Potential Hazards created by the Land Application of Biosolids

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ABSTRACT

As human population grows throughout the world, the production of sewage sludge is in constant rise. Wastewater treatment plants have the ability to treat residential and industrial wastes. However, through this process a quantity of solid byproduct, termed “biosolids,” remains to be dealt with. As an alternative to land filling and incineration, biosolids have been successfully used as an agricultural soil amendment and nutrient source for several decades. However, high content of nutrients, chemicals, and trace metal elements render biosolids a potential health and environmental hazard. This creates concerns for the use of biosolids in agricultural production, as well as in situations where hydrological runoff could carry pollutants to water sources. The intentions of this paper are to present a summary of material collected from various studies to determine what level of treatment is necessary to achieve a safe state in which biosolids can be safely applied to land.

KEYWORDS

Wastewater, biosolids, human waste, sewage, sludge, water contamination

INTRODUCTION

Decades ago, thousands of cities across the country disposed of raw sewage by dumping it into lakes, streams, and rivers. Today, the Clean Water Act, which was established by the United States Environmental Protection Agency (US EPA), requires that communities treat their wastewater as a means to safely return this resource to the environment. The objectives of wastewater treatment are to remove suspended solids, treat biodegradable organics, and eliminate pathogens. Depending upon the content and characteristics of a waste stream, there are various treatment options available including biological and chemical treatment methods.

According to Metcalf and Eddy, authors of *Wastewater Engineering Treatment and Reuse*, “The management of the solids and concentrated contaminants removed by treatment has been and continues to be one of the most difficult and expensive problems in the field of wastewater engineering” (Metcalf and Eddy, 2003). Wastewater solids, or biosolids, are the nutrient rich organic semisolid by-product of wastewater treatment. The disposal of biosolids is an increasing concern as limitations continue to bar options. Landfill disposal is discouraged due to the difficulties of creating new landfills and incineration has become more complicated as air emissions have become more stringent.

In the United States, biosolids production has steeply increased from approximately 4.6 million dry tons in 1972 to 6.9 million dry tons in 1998 (US EPA, 1999). There are procedures that have the constructive ability to stabilize biosolids. Once these biosolids have been properly treated, they can be recycled and applied to crop land to increase soil productivity and improve soil quality due to the abundance of nutrients and organic matter (US EPA, 1999). However, strict requirements for the land application of biosolids have also developed. According to the US EPA, only biosolids that meet the most stringent standards spelled out in the Federal and state rules can be approved for use as a fertilizer (US EPA, 2005). The dispensability of biosolids depends upon the characteristics of the solid waste and this is dependent upon the sources of the waste and the levels of treatment performed. Within an individual plant, biosolids characteristics have the potential to change annually, seasonally, or even daily due to the varying compositions of influent and the changes in the treatment processes. For the most part, the higher degree of treatment performed leads to more biosolids, and higher contaminant levels within these biosolids. The treatment process usually includes the addition of chemicals to precipitate solids from the waste stream, such as ferric chloride, alum, lime, or polymers, therefore excess concentrations of these chemicals may be present in the biosolids. Unintended effects may also occur, such as when aluminum hydroxide absorbs phosphorus or causes trace metals to precipitate out of the waste water and become part of the biosolids. The presence of these metals prevents the biosolids from being applicable to farmland.

Common types of biosolids treatment include stabilization and dewatering. Stabilization includes procedures to ensure reduction of odors, pathogens, and volatile solids. Major methods of stabilization include aerobic digestion (digestion of organics by microorganisms in the presence of oxygen), anaerobic digestion (digestion of organics by microorganisms in the absence of oxygen), alkali (lime) stabilization, composting, and/or heat drying (US EPA, 1999). The act of dewatering reduces the water content within the biosolids through the processes or air drying, belt filter pressing, filtering, or centrifuging (US EPA, 1999).

Table 1. Stabilization Technologies and Associated Use or Disposal Methods

Treatment Process	Use or Disposal Method
Aerobic or Anaerobic Digestion	Produces biosolids used as a soil amendment and organic fertilizer on pasture and row crops, forests, and reclamation sites; additional treatment, such as dewatering, also can be performed (see note below).
Alkali (lime) stabilization	Produces biosolids useful for land application and for use as daily landfill cover.
Composting	Produces highly organic, soil-like biosolids with conditioning properties for horticultural, nursery, and landscape uses.
Heat-Drying	Produces biosolids for fertilizers generally used at a lower rate because of higher cost and higher nitrogen content.

