

What Is Sewage Sludge and What Can Be Done with It?

In this document, "sewage sludge" will refer to wastewater treatment solids generally, and "biosolids" will refer specifically to material that is suitable for land application.

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Introduction

Before 1950, most communities in the United States discharged their wastewater, or sewage, into streams and rivers with little if any treatment. As urban populations increased, the natural ability of streams and rivers to handle the wastewater was overwhelmed and caused water quality to deteriorate in many regions. In response to concerns about water quality degradation, thousands of communities throughout the United States constructed wastewater treatment systems during the 1950s and 1960s. This resulted in greatly improved stream and river water quality, but created another material to deal with: sewage sludge. Approximately 99% of the wastewater stream that enters a treatment plant is discharged as rejuvenated water. The remainder is a dilute suspension of solids that has been captured by the treatment process. These wastewater treatment solids are commonly referred to as sewage sludge.

"Sewage sludge" or "biosolids"—What's In a Name?

The term "biosolids" recently has been introduced by the wastewater treatment industry. The industry defines biosolids as sewage sludge that has undergone sufficient treatment for stabilization and pathogen reduction, and that is of sufficiently high quality to be land applied. The term is intended to distinguish high-quality, treated sewage sludge from raw sewage sludge and from sewage sludge that contains large quantities of environmental pollutants. The term "biosolids" also helps to distinguish sewage sludge from industrial sludge by emphasizing that the former is produced by a biological process. The term has been criticized by some as an attempt to disguise the real nature of sewage sludge, thereby making land application of this material less objectionable to the general public. Although "biosolids" undoubtedly does not conjure up the same negative images as does "sewage sludge" or simply "sludge," it is a legitimate and functional term when correctly used to make the distinction described above. In this document, "sewage sludge" will be used to refer to wastewater treatment solids generally, and "biosolids" will be used to refer specifically to material that is suitable for land application.

Production of Municipal Sewage Sludge

Municipal wastewater, or sewage, refers to water that has been used in urban and suburban area homes or businesses for washing, bathing, and flushing toilets. Municipal wastewater also may include water from industrial sources. To remove chemicals or pollutants resulting from industrial processes, industrial contributors to municipal wastewater systems must pretreat their wastewater before it is discharged into the sewerage system. The wastewater is conveyed via the sanitary sewerage system to a centralized wastewater treatment plant (sometimes called a Publicly Owned Treatment Works, or POTW). At the POTW, the sewage passes through a series of treatment steps that use physical, biological, and chemical processes to remove nutrients and solids, break down organic materials, and destroy pathogens (disease-causing organisms) in the water. The rejuvenated water is released to streams and rivers, or may be sprayed over large areas of land.

Preliminary treatment of raw sewage involves screening to remove large objects such as sticks, bottles, paper, and rags, and a grit removal stage during which inorganic solids (sand, grit, cinders) rapidly settle out of the water. The screenings and grit removed in this stage of treatment typically are landfilled and do not become part of the sewage sludge.

Primary treatment involves gravity sedimentation and flotation processes that remove approximately half of the solid material that enters this stage. Solid material (both organic and inorganic) that settles out during this stage of treatment is drawn from the bottom and constitutes the primary sludge. In most POTWs, the floating material (oil, grease, wood, and vegetable matter) that is skimmed from the water surface during primary treatment is disposed of separately and does not become part of the primary sludge.

Secondary treatment is a carefully controlled and accelerated biological process in which naturally occurring microorganisms are used to degrade (break down or digest) suspended and dissolved organic material in the wastewater. This material is converted into carbon dioxide that is released to the atmosphere and into microbial cell mass.

In secondary sedimentation basins, the microbial cell mass settles to the bottom and is removed. This mainly organic material is called secondary sludge.

Some treatment plants also include tertiary treatment steps designed to further reduce plant nutrients (nitrogen and phosphorus), suspended solids, or biological oxygen demand in the wastewater. Chemically precipitated phosphorus and filtration produce a tertiary sludge.

Finally, the water undergoes disinfection treatment to destroy pathogenic microorganisms. The rejuvenated water is then released to a stream or river or may be sprayed over large areas of land.

