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College of Agriculture and Life Sciences
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Biosolids Land Use in Arizona

Janick F. Artiola
The University of Arizona

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 1. 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 <u>all</u> part of the problem. The continued safe use of biosolids depends on the participation of an informed public. 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.

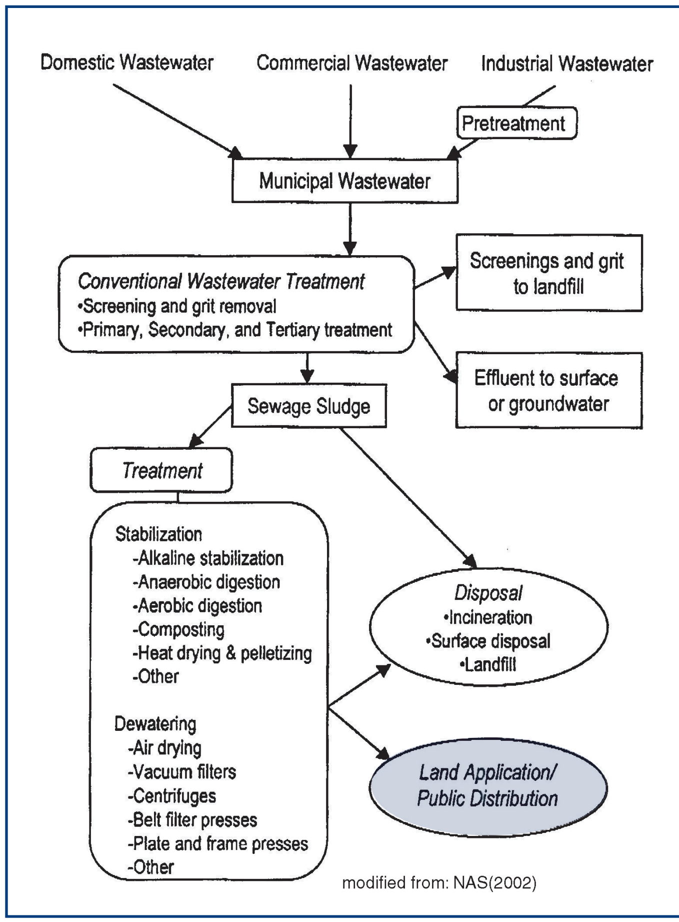

Figure 1. Municipal Wastewater and Sewage Sludge (Biosolids) Treatment Options. Source NAS(2002)

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 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 present in raw 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 stabilized to further reduce the levels of pathogens. These biosolids are often treated 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 or methane and ammonia gases. Also, it further reduces the concentrations of pathogens and

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)

[a]ND = Below detection limits.
* equivalent to part per million (ppm)
** equivalent to percent (%).
Source: I.L. Pepper

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

many of the odor-producing chemicals found in raw sewage and aerobically digested biosolids. The final product of digestion 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. 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 of a typical Arizona biosolids sample. Dried, stabilized biosolids. are usually dark gray in color with the consistency of potting soil (~5% water) with 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 2.

Under the Sludge Rule, biosolids are considered 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 excrement and higher levels of metals that 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. With time, pathogens in Class B biosolids are destroyed (inactivated) in the soil environment.

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

Pollutant	Biosolids Pollutant Ceiling Concentration Limits (Class B) (mg/kg)*	Exceptional Quality Biosolids Pollutant Concentration Limits (Class A) (mg/kg)*	Soil Annual Pollutant Loading Rates (kg/ha)**	Soil Lifetime Pollutant Loading Rates (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 or responsibility 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. It 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 use biosolids as a fertilizer in their agricultural lands in Arizona must register their land 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, 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 yet 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,


J. F. Artiola

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

representing no less than 1% of the total agricultural land (see 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 less-populated Western states that have available agricultural and range land. 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 life time 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) can applied annually to land

and the cumulative amount cannot exceed 41 kg/hectare (36.5 lbs/acre). Note that if biosolids are 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 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 2.

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 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 a 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 prolonged 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.

For more than 45 years 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.

Basic research [by W.H. Fuller and others] at the University 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 life time 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 the 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 has 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 on the fate of pollutants found in biosolids such as pesticides, soaps (surfactants), fire retardants [J. Chorover and others],

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

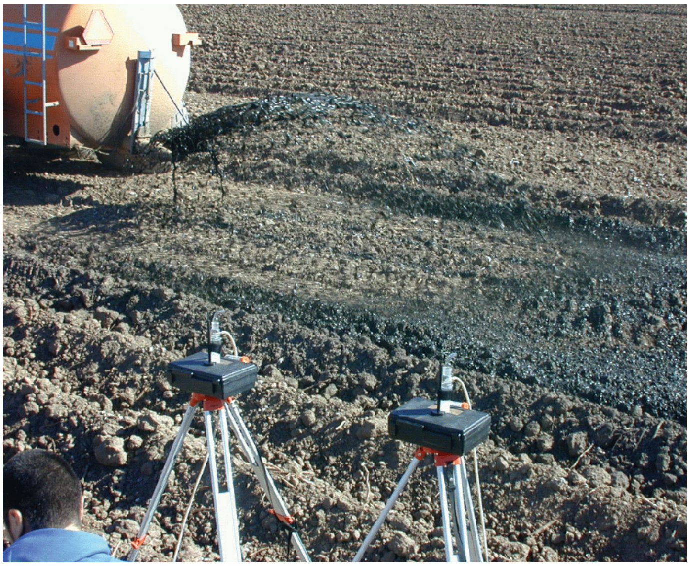

Figure 3. Land application of liquid biosolids via a spray applicator. Source: Environmental Pollution Science (2006) chap.23.

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.

Research continues at the 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 [C. Gerba, I.L. Pepper]. These researchers are also actively involved in the development of state and federal biosolids standards and reuse guidelines that protect human health and the environment.

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 with high concentrations of 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 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

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.

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 the types of microorganisms (microbial diversity), and plant cover found at mine tailings, see figure 4.

I.L. Pepper

Figure 4. Mine tailings revegetation using biosolids in southern Arizona research site.

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

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 more trapped and less mobile and therefore 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 once 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 threat in open spaces at very small concentrations. Biosolids storage facilities, 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, 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 in raw sewage water stays in the reclaimed water.

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 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.
- Limit the outdoor use of pesticides and avoid chemical spills on driveways. 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 waste waters 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 a valuable renewable source of 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. They 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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The University of Arizona
College of Agriculture and Life Sciences
Tucson, Arizona 85721

Janick F. Artiola
Associate Professor, Soil, Water & Environmental Sciences

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