

BIOSOLIDS LAND USE IN ARIZONA

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Introduction

The land application of biosolids (non-hazardous sewage sludge) has been in practice in Arizona since the 1960s. The controlled use of biosolids in agriculture and land reclamation provides numerous benefits. Biosolids are an excellent renewable source of plant nutrients such as nitrogen, phosphorous, copper and zinc, see table below. Biosolids provide much needed organic matter to our desert soils, improving their structure, water holding capacity and ease of management. The use of biosolids as fertilizers helps reduce the dependence on oil-derived commercial synthetic fertilizers and saves valuable landfill space. However, even treated municipal biosolids can contain organisms (pathogens) capable of transmitting and producing diseases and very low (trace) levels of toxic chemicals. Therefore, there are potential risks associated with the repeated use of biosolids, including the accumulation and uptake of pollutants in soils and plants, and groundwater and surface water pollution. But alternate forms of sludge disposal, such as land filling, incineration (not allowed in Arizona) and ocean dumping (practiced in coastal states but banned since 1988) are costly and pose greater risks to our health and the environment.

The following sections describe how biosolids are produced, summarize federal and Arizona regulations that control their disposal on land, present an overview of the research on biosolids at the University of Arizona, and answer some common questions about the land application of biosolids. All humans produce waste, so we are all part of the problem. The continued safe use of biosolids depends on an informed public and its participation. It is also important to support biosolids research and monitoring programs and regulations that are responsive to new health and environmental protection concerns, as they arise.

What Are Biosolids?

Biosolids, also known as municipal sewage sludge, are residues produced during the biological secondary treatment of municipal wastewaters in wastewater treatment plants, see diagram in figure 1. After the initial physical removal of large solids, sewage water is aerated and spiked (inoculated) with oxygen-loving microorganisms (aerobic bacteria) that digest (degrade) the sewage sludge organic (carbon-based) waste constituents and grow. This process produces residual solids that together with inorganic sediments such as soil, present in raw

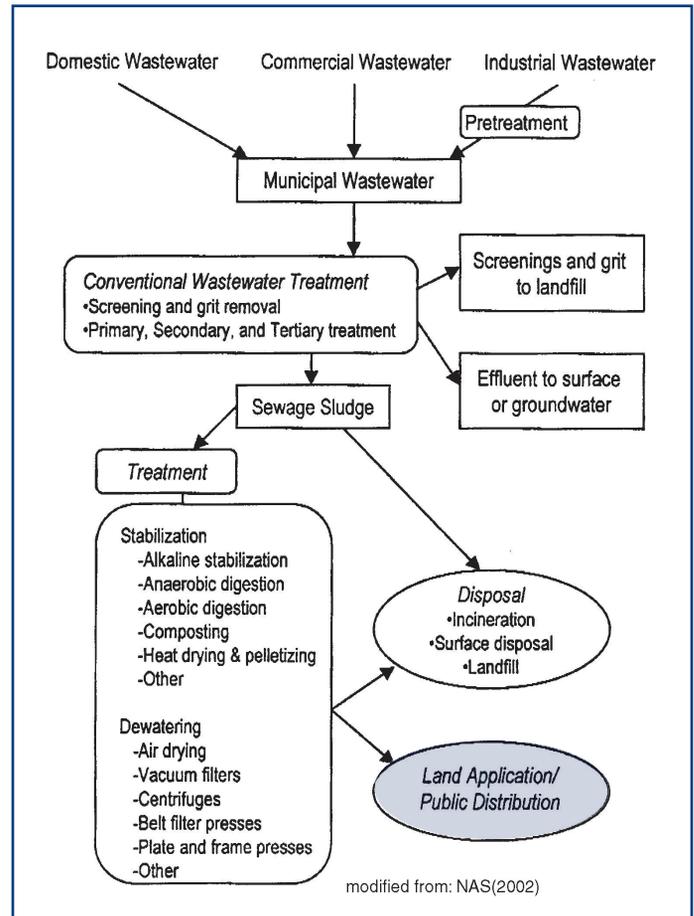


Figure 1. Municipal Wastewater and Sewage Sludge (Biosolids) Treatment Options. Source NAS(2002)