Treatment Methods for Municipal Sewage Sludge

Primary, secondary, and tertiary sludges normally are combined, and the resulting mixture, which contains from 1 to 4% solids, is called "raw" sewage sludge. Because of its pathogen content and its unstable, decomposable nature, raw sewage sludge is a potential health and environmental hazard; however, several treatment processes now are used to stabilize sewage sludge, decrease its pathogen content, and increase its solids content. Some of the more commonly used processes for stabilizing and reducing pathogen levels in sewage sludge are listed and briefly described in Table 1.

Table 1. Common methods for treating and stabilizing sewage sludge.

Treatment method	Description ¹	Effects on sludge
Thickening	Sludge solids are concentrated either by settling due to gravity or by introducing air, which causes sludge solids to float.	Sludge retains the properties of a liquid, but solids content is increased to 5 to 6%

Treatment method	Description ¹	Effects on sludge
Dewatering	<p>Several processes are used:</p> <ul style="list-style-type: none"> • air drying on sand beds • centrifugation • belt pressing (filtration) 	<ul style="list-style-type: none"> • Increases solids content to 15 to 30% • Air drying reduces pathogens • Centrifugation and filtration result in some loss of nutrients
Anaerobic digestion	<p>One of the most widely used methods for sludge treatment. Sludge is held in the absence of air for 15 to 60 days at temperatures of 68 to 131°F. Anaerobic bacteria feed on the sludge, producing methane and carbon dioxide. In some treatment plants, the methane is collected and burned to maintain the treatment temperature.</p>	<ul style="list-style-type: none"> • Increases solids content • Reduces odors • Decreases volatile solids • Decreases viable pathogens • Conserves plant nutrients
Aerobic digestion	<p>Sludge is agitated with air or oxygen for 40 to 60 days at temperatures of 59 to 68°F. Aerobic bacteria feed on the sludge, producing carbon dioxide.</p>	<ul style="list-style-type: none"> • Increases solids content • Reduces odors • Decreases volatile solids • Reduces viable pathogens • Some loss of nitrogen usually occurs
Alkaline stabilization	<p>Sufficient alkaline material, most commonly lime (CaO), is added to the sludge to increase its pH to at least 12 for 2 hours. The pH must remain above 11.5 for an additional 22 hours.</p>	<ul style="list-style-type: none"> • Decreases volatile solids • Reduces viable pathogens • Loss of ammonia (NH₃) • Phosphorus may be converted to forms not readily available to plants

Treatment method	Description ¹	Effects on sludge
Composting	Sludge is dewatered to increase solids content to around 20%, then mixed with a high-carbon organic material such as sawdust. The mix is composted under aerobic conditions at temperatures of at least 131°F for several days during the composting process.	<ul style="list-style-type: none"> • Volume reduction of sludge • Reduces odors • Decreases volatile solids • Stabilizes organic matter • Eliminates most pathogens • Decreases plant nutrient value

¹Most of these processes are highly technical and have very specific requirements for variables such as holding time, temperature, pH, and solids content. The descriptions provided here are intended only to give the reader a general concept of the process.

What is in Sewage Sludge?

Sewage sludge is composed of both inorganic and organic materials, large concentrations of some plant nutrients, much smaller concentrations of numerous trace elements² and organic chemicals, and some pathogens. The compositions of sewage sludges vary considerably depending on the wastewater composition and the treatment processes used. Table 2 gives median and 95th percentile concentrations of plant nutrients and some of the trace elements found in sewage sludge. These data are from an extensive survey of sewage sludges produced in Pennsylvania during 1996 and 1997.

² "Trace element" refers to any element that is present in small or minute quantities on the surface of the earth. It is used in this fact sheet to refer to any of a number of possible inorganic pollutants. "Trace element" is used in preference to "trace metal" or "heavy metal" because some inorganic pollutants such as arsenic and selenium are not metals.

