphenyls (PCBs), used as a flame retardant, although they are being phased out in many products because they are persistent chemicals and they bioaccumulate.

polychlorinated biphenyls (PCBs). Organic chemicals, structurally similar to polybrominated diphenyl ethers (PBDEs), that were used as a flame retardant until they were banned in 1979 because they were found to be carcinogens.

polyvinyl chloride (PVC). A widely produced synthetic thermoplastic resin used chiefly for thin coatings, insulation, and piping. See resin.

protozoa. Single-celled organisms larger than bacteria, but smaller than helminth worms, that exhibit animal-like behaviors.

protozoan parasites. Microscopic, single-celled parasitic organisms transmitted to humans by such means as contaminated water, waste, blood, poorly handled food, and insects, potentially causing serious illness.

reservoir for pathogens. A long-term host for pathogens of an infectious disease.

resin. A solid or highly viscous substance that is malleable until it sets into a hard finish.

risk assessment. A process used to evaluate the nature and magnitude of a possible negative outcome in a defined situation, such as evaluating the level of risk or threat certain chemical contaminants pose to human and environmental health.

Salmonella spp. Bacteria, usually motile (capable of motion), that are pathogenic to humans and other warm-blooded animals and cause food poisoning, gastrointestinal inflammation, typhoid fever, and septicemia.

sewage sludge. Residual, semi-solid material that is produced as a by-product during municipal and industrial sewage and wastewater treatment.

Shigella. Gram-negative bacterium related to *Salmonella* that causes disease in primates and humans and is one of the leading causes of bacterial diarrhea worldwide.

soil aggregation. The arrangement of soil particles into stable units or aggregates.

soil conditioner. A substance that is added to a soil to improve its physical qualities, such as texture, structure, and porosity, in order to increase its ability to provide plant nutrition.

soil porosity. A measure of the amount of air space between soil particles.

solubility. The ability of a solid, liquid, or gaseous chemical to dissolve into a bulk amount of material (solid, liquid, or gas), depending on its physical and chemical properties as well as temperature and pH.

sorption. A physical and chemical process by which one substance becomes attached to another.

surface runoff. Excess stormwater, meltwater, or water from other sources that flows over the Earth's surface.

surfactants. Substances that tend to reduce the surface tension of a liquid in which they are dissolved.

sustainable practices. Practices that can be maintained over time without adverse consequences.

synthetic. Of, relating to, or produced by chemical or biochemical synthesis, especially to imitate a natural product.

terrestrial system. Land-based communities that include living and non-living things.

tetrachlorodibenzo-*p*-dioxin (TCDD). The most potent of the toxic dioxin compounds, it is a persistent and carcinogenic chemical that is also known as Agent Orange.

trace element. An element (in the periodic table of elements) present in very small amounts.

triclosan. Antibacterial and antifungal agent found in consumer products, such as soaps, detergents, surgical cleaning treatments, and children's toys.

viruses. Submicroscopic infective agents that replicate inside living cells and often cause disease.

wastewater residuals. Materials comprised of suspended solids and sludge from the primary and secondary wastewater processing steps used by wastewater treatment plants, which after being treated and stabilized become biosolids.

water-holding capacity. Amount of water that can be stored in the soil.

Yersinia enterocolitica. Gram-negative bacteria that can infect both humans and animals, causing diarrhea in humans; animals that recover become carriers, and dogs, sheep, wild rodents, and environmental water may be reservoirs for pathogenic strains.

Definitions adapted from Merriam-Webster.com, wikipedia.org, U.S. Environmental Protection Agency (EPA), and Centers for Disease Control and Prevention (CDC).

References

Brooks, J.P., S.L. Maxwell, C. Rensing, and I.L. Pepper. 2007. Occurrence of Antibiotic-Resistant Bacteria and Endotoxin Associated with the Land Application of Biosolids. *Canadian Journal of Environmental Microbiology* 53: 616–622.

Brooks, J.P., C.P. Gerba, and I.L. Pepper. 2015. [Antibiotic Resistant Bacteria](#). Animal Manure Management. *eXtension*.

Centers for Disease Control and Prevention (CDC). 2002. [Guidance for Controlling Potential Risks to Workers Exposed to Class B Biosolids](#). Cincinnati, OH: The National Institute for Occupational Safety and Health (NIOSH).