sewage, are allowed to settle out of the water. A small portion of these solids is sent back to the aeration tanks to reactivate the biodegradation of new raw sewage. The bulk of biosolids may be de-watered and send to a landfill or treated to further reduce the levels of pathogens. Biosolids are often stabilized further in wastewater treatment plants using microorganisms that grow in the absence of oxygen (anaerobic bacteria) in a closed vessel. This process, called anaerobic digestion, produces renewable energy in the form of methane and ammonia gases and further reduces the concentrations of pathogens and many of the odor-

Footnote: (text) denotes a technical term.

Table 1. Composition of anaerobically digested sludge from Tucson, Arizona.

Element	Concentration (dry weight basis)
Metals	----- (mg/kg ⁻¹)* -----
Copper	520
Nickel	13
Lead	59
Chromium	29
Cadmium	3.5
Zinc	1900
Silver	4.7
Arsenic	ND ^a
Mercury	0.51
Molybdenum	12
Selenium	ND ^a
Other Elements	----- (g 100 g ⁻¹)** -----
Phosphorus	3.3
Calcium	3.6
Magnesium	0.45
Sodium	0.4
Organic carbon	16.6
Nitrogen	
Total Kjeldahl N	3.4
inorganic N	0.16
Total solids	2.8 (wet basis)

^aND = Below detection limits.
* equivalent to part per million (ppm)
** equivalent to percent (%).
Source: I.L. Pepper

Biosolids are complex and variable mixture of organic residues rich in plant nutrients, with soil and sediment particles, contaminants (metals and trace organic chemicals), microorganisms (benign and pathogenic), and water.

producing chemicals found in raw sewage and aerobically digested biosolids. The final product is a black slurry (up to 98% water) with a pungent ammonia and sulfur-like odor. To reduce disposal and transportation costs of this waste, water may be filtered out of the biosolids using centrifuges, heat or drying beds. Anaerobically treated biosolids usually meet Class B biosolids standards (described below) and can be land applied without further treatment. However, additional forms of treatment to further stabilize biosolids include composting, controlled drying or other sterilization methods that can produce Class A biosolids (described below). See table 1 for the chemical composition or a typical Arizona biosolids sample. Dried, stabilized biosolids are usually dark gray in color with the consistency of potting soil (~5% water) and a musty smell.

Arizona Biosolids Regulations

In 1993 the U.S. Environmental Protection Agency (USEPA) promulgated the Standards for the Use and Disposal of Sewage Sludge (biosolids) published in the Code of Federal Regulations Title 40 (Parts, 257,403, and 503). The biosolids standards, listed in this commonly referred “Sludge Rule”, set specific limits on the biosolids concentrations and land application rates of ten metals, see table below.

The Sludge Rule classifies biosolids as Class A, as being essentially 100% pathogen-free. In addition, when these Class A biosolids are also very low in metal concentrations, they are considered “exceptional quality” biosolids, see table 2. Class A biosolids are considered safe enough for direct use in home gardens and to produce food for human consumption. Class B biosolids must achieve at least a 99% reduction during treatment in the pathogens measured in untreated biosolids. Thus, these residues may still contain detectable amounts of pathogens (bacteria, viruses and helminthes) found in human excrements and higher levels of metals than Class A biosolids. Therefore, Class B biosolids exposure to humans and animals must be limited. For example, farm or grazing lands amended with Class B biosolids must restrict access to human and foraging animals for a least one month. Also, food crops may not be harvested for at least 14 months following biosolids application. It is assumed that given enough time pathogens in Class B biosolids will be destroyed (**inactivated**) in the soil environment.

Table 2. Pollutants found in biosolids regulated under the 503 Sludge Rule.