Table 2. Median and 95th percentile concentrations of major and trace elements in Pennsylvania sewage sludges.³

Major Elements	Median ⁴	95th Percentile ⁵
Nitrogen	4.8	7.7
Phosphorus	2.2	3.9
Potassium	0.22	0.7
Calcium	3.1	18.0
Magnesium	0.4	0.8
Trace Elements	(mg/kg)	(mg/kg)
Arsenic	3.6	18.0

Cadmium	2.3	7.4
Chromium	35.0	314.0
Copper	511.0	1,382.0
Mercury	1.5	6.0
Molybdenum	8.2	36.0
Nickel	22.0	85.0
Lead	65.0	202.0
Selenium	4.3	8.5
Zinc	702.0	1,985.0

³Based on over 1,000 analyses of sewage sludges produced in Pennsylvania in 1996 and 1997.

⁴Half of the sludge samples tested lower than the median concentration and half of the samples tested higher than the median. By contrast, the mean, or average concentration is determined by adding up the concentrations measured in each sample and dividing by the number of samples.

⁵The 95th percentile is the concentration of a given element at or below which 95% of the sewage sludge samples tested.

The concentrations and occurrence of trace metals and other pollutants in sewage sludge have decreased substantially over the past 20 years, primarily because of mandatory industrial pretreatment of wastewater.⁶ Some of the remaining trace elements and organic compounds come from human waste and disposal of consumer products, but a significant proportion comes from corrosion of plumbing systems and water mains. In some communities, stormwater drains are connected to sanitary sewer systems, so some of the pollutants in street dirt and rainwater are retained in the sewage sludge.

⁶From the extension fact sheet Land Application of Sewage Sludge in Pennsylvania: Biosolids Quality.

In addition to the trace elements listed in Table 2, several others can be found in sewage sludge, as well as thousands of organic chemicals. Most of the organic chemicals are detected in only a few sludges and exist at very low concentrations. When higher-than-normal concentrations of trace elements or organic pollutants are found in sewage sludge, their presence usually can be linked to a particular industry.

How Much Sewage Sludge Do We Produce?

The POTWs operating in the United States today generate about 0.16 pounds (dry weight basis) of sewage sludge each day for every person that the sewerage system services. Pennsylvania's current population is near 12 million, and approximately 85% of its residents live in metropolitan areas serviced by centralized sewerage systems. This means that Pennsylvania's POTWs generate approximately 300,000 tons of sewage sludge (dry weight basis) each year.

Whose Responsibility Is It?

Pennsylvania's environmental regulations make it clear that POTWs are responsible for the proper use or disposal of the sewage sludge they produce. Directly or indirectly, however, we all contribute to sewage sludge production. Because sewage sludge is generated from the wastewater of towns and cities served by POTWs, its use or disposal typically is perceived to be an urban or suburban issue. But rural

areas also contribute to the generation of municipal sewage sludge, and they certainly have a stake in the decision of what to do with it. Most rural residents are served by on-lot septic systems that require periodic pumping. Septage pumpings often are delivered to POTWs, where they contribute directly to the generation of sewage sludge. There also is an economic and organic connection between rural and urban areas. Rural residents are dependent upon urban markets for agricultural products. Large amounts of organic matter and plant nutrients are transported from rural to urban areas as food. Consumption of those products generates human waste and ultimately, sewage sludge. Rural areas therefore contribute both directly and indirectly to the generation of sewage sludge. Finally, most options for the beneficial reuse or disposal of sewage sludge also involve rural areas. Thus, the issue of what to do with our sewage sludge should involve all of us.

Options for Dealing with Sewage Sludge

Sewage sludge can be viewed either as an organic and nutrient resource to be used beneficially or as a waste material to be disposed of. Before 1991, large amounts of sewage sludge, including some from Pennsylvania, were disposed of by ocean dumping. Concerns about excess nutrient loading of ocean waters led to the banning of this practice. At present, almost all sewage sludge produced in Pennsylvania has been treated and is of sufficiently high quality to be classified as biosolids. Somewhat less than half of this material is disposed of by landfilling or incineration, while the remaining biosolids are recycled to the soil by use in agriculture, mine reclamation, landscaping, or horticulture. Each of these options has economic and environmental benefits, problems, and risks associated with it.