Note: Two or more processes are often used for treating biosolids (e.g., anaerobic digestion with dewatering and composting).

Source: US EPA, 1999

MARKETABLE SOLUTIONS TO BIOSOLIDS DISPOSAL

"Wastewater treatment plants from across the nation report techniques for creating a 'consumer friendly product' that brings cost savings and pathogen reduction" (Brown, 2005). Sally Brown examines two different municipalities and their production of Class A biosolids in the April 2005 issue of Biocycle. The New Jersey Eastern Municipal Water District utilizes heat exchangers to pasteurize biosolids which allows accomplishment of Class A pathogen reduction (Brown, 2005). In this particular process, the biosolid mass is dried and then applied to sod farms, where high rates of nitrogen are necessary for the production of sod (Brown, 2005). In Orange County, California, 60% of the biosolids are composted and limed to achieve Class A pathogen reduction as a product marketed to home gardeners and agricultural producers (Brown, 2005). The City of Centralia, Washington discovered that lime stabilization can be used as a cost effective means to achieve Class A biosolids, and the final product may be given away on the local market.

While these examples demonstrate beneficial results from biosolids application to land, it must be understood that getting rid of pathogens does not completely solve the problem. Some conclusions that have been drawn from this study include the fact that Class A biosolids cake can result in very large cost savings for municipalities, however, the cost savings do not follow as an immediate consequence of removing the pathogens (Brown, 2005). In order to achieve economic gains from producing Class A biosolids, it is pertinent to minimize transportation costs; therefore this may include marketing such products to municipal residents. This creates challenges as the distribution to local consumers requires the biosolids to be in a user friendly form, with reduced odors and vector attraction, as well as ease of use.

The only solutions to the ongoing problem of biosolids production seem to be volume reduction and the creation of Class A biosolids which are beneficial and easy to use. Examples around the world display how it is possible to market and distribute these solids wastes. The only concern is, are Class A Biosolids clean enough for land application? To understand the characteristics of Class A and its successive level of treatment, Class B, tables 2 and 3 are provided which display the US EPA requirements.

Table 2. Criteria for Meeting Class A Requirements

Parameter	Unit	Limit
Fecal Coliform or Salmonella	MPN/g TS*	1000
	MPN/4g TS	3
AND, one of the following process options		
Temp/Time based on % Solids	Alkaline Treatment	
Prior test for Enteric Virus/Viable Helminth	Post test for Enteric Virus/Viable Helminth Ova	
Composting	Heat Drying	
Heat Treatment	Thermophilic Aerobic Digestion	
Beta Ray Irradiation	Gamma Ray Irradiation	
Pasteurization	PFRP** Equivalent Process	

* Most probable number per gram dry weight of total solids
**Process to Further Reduce Pathogens

Source: US EPA, 2000

Table 3: Criteria for Meeting Class B Requirements

Parameter	Unit	Limit
Fecal Coliform	MPN or CFU/g TS*	2,000,000
OR, one of the following process options		
Aerobic Digestion	Air Drying	
Anaerobic Digestion	Composting	
Lime Stabilization	PSRP** Equivalent	

*Most probably number of colony-forming units per gram dry weight of total solids
**Process to Significantly Reduce Pathogens

Source: US EPA, 2000

The US EPA specifies pathogen limitations within Class A and Class B biosolids (US EPA, 2000). Class B biosolids have a significantly reduced level of biosolids with respect to untreated sewage, while Class A biosolids have no detectable pathogens (US EPA, 2000). The pathogenic organisms within Class B biosolids should be reduced to a level that is unlikely to pose a threat to public health and the environment (US EPA, 2000). Due to the nature of Class B biosolids, there are restrictions in place to minimize the potential for human and animal contact within a period of time following land application (US EPA, 2000). Additionally, Class B biosolids are not allowed to be sold or given away in any container, nor are they intended for application on home gardens and lawns.