Centers for Disease Control and Prevention. 2015. [Adenoviruses: Symptoms](#). Atlanta, GA.

Clarke, B.O., and S.R. Smith. 2011. Review of 'Emerging' Organic Contaminants in Biosolids and Assessment of International Research Priorities for the Agricultural Use of Biosolids. *Environment International* 37: 226–247.

Cogger, C.G., D.M. Sullivan, C.L. Henry, and K.P. Dorsey. 2000. [Biosolids Management Guidelines for Washington State](#). Publication #93-80. Olympia: Department of Ecology Publication Distribution Center.

Cogger, C.G., A.I. Bary, A.C. Kennedy, and A-M. Fortuna. 2013. Long-Term Crop and Soil Response to Biosolids Applications in Dryland Wheat. *Journal of Environmental Quality* 42: 187–1888.

Cogger, C.G. 2014. [Using Biosolids in Gardens and Landscapes](#). *Washington State University Extension Publication* FS156E.

Defra (Department for Environment, Food and Rural Affairs), Toxic Substances Division. 1991. [Environmental Hazard Assessment: Di-\(2-ethylhexyl\) Phthalate](#). Directorate for Air, Climate and Toxic Substances. Department of the Environment.

Defra (Department for Environment, Food and Rural Affairs). 2011. Archive: Codes of Good Agricultural Practice—Definitions. [Slurry, Options for Treatment by Anaerobic Digestion](#). University of Hertfordshire: Agricultural Document Library.

Environment & Human Health, Inc. 2008. [Plastics That May Be Harmful to Children and Reproductive Health](#). North Haven, CT: Environment & Human Health, Inc.