Landfill Disposal

From a management and materials handling perspective, landfilling is perhaps the simplest solution. From an economic standpoint, landfilling presently compares favorably with other options. This undoubtedly will change, however, as landfill space becomes more limited and tipping fees (waste-dumping costs) increase. From an environmental standpoint, landfilling prevents the release of any sludge-borne pollutants or pathogens by concentrating the sludge into a single location. If the landfill is properly constructed and maintained, environmental risks are minimal.

There are, however, risks associated with landfill disposal of sewage sludge. Organic wastes undergo anaerobic decomposition in landfills, producing methane gas that could be released to the atmosphere. Methane is a greenhouse gas that has been implicated in global warming. Other gasses released from landfills can cause unpleasant odors. The large quantities of nutrients that sewage sludge adds to a landfill pose a risk to the local environment. Should a failure of the landfill liner or leachate collection system occur, these nutrients could contaminate local groundwater and surface water. Landfilling sewage sludge also takes up valuable landfill space and forfeits the potential benefits of the organic matter and plant nutrients in the sludge.

Incineration Disposal

Sewage sludge incineration reduces the volume of the material to be disposed of, completely destroys pathogens, decomposes most organic chemicals, and recovers the small amount of heat value contained in sewage sludge. The residual ash is a stable, relatively inert, inorganic material that has just 10 to 20% of the original sludge's volume. Most trace metals in the sewage sludge become concentrated in the ash (a five- to tenfold increase in concentration). This material most commonly is landfilled, although it potentially could be used in construction materials.

Incineration also releases carbon dioxide (another greenhouse gas) and possibly other volatile pollutants (cadmium, mercury, lead, dioxins) into the atmosphere. Incinerator operation requires sophisticated systems to remove fine particulate matter (fly ash) and volatile pollutants from stack gasses. This makes incineration one of the more expensive options for sewage sludge disposal. As with landfilling, the potential benefits from organic matter and plant nutrients in sewage sludge are lost.

Land Application

Whereas landfilling and incineration represent a one-way flow of energy and material from production to disposal, land application seeks to beneficially reuse the organic matter and plant nutrients in biosolids. The source of most of the organic matter and nutrients in biosolids ultimately is from crops grown on agricultural lands. Land application of biosolids returns those materials to the soil so they can be used to produce another crop. In Pennsylvania, land application of biosolids occurs primarily on agricultural and mined land. Organic matter provides numerous benefits to the soil and is valuable particularly in soils where organic matter has been depleted through continuous row cropping, or in mine reclamation where little or no soil exists. The commercial value of biosolids can be increased by subjecting them to processes such as composting, heat drying, pelletizing, and pasteurizing. The resulting biosolids products are sold to agricultural, landscaping, nursery, and homeowner markets.

Biosolids also provide a direct economic benefit to farmers, because the nutrients they contain will substitute for purchased inorganic fertilizers. Because many of the plant nutrients in biosolids are in a slow-release organic form, the potential for loss by leaching or runoff is lower than that of similar amounts of inorganic fertilizer. Along with the organic matter and nutrients, however, the soil also receives whatever pollutants and pathogens might be in the biosolids. If not properly monitored and managed, these could adversely affect human and animal health, soil quality, plant growth, and water quality. As with any fertilizer material, improper application or overapplication of biosolids could lead to nutrient runoff or leaching.

Clearly, no perfect solution to the question of how to deal with sewage sludge exists. Deciding among the options must involve an assessment of the benefits and risks of each. The remainder of this fact sheet focuses on the land application option and provides a brief description of the regulation, risks, and implications of land applying biosolids.

Regulation of Land-applied Biosolids

The current regulations for land application of biosolids were established by the U.S. Environmental Protection Agency (E.P.A.) in 1993. In 1997, Pennsylvania revised its regulations for land application of biosolids by largely adopting the technical aspects of the Federal regulations and by adding several requirements specific to Pennsylvania. The underlying premise of both the Federal and the Pennsylvania regulations is that biosolids contain resources that should be reused in a manner that limits risks to human health and the environment. The regulations prohibit land application of low-quality biosolids, limit the quantity of intermediate-quality biosolids that may be land applied, and encourage land application of biosolids that are of sufficiently high quality that they will not adversely affect human health or the environment. Determination of biosolids quality is based on pathogen reduction, disease vector attraction reduction, and trace element concentrations. For more complete information on Pennsylvania's regulations for land application of biosolids, see [Land Application of Sewage Sludge in Pennsylvania: A Plain English Tour of the Regulations](https://extension.psu.edu/sewage-sludge-a-plain-english-tour-of-the-regulations) (<https://extension.psu.edu/sewage-sludge-a-plain-english-tour-of-the-regulations>).