BENEFITS FROM LAND APPLICATION OF BIOSOLIDS

A reported 6.9 million tons of biosolids were generated in 1998, and of this, 60% was utilized for land application, compost, and landfill cover, while the remaining 40% was discarded without any attempt to recover nutrients or other valuable properties (US EPA, 1999). "In 2000, we estimate that 7.1 million tons of biosolids will be generated for use or disposal, growing to 7.6 million tons in 2005 and to 8.2 million tons in 2010" (US EPA, 1999). The history of biosolids and predicted future indicate that this is a concern which demands an environmentally friendly solution.

As stated in the US EPA's *Biosolids Generation, Use, and Disposal*, when properly treated and managed in accordance with existing regulations and standards, biosolids are safe for the environment and human health (US EPA, 1999). This is very encouraging because many positive results arise from the land application of biosolids such as soil enhancement, promotion of plant growth, and pollution reduction. Compost and organic matter applied to land improved the soil's water retainage as well organic content which allows agricultural practices to take place in areas with high clay contents (Garrido et al., 2005). Table 4 narrates the positive outcomes from compost application.

Table 4. Benefits of Using Compost

Benefit	Description
Soil Enhancement	Compost aerates the soil and improves the soil's water-holding capacity and structure by adding organic materials.
Plant Growth	Compost provides a slowly released, long-term source of nutrients, promotes faster root development, and can reduce plant disease promoting beneficial microorganisms that reduce plant parasites.
Pollution Prevention	The soil and plant improvements that composting provides can result in reduced use of fertilizers and pesticides. When compost is used, fertilizers, metals, organic chemicals, and pesticides are less able to migrate to and contaminate ground water and surface water. Compost also can help prevent soil erosion by increasing water infiltration. Composting instead of land filling reduces methane gas formation in landfills, which can contribute to global warming if not appropriately captured and utilized.

Source: US EPA, 1999

A study conducted in the Mexican Plateau was established to investigate the accumulation of heavy metals in the soil and broad bean crops, as well as determine the nutritional quality of broad bean seeds grown in soils treated with biosolids (Garrido et al., 2005). The authors of this article sought to determine the environmental hazards from extended use of biosolids as fertilizer. The conclusions that were reached proved that the use of biosolids did not impose excessive environmental risks for this particular situation (Garrido et al., 2005). This result is an indication that they have established a solution for the final disposal of biosolids in this region (Garrido et al., 2005). By Mexican Official Standards, the metals concentration within the biosolids was found to be within the permitted limits and therefore determined to be stable for agricultural uses (Garrido et al., 2005). The most positive result from the production perspective was that the broad bean plants which were grown in plots containing biosolids showed greater growth and yields three times greater than that of the controlled plots.

POTENTIAL HAZARDS FROM LAND APPLICATION OF BIOSOLIDS

While biosolids provide plants with nutrients such as nitrogen, phosphorus, calcium, potassium, boron, copper, iron, magnesium, nickel, and zinc, these constituents can be toxic for a plant in high quantities. Additionally, the presence cadmium and chromium within the soil could be detrimental. Effects of such contamination could include decreased productivity and increased stresses on a plant. While treatment processes aim to eliminate pathogens from the biosolids, this cannot always be guaranteed.

Survival of E. coli

According to the Centers for Disease Control and Prevention (CDC), *E. coli O157:H7* causes an estimated 73,000 cases of infection and 61 deaths annually in the United States (CDC, 2005). While most of these cases have been related to the consumption of undercooked or contaminated beef, they have also been caused by swimming in or drinking sewage-contaminated water. In April, the Journal of Applied Microbiology published a research paper entitled, "Survival of *E. coli O157:H7* in organic wastes destined for land application" written by Avery, Killham, and Jones. The goal of this study was to determine the persistence of *Escherichia coli (E. coli) O157:H7* in contrasting organic wastes spread onto land and to assess the potential environmental risks associated with the disposal of these wastes (Avery et al., 2005).

The conclusions of this study demonstrated that current sludge treatment requirements may not be sufficient to protect the environment from *E. coli* during the application to land. When biosolids are applied to agricultural land there is a risk for spread *E. coli* infection. For instance, when farm animals graze at a biosolids application site, they may potentially carry infections when they are processed for meat. The production of fruit and vegetables could be threatened by contamination if biosolids are used as an agricultural fertilizer. Site hydrological runoff to surface water and infiltration into groundwater could transport contaminants. Propagation of pathogenic organisms could occur throughout the environment via birds or other vectors (Avery et al., 2005). Additionally, there have been a few reports which indicate the potential for re-growth of *E. coli O157:H7* in previously treated wastes (Avery et al., 2005).