Pollutant	Biosolids	Exceptional Quality Biosolids	Soil	Soil
	Pollutant Ceiling	Pollutant Concentration Limits	Annual Pollutant Loading Rates	Lifetime Pollutant Loading Rates
	(Class B)	(Class A)		
	(mg/kg)*	(mg/kg)*	(kg/ha)**	(kg/ha)**
Arsenic	75	41	2	41
Cadmium	85	39	1.9	39
Chromium	3000	Under revision	by	EPA
Copper	4300	1500	75	1500
Lead	840	300	15	300
Mercury	57	17	0.85	17
Molybdenum	75	Under revision	by	EPA
Nickel	420	420	21	420
Selenium	100	100	5	100
Zinc	7500	2800	140	2800

* assumed to be equal to parts per million (ppm)
** kg/ha is approximately equal to pounds/acre (lbs/ac)

Key Components of 503 Sludge Rule for land application of biosolids:

- Pollutant Limits
- Pathogens and Vector Attraction Reduction
- Nutrient and Land Management Practices
- Record Keeping, Monitoring and Reporting.

In 1996 the Arizona Biosolids Program was created under the Arizona Department of Environmental Quality (AZDEQ) Solid Waste Program. This program adopted the USEPA Sludge Rule. According to the AZDEQ, the Biosolids Program complies with the Clean Water Act (1977 sludge application amendment). Arizona is also one of a few states with primacy; that is, responsible for the administration and enforcement of its own biosolids program. The requirements for use and transportation of biosolids are described in the Arizona Biosolids Rule which also includes an Arizona Pollutant Discharge and Elimination System (AZPDES) permit to comply with the United States Clean Water Act (see the Arizona Administrative Code, Title 18, Chapter 9, Article 10).

Farmers who want to apply biosolids on their agricultural lands must register it with AZDEQ, and provide very detailed information about the biosolids, including metal pollutants concentrations and nitrogen content. For example, biosolids must be tested periodically for pathogens and metals and meet Class A or Class B pathogen reduction and animal disease transmission control (**vector reduction**) requirements (see AZDEQ website). This information, together with the amounts of biosolids and the exact locations, must be reported annually to AZDEQ. There are numerous restrictions to the use of biosolids on land including depth to groundwater, slope, and proximity to neighbors. There are also restrictions on the types of crops, land access and harvest dates that must be documented when using Class B biosolids as fertilizers for agronomic crops. Farmers must also limit their land application of biosolids to supply only the amount of nitrogen required to grow a given crop annually using Best Management Practices (BMPs).

Land Application of Biosolids in Arizona and in the US

According to the AZDEQ there are currently about 124 biosolids land application sites registered in Arizona. However, to date summary data about the total number of acres registered, number of these acres that receive biosolids annually, and the type (solid, slurry) and quality (Class A or Class B) being applied to Arizona agricultural land has not been made available to the public by ADEQ. Figure 2 shows anaerobically digested liquid sludge injected into an agricultural field in Marana Arizona.

Nationwide about 50% of the approximately 6 million dry tons of biosolids generated annually are applied to land in 50 states, representing no less than 1% of the total agricultural land (see



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Figure 2. Anaerobically digested biosolids in a Marana, AZ field.

USEPA website). The rest of the biosolids are put in landfills or incinerated. The amount of nitrogen that biosolids provide is less than 2% of the nitrogen fertilizer used to produce crops in the U.S. Small but densely populated states like New York and New Jersey produce large amounts of biosolids that cannot be safely land applied year after year on their lands. This has led to the transfer of biosolids to Western states less populated that have available agricultural and rangeland. Arizona for example, imports or has imported dried biosolids from neighboring California and from Eastern states like Connecticut and New York. These residues are considered safe for land disposal as long as they meet all Arizona regulations, outlined previously. Remember that there are strict numerical limits to the annual and lifetime amounts of metals derived from biosolids that can be applied to a field. For example, according to the above table, biosolids that contain concentrations of metals above any value listed in the Class B Biosolids Ceiling Concentrations column cannot be applied to land. In the case of Arsenic (As), for example, only 2 kg/hectare (1.8 lbs/acre) of As can be applied annually to land and the cumulative amount of As cannot exceed 41 kg/hectare (36.5 lbs/acre). Note that if biosolids were applied annually with at least one metal being applied at its maximum

annual loading rate, the useful life of the land would be limited to 20 years.