The regulations contain several additional risk-management requirements designed to limit the potential for pollutants or pathogens to be transported from the application site to groundwater or surface water, or to animals or humans. Some of these measures include:

- prohibiting application in environmentally sensitive areas
- prohibiting application on steep slopes and where the water table is close to the soil surface
- requiring the farm to have an implemented soil conservation plan
- requiring setback distances from homes, wells, streams, rivers, and sinkholes
- limiting the contact between biosolids and possible disease vectors such as mosquitoes, flies, and rodents
- restricting crop harvest and grazing for specified time intervals after biosolids application
- mandatory training of individuals responsible for land-application programs

Pennsylvania's biosolids regulations contain several risk-management requirements that are more restrictive and stringent than the Federal requirements.⁷ POTWs and companies involved in land application of biosolids are required to follow these requirements, and many have voluntarily adopted management practices that exceed regulatory requirements. If local, county, and state agencies work together to ensure that all aspects of the regulations are followed carefully, risks from land application of biosolids can be managed at very low levels.

⁷A detailed description of those aspects of Pennsylvania's regulations that are more stringent than the Federal regulations is given in Pennsylvania Bulletin, 27:4, January 25, 1997, 523-25.

The Risk-assessment Approach to Regulation

The biosolids quality standards and quantity limits were derived from extensive environmental risk assessments conducted by scientists at the E.P.A. and the U.S. Department of Agriculture. The goal of the risk assessments was to provide reasonable "worst-case" protection to human health and the environment, not absolute protection.

Worst-case protection in this instance means that the standards and practices established in the regulations would protect a person, animal, or plant that is highly and chronically (continuously) exposed to sludge pollutants. The rationale was that if a highly exposed individual were protected, then the remaining portion of the population, with lower exposure, also would be protected. It should be noted that while standards for sludge pollutants were based on risk assessment, standards for pathogen reduction in sludge were based on a "best-available-technology" approach that is described in the next paragraph.

Alternative Approaches to Regulation

The risk-assessment procedure used by the E.P.A. is not the only approach to regulating land application of biosolids. Two other approaches that have been used by other countries are "noncontamination" and "best available technology" (BAT). The noncontamination approach does not allow application of any biosolids that would cause an increase in soil concentrations of any pollutant. Any addition of a pollutant to the soil must be matched by removal of that pollutant so that no long-term buildup occurs in the soil. The BAT approach limits pollutants in biosolids to levels attained by the best current technology (industrial pretreatment and separation of sanitary, storm, and industrial sewerage).

Each of these approaches is much more restrictive of land application than is the risk assessment approach. Consequently, with regulation under the noncontamination or BAT approaches, more biosolids will be landfilled or incinerated and less will be land applied. Although this reduces to near zero any environmental risks from land application of biosolids, it increases the environmental risks associated with landfilling and incineration. Landfilling or incinerating a larger percentage of biosolids also reduces the reuse or recycling of valuable resources and may increase the overall cost of biosolids disposal.

How Much is Too Much?

The risk-assessment procedures used by the E.P.A. to develop the current regulations have been studied and reviewed by numerous scientists. Many have concluded that the limits established in the regulations are protective of public health and the environment.⁸ Other scientists, however, have expressed concern that the regulations are not protective enough.⁹ Much of the concern and debate focuses on what is known as "cumulative loading" of trace elements in the soil. Cumulative loading refers to the long-term buildup of trace elements in soil as a result of repeated biosolids applications. As soil levels of these trace elements increase, the elements could become toxic to plants or soil-dwelling animals, or enter the food chain in undesirable amounts. The debate centers on when applications should cease to prevent this from happening.

⁸ Use of Reclaimed Water and Sludge in Food Crop Production. National Research Council. National Academy Press, Washington, D.C. 1996.