To determine the survival rates of *E. Coli O157* over a 2 month period, Avery, Killham, and Jones experimented with the following different types of waste: Bovine slurry waste, abattoir (slaughterhouse) waste, sewage waste (treated and untreated), sewage sludge waste, and creamery waste (Avery et al., 2005). In Figure 1, it can be observed that pathogen persistence varies between wastes of a similar nature. For example, the "untreated sewage" had a decline of *E. Coli O157* cells greater than that of the "treated sewage" (Avery et al., 2005).

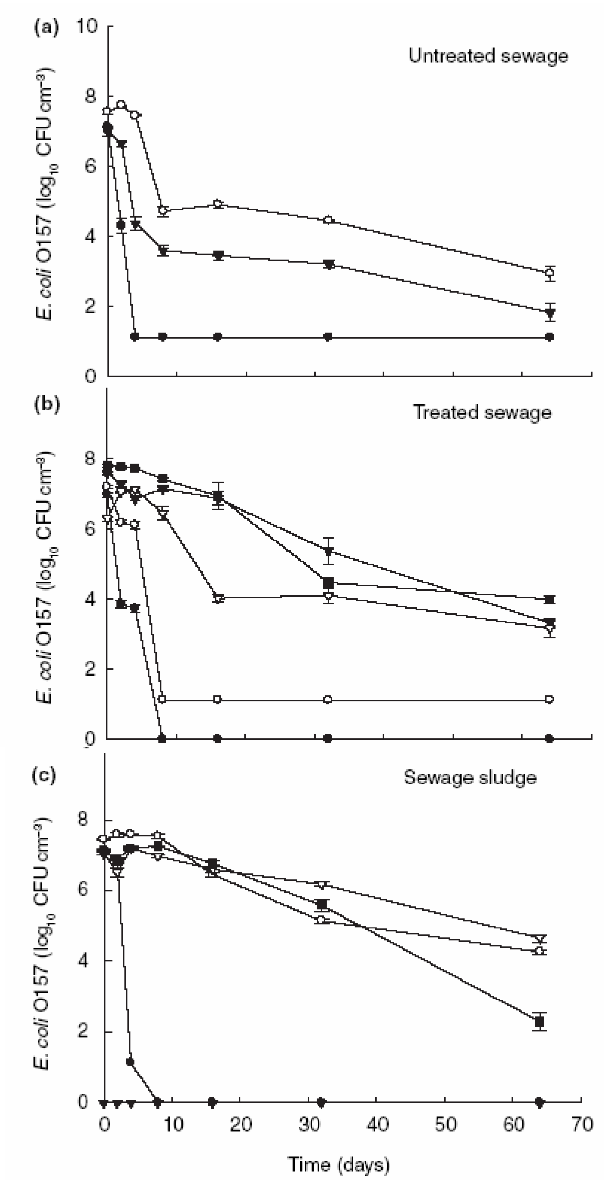

Fig. 1 Survival of Escherichia coli O157:H7 in sewage. (a) *E. coli O157:H7* persistence in three untreated liquid sewage samples [influent sewage; (●) USW1, (○) USW2, (▽) USW3]. (b) *E. coli O157:H7* persistence in five treated liquid sewage samples [effluent; (●) TSW1, (○) TSW2, (▽) TSW3, (▼) TSW4, (■) TSW5]. (c) *E. coli O157:H7* persistence in five sewage sludges [(●) SSW1, (○) SSW2, (▽) SSW3, (▼) SSW4, (■) SSW5]. The data shown are $\log_{10}(\gamma + 1)$ transformed means of plate counts (CFU cm^{-3}). Values represent mean ± S.E.M. (n=6).

Source: Avery, L.M., Killham, K., and Jones, D.L. (2005)

Avery, Killham, and Jones concluded that the most important results unveiled were that *E. coli O157:H7* could endure for more than 2 months in 21 of the 27 wastes tested and that the organism's persistence varied between waste samples of similar origin (Avery et al., 2005). It is also crucial to note that in some of the samples, after an initial decrease in *E. coli O157* cells there was a slight increase during the early stages before ultimately diminishing (Avery et al., 2005).