Experts agree that metal standards for biosolids are very conservative because very restrictive pathways of exposure were used to set the standards. These pathways of exposure are, sludge eaten by a child, plant toxicity, and animal feed toxicity. Thus, it is very unlikely that any of these metals will ever reach harmful levels in soils if biosolids are applied according to current regulations. However, some of these standards are under revision and may change as research provides new information on the health effects and fate of these and other chemicals in the environment, see table above.

History of Biosolids Research at the University of Arizona

Research into the agronomic benefits and potential risk of biosolids use in Arizona started in the 1950s at the University of Arizona College of Agriculture and Life Sciences and the Agricultural Experiment Station [W.H. Fuller, A.D. Day, T.C. Tucker and others]. Field plot experiments showed that in Arizona soils and wheat crops would produce similar or higher yields in soils amended with biosolids rather than conventional fertilizers. It was also observed that some grains like wheat grown in biosolids amended soil had higher concentrations of metals like zinc, lead, and nickel than wheat grain grown with conventional fertilizers.

In the mid 80s and early 90s biosolids research focused on the beneficial use of biosolids for cotton production and on the fate and transport of metals, nitrates and pathogens from biosolids [B.B. Taylor, I.L. Pepper, C.P. Gerba, J.F. Artiola, M.J. Ottman and others]. Field plot studies conducted at the Marana Agricultural Research Center showed that adding amounts of biosolids in excess of crop nutritional demands produced excessive vegetative growth and reduced cotton yields. It was also shown that cumulative applications biosolids could result in excessive leaching of nitrates below the root zone in furrow-irrigated cotton fields. Research in these plots also showed that pathogenic viruses and bacteria, can only survive (**remain viable**) a few days to a few months in the soil environment. Arizona's soil-climate conditions (high temperatures, and long dry periods) are also very favorable to the destruction (**inactivation**) of pathogens. Thus, pathogens from biosolids are no longer detectable in the soil after about six months.

Basic research [by W.H. Fuller and others] at the University

The University of Arizona has been actively involved in research and extension work on the benefits and potential health and environmental issues related to the land application of biosolids for more than 45 years.

of Arizona in the 1970s contributed to the development of the maximum allowable soil metals loadings defined in the Sludge Rule, see Fuller (1984). It is now well accepted that metal contaminants found in biosolids in the form of cations (**+ charge ions**) are quickly retained (adsorbed) or form water insoluble minerals in alkaline, high pH soils common in Arizona. However, metal pollutants that form anions (**- charge ions**) are more mobile and plant available in alkaline soils. Recent research at the University of Arizona [J.F. Artiola, M.L. Brusseau] on the fate of molybdenum (Mo) may help modify Mo soil loading rates in biosolids amended soils under revision by the USEPA. The metal pollutant loading limits in agricultural and range lands have to date proven safe. These maximum annual and lifetime loadings for metals were risk-based set by the USEPA with the knowledge that exceeding these limits could produce negative health and environmental effects.

Although metals in biosolids continue to be a concern, it is comforting to know that even before the promulgation of the Sludge Rule, metals concentrations in biosolids have been on a decline in the U.S.. This trend is due to federal and state regulations that require the control and pre-treatment of pollutants before they enter municipal wastewater treatment plants. This has made the land application of biosolids safer despite new concerns and some negative public perceptions.

Biosolids Research in Arizona: Emerging Issues

The increasing urban encroachment into rural areas has made the general public more aware of use of biosolids and their potential impacts. Unpleasant odors that emanate during the handling of biosolids and the realization that these residues may contain pollutants and pathogens have made the public more aware about possible health hazards. Research at the University of Arizona [I.L. Pepper, C. Gerba and others] has demonstrated that aerosols associated with the land application of liquid biosolids do not pose a significant health hazard to nearby communities, see figure 3. Similarly, ammonia odors associated with the land application of these residues are quickly dispersed over short distances and are many times below allowable industrial worker exposure levels [J.F. Artiola, A.L. Matthias and others]. In response to concerns about pathogens and odors, research at the University of Arizona is assisting in the development of cost-effective methods to dry and reduce the numbers of pathogens in biosolids prior to land application using drying beds engineered to use solar energy. [C. Choi, C. Gerba and others].