⁹ The Case for Caution: Recommendations for Land Application of Sewage Sludges and an Appraisal of the U.S. E.P.A.'s Part 503 Sludge Rules. E. Z. Harrison, M. B. McBride, and D. R. Bouldin. Cornell Waste Management Institute, 1997.

The E.P.A. regulations establish cumulative loading limits for eight trace elements. The limit represents the total amount of the element that may be added to a soil before no further addition of biosolids is allowed. The cumulative limits established by the E.P.A. would allow soil concentrations of these elements to increase to levels that are 10 to 100 times the normal background concentration in soil (see Table 3). Proponents of the rules contend that numerous scientific studies have demonstrated that these levels are protective. Detractors claim that insufficient data was collected to establish some of the levels, and that in some cases the assumptions built into the risk-assessment procedures were not conservative enough. These questions are being debated actively among scientists (including some at Penn State) who are involved in biosolids research.

Table 3. Possible effects of sewage sludge application on soil trace element concentrations and number of years required to reach cumulative loading limits for regulated trace elements.

Trace element	Typical background concentration range for noncontaminated soils (mg/kg)	Theoretical soil concentration at EPA cumulative loading limit ¹⁰ (mg/kg)	Number of years required to reach cumulative loading limit ¹¹
Arsenic	6-10	21	741
Cadmium	0.2-0.5	20	1,614
Copper	17-65	750	278
Lead	8-22	150	360
Mercury	0.06-0.15	9	1,068
Nickel	7-45	210	1,684
Selenium	0.3-0.4	50	2,258
Zinc	19-82	1,400	368

¹⁰Theoretical maximum level to which soil concentrations of these elements would be increased after application of the maximum allowable amount of that element.

¹¹ Assumes an annual application rate of 4.5 tons/acre of a sewage sludge with trace element concentrations equivalent to the median concentrations listed in Table 2.

Some aspects of the current biosolids regulations are being reassessed by the E.P.A., and some changes to the regulations may result. These changes could include adding one or more organic chemicals to the list of regulated pollutants and modifying the existing cumulative loading limits.

What Does This Mean for Pennsylvania?

The question that confronts municipalities, farmers, and rural communities in Pennsylvania is whether or not biosolids can be applied to land without creating undue risk to human health and the environment. When considering this question, it is helpful to separate short-term and long-term risk.

In the short term, the risk from land application of biosolids can be maintained at very low levels if all applicable regulatory requirements are followed. The primary short-term risk from land-applied biosolids is similar to that from animal manure: the possibility of nitrate or phosphorus movement to groundwater or surface water.

Long-term risks from land-applied biosolids relate to the buildup of trace elements in soil. This buildup is a long-term risk because trace element concentrations in most biosolids are low enough that it would take literally hundreds of years of continuous annual applications to reach the currently established loading limits. Estimates of the number of years required to reach the cumulative loading limits are shown in Table 3. These are conservative estimates because most sites do not receive biosolids every year and it is highly unlikely that a given field would remain in a biosolids application program continuously for 200 or more years.

It must be emphasized, however, that these estimates are based on median trace element concentrations, and any element in any given biosolids sample could be present in much higher or lower quantities than the median value.

The most conservative scientists in the debate over risk from biosolids application have recommended cumulative loading limits approximately one-tenth of those in the current regulations for all trace elements except lead. Under this highly conservative scenario, it would take one-tenth the number of years given in Table 3 to reach the various loading limits. An application site, therefore, could receive about 28 applications of biosolids before the more conservative suggested loading limits would be reached (for copper). Because most biosolids application sites in Pennsylvania have had fewer than 10 applications, this practice can continue for at least 18 years before even these highly conservative limits would be reached. During this 18-year period, some resolution of the scientific debate over these issues should be reached.

Over the long term, public health and environmental risks can be reduced even further by decreasing the quantity and increasing the quality of the biosolids that are produced. This can be done by strictly enforcing requirements for industrial pretreatment of wastewater, by separating storm and sanitary sewerage, and by investing in new wastewater treatment technologies that will generate less biosolids. Most of these measures will require monetary investments, so wastewater treatment authorities will need the support of their communities to make these changes.

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