In a different study, D.L. Jones, author of "Potential health risks associated with the persistence of *Escherichia coli O157* in agricultural environments" suggested that storage could be a useful method to reduce pathogens in contaminated animal waste. However, studies conducted with other strains of *E. coli* have shown persistence for more than 60 days at 25°C and 100 days at 4°C (Jones, 1999). Jones also refers to another study where it appears that *E. coli O157* survived in turf grass soil for up to 4 months with only a small loss in potential.

As a result of these studies, Avery, Killham, and Jones concluded that storage could be considered an economical means of reducing *E. coli O157* in wastes, in comparison to the expensive anaerobic digestion and the detrimental liming process. Additionally, some of the samples in this study resulted in *E. coli O157* with a rapid mortality rate. This was determined to be caused by high levels of alkalinity (Avery et al., 2005). Clearly, *E. coli O157* can be effectively eliminated by raising the pH of organic wastes, however this is a variable outcome since the natural waste characteristics depend upon the processes within industry. In the conclusion of their study, Avery, Killham, and Jones disclosed that further studies are necessary to determine factors regulating pathogen survival in wastes.

Nutrient transfer during runoff

A study published in the Environmental Monitoring and Assessment Journal, examined the nutrient transfer by runoff from sewage sludge amended soil under simulated rainfall. Due to the varying characteristics between sewage sludge depending on the source and the treatment processes undergone, the goal of this study was to compare different biosolid samples and simulate their effects on identical soil samples (Quilbe et al., 2005). This study was conducted in France and the samples consisted of an anaerobically digested, thermically stabilized sludge, and a limed sludge (Quilbe et al., 2005). The examinations of this study were mainly focused on the effects of ammonium nitrogen and particulate phosphorus as these nutrients are more susceptible to rapid runoff (Quilbe et al., 2005). Likewise, runoff composed of high levels of phosphorus and nitrogen is considered likely to contribute to eutrophication of downstream surface waters (Quilbe et al., 2005).

The creators of this essay were careful to analyze factors that affect erosion and could therefore alter the rates at which nutrients are transferred from biosolid treated soil. Control of erosion processes such as rain erosivity, slope and soil characteristics, or tilling management could alleviate that effects of contaminated runoff, however studies have shown that if sludge disposal reduces the amount of runoff water and sediment, it increases the concentration of phosphorus in the runoff water (Quilbe et al., 2005).

Effects on Soil and Groundwater

Another research study examined the impact of biosolids application on underlying soil and groundwater, by monitoring the transport of contaminants following a simulated rainfall (Lyberatos et al., 2004). After assessment of different rainfall intensities and durations, it was concluded that leaching rates where a function of rainfall quantity (Lyberatos et al., 2004). According it the European Economic Community (EEC) Directive, the metal concentrations found in these leachates were permissible for agricultural applications (Lyberatos et al., 2004). However, groundwater contamination was inevitable due to the heavy metals contamination and phosphorus levels above the allowed discharge limitations (Lyberatos et al., 2004). In conclusion, it was determined that while biosolid application could be very useful for soils that are phosphorus deficient, this should be avoided in locations that receive strong rainfalls (Lyberatos et al., 2004). As seen in Figure 2, the rate of metal leaching is most notably affected by the rates of rainfall.