There are new concerns about the fate of organic pollutants, which are not regulated, in biosolids. Research is underway at the University of Arizona on the fate in the soil and water environment of so called "emerging" contaminants found in biosolids and wastewaters in minute (**ultra trace**) quantities [D. Quanrud and others]. There is much need for more information

Footnote: text in [] are past and present faculty involved in biosolids research at the University of Arizona.

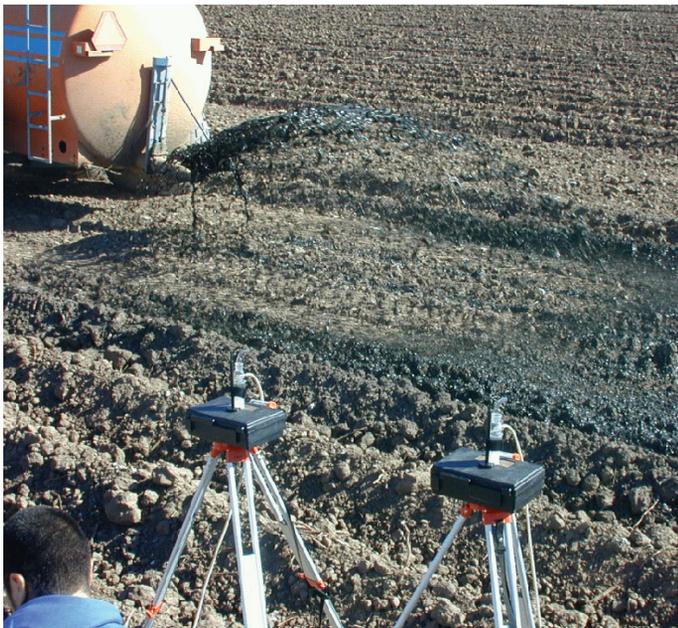


Figure 3. Land application of liquid biosolids via a spray applicator. Source: Environmental Pollution Science (2006) chap.23.

on the fate of pollutants found in biosolids such as pesticides, soaps (**surfactants**), fire retardants [J. Chorover and others], pharmaceuticals, and other possible endocrine disruptors (EDCs, see footnote). These chemicals could enter food and water supplies if not trapped or degraded in soils that receive biosolids.

Extensive research has been done at University of Arizona on the detection of new and emerging pathogens found in biosolids and to determine their ultimate fate in the soil and water environments [I.L. Pepper, C. Gerba and others]. These researchers summarized their findings on the survival of pathogens and effects to native soil organisms from 20 years of applications of Class B biosolids to agricultural lands as follows:

“Data show that land application of Class B biosolids had no significant long-term effect on indigenous soil microbial numbers including bacteria, actinomycetes, and fungi compared to unamended control plots. Importantly, no bacterial or viral pathogens were detected in soil samples collected from biosolid amended plots in December (10 mo after the last land application) demonstrating that pathogens introduced via Class B biosolids only survived in soil transiently. However, plots that received biosolids had significantly higher microbial activity or potential for microbial transformations, including nitrification, sulfur oxidation, and dehydrogenase activity, than control plots and plots receiving inorganic fertilizers. Overall, the 20 annual land applications showed no long-term adverse effects, and therefore, this study documents that land application of biosolids at this particular site was sustainable throughout the 20-yr period, with respect to soil microbial properties.”

Researchers at the University of Arizona are actively involved in relevant biosolids research. Understanding the fate of emerging pathogens and pollutants in the soil and water environments is necessary for the continued safe land disposal of biosolids.