- Epstein, E. 2003. *Land Application of Sewage Sludge and Biosolids*. Boca Raton, FL: CRC Press.
- European Parliament and the Council of the European Union (EPCEU). 2006. Regulation (EC) No. 1907/2006 of the European Parliament and of the Council of 18 December 2006. Annex XVII. [Restrictions on the Manufacture, Placing on the Market and Use of Certain Dangerous Substances, Mixtures and Articles](#).
- Fiedler, H. 2003. [Dioxins and Furans](#). In *The Handbook of Environmental Chemistry Vol. 3, Part O. Persistent Organic Pollutant*, edited by H. Fiedler, 125–201. Springer-Verlag: Berlin-Heidelberg.
- Gerba, C.P., and J.R. Smith. 2005. Sources of Pathogenic Microorganisms and Their Fate during Land Application of Wastes. *Journal of Environmental Quality* 34: 42–48.
- Gerba, C.P., A.H. Tamimi, C. Pettigrew, A.V. Weisbrod, and V. Rajagopalan. 2011. Sources of Microbial Pathogens in Municipal Solid Waste Landfills in the United States of America. *Waste Management & Research* 29: 781–790.
- Gilmour, J.T., C.G. Cogger, L.W. Jacobs, G.K. Evanylo, and D.M. Sullivan. 2003. Decomposition and Plant-Available Nitrogen in Biosolids: Laboratory Studies, Field Studies, and Computer Simulation. *Journal of Environmental Quality* 32: 1498–1507.
- Girovich, M.J. 1996. *Biosolids Treatment and Management: Processes for Beneficial Use*. Boca Raton, FL: CRC Press.
- González, M.M., J. Martín, D. Camacho-Muñoz, J.L. Santos, I. Aparicio, and E. Alonso. 2010. Degradation and Environmental Risk of Surfactants after the Application of Compost Sludge to the Soil. *Waste Management* 32: 1324–1331.
- Goodman, R.M. 2004. *Encyclopedia of Plant and Crop Science*. New York, NY: M. Dekker.
- Greens, T., L. Roosens, H. Neels, and A. Covaci. 2009. Assessment of Human Exposure to Bisphenol-A, Triclosan and Tetrabromobisphenol-A through Indoor Dust Intake in Belgium. *Chemosphere* 76: 755–760.
- Heuer, H., and K. Smalla. 2007. Manure and Sulfadiazine Synergistically Increased Bacterial Antibiotic Resistance in Soil over At Least Two Months. *Environmental Microbiology* 9: 657–666.
- Heuer, H., H. Schmitt, and K. Smalla. 2011. Antibiotic Resistance Gene Spread Due to Manure Application on Agricultural Fields. *Current Opinion in Microbiology* 14: 236–243.
- Higgins, C.P., J.O. Sharp, J.G. Sepulvado, B.J. Littrell, G. O'Connor, E. Snyder, and D. McAvoy. 2010. Trace Organic Chemicals in Biosolids-Amended Soil: State-of-the-Science Review. Final Report SRK5T09. Water Environment Research Foundation. Alexandria, VA.
- Kato, K., A.M. Calafat, and L.L. Needham. 2009. Polyfluoroalkyl Chemicals in House Dust. *Environmental Research* 109: 518–523.
- King, G.M., J.P. Brooks, S. Brown, C. Gerba, G.A. O'Connor, and I.L. Pepper. 2011. [Land Application of Organic Residuals: Public Health Threat or Environmental Benefit?](#) Washington, DC: American Society for Microbiology.
- Low, S.Y., T. Paez-Rubio, C. Baertsch, M. Kucharski, and J. Peccia. 2007. Off-Site Exposure to Respirable Aerosols Produced during the Disk-Incorporation of Class B Biosolids. *Journal of Environmental Engineering* 133: 987–994.
- Massé, D.I., N.M.C. Saady, and Y. Gilbert. 2014. Potential of Biological Processes to Eliminate Antibiotics in Livestock Manure: An Overview. *Animals* 4: 146–163.
- Mendiola, J., J.D. Meeker, N. Jørgensen, A.-M. Andersson, F. Liu, A.M. Calafat, J.B. Redmon, E.Z. Drobnis, A.E. Sparks, C. Wang, R. Hauser, and S.H. Swan. 2012. Urinary Concentrations of Di(2-ethylhexyl) Phthalate Metabolites and Serum Reproductive Hormones: Pooled Analysis of Fertile and Infertile Men. *Journal of Andrology* 33: 488–498.
- Minur, M., K. Wong, and I. Xagorarakis. 2011. Release of Antibiotic Resistant Bacteria and Genes in the Effluent and Biosolids of Five Wastewater Utilities in Michigan. *Water Research* 45: 681–693.
- National Institutes of Health. 2012. [Perfluorinated Chemicals \(PFCs\)](#). Research Triangle Park, NC: *National Institute of Environmental Health Sciences*.
- National Research Council. 2002. [Biosolids Applied to Land: Advancing Standards and Practices](#). Committee of Toxicants and Pathogens in Biosolids Applied to Land. National Research Council. Washington, DC: National Academy Press.
- Oun, A., A. Kumar, T. Harrigan, A. Angelakis, and I. Xagorarakis. 2014. Effects of Biosolids and Manure Application on Microbial Water Quality in Rural Areas in the US. *Water* 6: 3701–3723.