Based on this 20-year study, the researchers went on to conclude that:

“The study showed that land application of Class B biosolids had no significant long-term effect on soil pH and CaCO_3 . However, land application significantly increased soil macro-nutrients (C, N and P). Soil nitrate values in plots that received biosolids or inorganic fertilizer amendments were high indicating the potential for groundwater contamination. In addition, total and available soil P concentrations increased to values above that necessary for plant growth but P values attenuated to background levels at a soil depth of 150 cm. Total metal concentrations attenuated rapidly with increasing soil depth, and were generally similar to values found in control soils at a depth of 150 cm. Application of biosolids for nonfood agricultural crop production at this arid southwest site seems to be sustainable with respect to soil chemical entities.”

The reader should note that these observations and conclusions might not be applicable to other regions of the US. For example, while not a serious concern in AZ, high (Phosphate) levels in soils can pollute surface waters in areas with higher rainfall and surface water runoff. Concerns remain (based on this and other studies) about significant increases in nitrate levels in AZ agricultural soils, due to repeated applications of fertilizers and/or biosolids, and the potential for groundwater contamination. See Arizona Cooperative Extension Bulletin AZ1536.

Biosolids Use for Land Reclamation

Biosolids are also used to improve fertility (**nutrient status**) and structure of disturbed lands and mine tailings. Biosolids can provide much needed nutrients, and organic matter to these barren materials, increasing microbial activity and nutrient cycling for sustained plant growth. In Arizona the major goal of mine tailings reclamation is to facilitate plant establishment to control offsite dust and sediment runoff. For example, during periods of high winds and dryness dust (**fine particles**) with high concentrations of arsenic (As) and lead (Pb) and other metals can be transported into residential areas, exposing its population to these toxic chemicals. Similarly, during high rainfall periods exposed mine tailing sediments can wash off-site and contaminate surface waters and wildlife.

The application of biosolids to disturbed land is best determined by local soil, plant, and climatic conditions. For example, the addition of biosolids to disturbed lands in arid

Footnote: EDCs are chemicals that can interfere with hormone production/release and/or hormonal activity and even mimic hormones.



Figure 4. Revegetation of mine tailings using biosolids in southern Arizona research site.

and semi-arid climates produces rich soil nutrient conditions favorable to microbial growth and nutrient cycling. But these same soil conditions also favor the growth of imported (*exotic*) and unwanted invasive plant species over native plants. In the state of Utah, for example a one-time application of Class A biosolids to disturbed are lands is limited to “agronomic rates” based on the known annual plant nutrient needs and the nitrogen available in the biosolids source. With few exceptions the application rates of biosolids range between 5-20 tons of dry biosolids per acre. Presently, research at the university of Arizona [I.L, Pepper, T. Thompson and others] focuses on the use of up to 150 tons of Class A biosolids to produce an “instant soil” and determine the long-term effects of biosolids on mine tailings types of microorganisms (*microbial diversity*), and plant cover, see figure 4.

Answers to Concerns about the Safety of Biosolids Land Use

There are concerns about the accumulation followed by the sudden release of pollutants in the soil environment (time bomb effect).

In the case of metals, evidence exists that these pollutants become in fact more trapped and therefore less mobile and less plant available in soils with little or no acidity (pH > 6.5). Some trace organic pollutants may be trapped in the soil organic matter (OM) and later be released as OM breaks down. Evidence indicates that free organic contaminants, although more mobile, are also much more likely to biodegrade in the soil environment.

Odors from biosolids may affect my health.

Biosolids produce nuisance odors associated with sulfur and nitrogen bearing volatile chemicals. This has led to increasing complaints in urbanized areas that were traditionally only agricultural. Research to date has shown that these and other chemicals quickly dissipate into the air once biosolids are applied to land and incorporated into the soil. These and other naturally occurring gases can be toxic if inhaled at high concentrations, but are not known to be a health treat in open spaces at very small concentrations. Biosolids storage facilities and transportation and land application activities can produce odors when not managed properly. Unfortunately, direct spray and slinger methods of biosolids application can produce unwanted odors. Thus, direct injection of biosolids into soils remains the preferred but costlier method of land application to eliminate odors. Nuisance complains should be addressed to the AZDEQ biosolids coordinator.

Pathogens in biosolids can contaminate air and water and cause diseases.