- Pepper, I.L., J.P. Brooks, R.G. Sinclair, P.L. Gurian, and C.P. Gerba. 2010. Pathogens and Indicators in United States Class B Biosolids: National and Historic Distributions. *Journal of Environmental Quality* 39: 2185–2190.
- Roccaro, P., and F.G.A. Vagliasindi. 2014. Risk Assessment of the Use of Biosolids Containing Emerging Organic Contaminants in Agriculture. *Chemical Engineering Transactions* 37: 817–822.
- Rudel, R.A., D.E. Camann, J.D. Spengler, L.R. Korn, and J.G. Brody. 2003. Phthalates, Alkylphenols, Pesticides, Polybrominated Diphenyl Ethers, and Other Endocrine-Disrupting Compounds in Indoor Air and Dust. *Environmental Science & Technology* 37: 4543–4553.
- Smith, S.R. 2009. Organic Contaminants in Sewage Sludge (Biosolids) and Their Significance for Agricultural Recycling. *Philosophical Transactions of The Royal Society A* 367 (1904): 4005–4041.
- Sullivan, D.M., C.G. Cogger, and A.I. Bary. 2015. [Fertilizing with Biosolids](#). *Pacific Northwest Extension Publication* PNW 508-E. Oregon State University.
- U.S. Environmental Protection Agency. 2000. [Biosolids and Residuals Management Fact Sheet: Odor Control in Biosolids Management](#). EPA 832-F-00-067. Washington, DC: U.S. Environmental Protection Agency.
- U.S. Environmental Protection Agency. 2003. [Final Action Not to Regulate Dioxins in Land-Applied Sewage Sludge](#). EPA-822-F-03-007. Washington, DC: U.S. Environmental Protection Agency.
- U.S. Environmental Protection Agency. 2009. [Targeted National Sewage Sludge Survey](#). EPA-822-R-08-018. Washington, DC: U.S. Environmental Protection Agency.
- U.S. Environmental Protection Agency. 2011. [Problem Formulation for Human Health Risk Assessments of Pathogens in Land-Applied Biosolids](#). Washington, DC: U.S. Environmental Protection Agency.
- U.S. Environmental Protection Agency. 2012. [Dfe Alternatives Assessment for Nonylphenol Ethoxylates](#). Washington, DC: U.S. Environmental Protection Agency.
- U.S. Environmental Protection Agency. 2013a. [Learn about Polychlorinated Biphenyls \(PCBs\)](#). Washington, DC: U.S. Environmental Protection Agency.
- U.S. Environmental Protection Agency. 2013b. [Literature Review of Contaminants in Livestock and Poultry Manure and Implications for Water Quality](#). EPA 820-R-13-002. Washington, DC: U.S. Environmental Protection Agency.
- U.S. Environmental Protection Agency. 2014a. [Water: Sewage Sludge \(Biosolids\) – Introduction](#). Washington, DC: U.S. Environmental Protection Agency.
- U.S. Environmental Protection Agency. 2014b. [Significant New Use Rules: Certain Nonylphenols and Nonylphenol Ethoxylates](#). 40 CFR Parts 721. EPA-HQ-OPPT-2007-0490-0211. Washington, DC: U.S. Environmental Protection Agency.
- Washington Department of Ecology. 2009. [Pet Waste FAQs](#). Olympia: Washington State Department of Ecology.
- Washington Department of Ecology. 2014a. [Biosolids](#). Olympia: Washington State Department of Ecology.
- Washington Department of Ecology. 2014b. [Biosolids: 2015 General Permit for Biosolids Management Process](#). Olympia: Washington State Department of Ecology.
- U.S. Environmental Protection Agency. 2015a. [Basic Information: Pathogen Equivalency Committee](#). Washington, DC: U.S. Environmental Protection Agency.
- U.S. Environmental Protection Agency. 2015b. [Learn About Dioxin](#). Washington, DC: U.S. Environmental Protection Agency.
- U.S. Environmental Protection Agency. 2015c. [Polybrominated Diphenyl Ethers \(PBDEs\) Action Plan Summary](#). Washington, DC: U.S. Environmental Protection Agency.
- Washington Department of Ecology. 2014. [What are Flame Retardants?](#) Olympia: Washington State Department of Ecology.
- World Health Organization. 2015. [Dioxins and Their Effects on Human Health](#). *WHO Media Centre Fact Sheet* N°225.
- Zerzghi, H., C.P. Gerba, J.P. Brooks, and I.L. Pepper. 2010. Long-Term Effects of Land Application of Class B Biosolids on the Soil Microbial Populations, Pathogens, and Activity. *Journal of Environmental Quality* 39: 42–408.
- Zhao, L., Y.H. Dong, and H. Wang. 2010. Residues of Veterinary Antibiotics in Manures from Feedlot Livestock in Eight Provinces of China. *Science of the Total Environment* 408: 1069–1075.



Copyright 2016 Washington State University

WSU Extension bulletins contain material written and produced for public distribution. Alternate formats of our educational materials are available upon request for persons with disabilities. Please contact Washington State University Extension for more information.

Issued by Washington State University Extension and the U.S. Department of Agriculture in furtherance of the Acts of May 8 and June 30, 1914. Extension programs and policies are consistent with federal and state laws and regulations on nondiscrimination regarding race, sex, religion, age, color, creed, and national or ethnic origin; physical, mental, or sensory disability; marital status or sexual orientation; and status as a Vietnam-era or disabled veteran. Evidence of noncompliance may be reported through your local WSU Extension office. Trade names have been used to simplify information; no endorsement is intended. Published May 2016.