Raw sewage is the most common source of disease causing pathogens in water. Modern sewage treatment plants produce Class A and Class B biosolids with no measurable or only small quantities of pathogens. Biosolids are not known to produce or spread diseases when stored, handled and land applied properly. Intestinal pathogens found in class B biosolids cannot survive in the soil environment for more than a few months. But direct exposure to raw sewage and Class B biosolids can cause diseases and contaminate water sources and should be avoided.

Pollutants and salts in biosolids applied to land contaminate surface and groundwater sources.

When biosolids are applied at rates not exceeding USEPA pollutant standards and local crop fertility requirements, these residues are not known to cause pollution. But applications of biosolids, animal wastes or commercial fertilizers in excess of crop nitrogen (N) and phosphorous (P) fertilizer needs can cause N and P surface and groundwater pollution. Excessive salt accumulations from biosolids applied to soils are not common in Arizona. Biosolids are typically low in salts, compared to animal wastes, because bulk of the soluble minerals found raw sewage water stays in the reclaimed water.

I.L. Pepper

Besides metals, are there any other chemicals regulated in biosolids?

Prior to the passage of the 503 Sludge Rule in 1993, the USEPA conducted national sewage quality surveys and determined that other than metals most toxic organic chemicals could not be detected or were measured at extremely low concentrations in a small percentage of sludge samples. In 2003 the USEPA decided after several years of studies not to regulate dioxins levels in biosolids due to the fact that concentrations of these chemicals continue to decline in biosolids and they are a very low health risk to the public. Recently, due to the development of new analytical chemical testing tools, many other toxic or potentially toxic chemicals (“emerging” contaminants) have been detected in biosolids and reclaimed waters at ultra-trace concentrations. The potential risks of these chemicals to human health and the environment are a new concern that we must continue to monitor and research.

How can we contribute to the safe disposal of biosolids on land?

What can be done to make biosolids a safer and more valuable fertilizer source?

As end-users of numerous household products that contain toxic and hazardous chemicals, limiting the use and disposal of these products into the sewage system will continue to improve the quality of biosolids. **What should we do?**

- Use no or low phosphate, biodegradable soaps and detergents at manufacturer recommended amounts.
- Do not dump leftover household chemicals such as oil products, pesticides, paints, solvents and medicines down the toilet or sink. Instead, take unused or spent products to local recycling centers.
- Do not use or limit the outdoor use of yard pesticides and avoid chemical spills on driveways, as these activities can contaminate runoff water entering the sewage system.

Are commerce and industries also responsible for the quality of biosolids?

Yes, commercial and pretreated industrial wastewaters are eventually discharged into municipal wastewater systems that produce biosolids. **What can we do?**

- Support strict regulations for the pre-treatment of industrial wastewaters before they enter municipal sewage systems.
- Support waste minimization and recycling programs, incentives and regulations that can contribute to cleaner biosolids.
- Support manufacturers of household goods that use environmentally friendly (green) products and chemicals.

Remember

As the population grows so will the production of biosolids and the need for safer disposal options.

Biosolids can continue to be valuable renewable source nutrients for agricultural soils, rangeland, and land reclamation as long as the quality of these residues continues to improve.

This can be done by controlling unwanted chemicals (metals, synthetic chemicals, medicines) in sewage streams and by improving biosolids pathogen and pollutant reduction methods.

Healthy soils contain hundreds of millions of beneficial bacteria and other microorganisms per gram that recycle plant nutrients, and degrade pathogens and organic pollutants.

Also, healthy soils usually have an excess capacity (minerals, organic matter and favorable chemical conditions) to trap and retain metals preventing them from contaminating plants and polluting other environments

Soils can continue to provide this valuable service as long as they are not overwhelmed by excessive amounts of wastes, pollutants or other adverse soil conditions.

Biosolids are not a significant health threat as long as they are treated, stored, handled, and applied to land following accepted guidelines and regulations.

But, federal and state biosolids guidelines, regulations and monitoring programs must continue to evolve. They must adapt to new concerns about biosolids based on new scientific information.

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