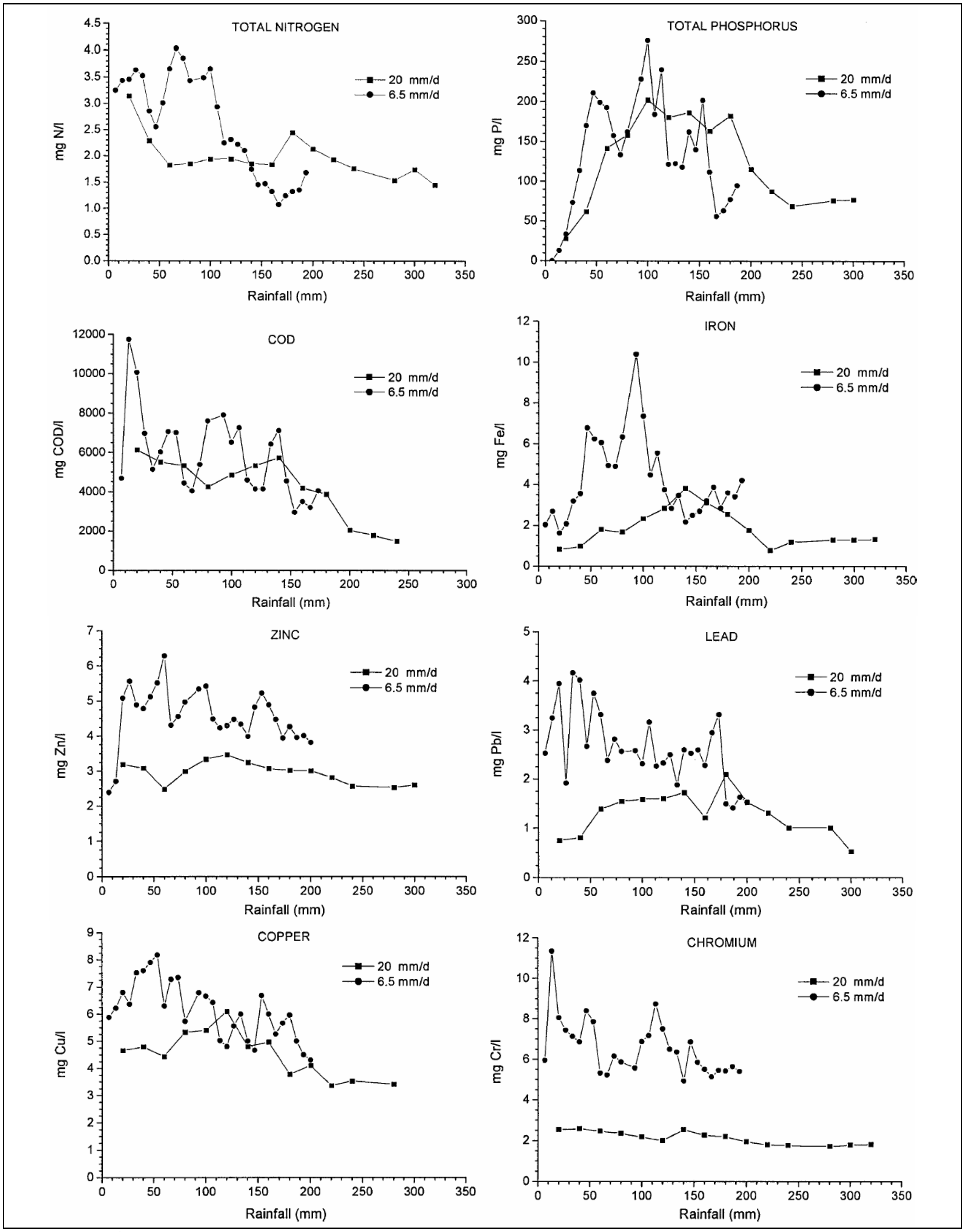

Figure 2. Concentrations of the various contaminants as a function of accumulated rainfall for the experiments.

Source: Lyberatos et al., 2004

POSITIVE RESULTS THROUGH LAND RECLAMATION

Several researchers have studied the effectiveness of biosolid utilization for reclamation purposes. Experiments have compared crop performance, soil microorganism viability and propagation, and effective loading rates of sludge amended soils with other treatments. Results of a study in New Mexico mine soils showed that microorganism growth was encouraged by organic amendments (Linderman et al., 1984). Biosolids can provide nitrogen and phosphorus which are essential for plant growth. The added organic matter enhances soil quality, making clay soils more permeable to water and air, and increasing the water and nutrient-holding capacity of sandy or gravelly soils (Hope, 1986). Procedures conducted in the state of Washington have demonstrated the use of biosolids for reclaiming a large coal strip mine located in Centralia (Hope, 1986). “The properties of mine soils prior to reclamation (low pH, low nutrient and organic carbon, poor stability) make them limiting to ecosystem recovery” (Reuter, 1997). Through studies it has been determined that biosolid amendments increase overall productivity of mine soils when compared to other treatments and successful reclamation methods will return the disturbed soil to a productive state (Reuter, 1997).

CONCLUSION

Since the early 1970’s, the perspective of biosolids application on agricultural land has received increasing attention, while research efforts have been focused on the fate of toxic contaminants and pathogens. The final use that may be given to biosolids that result from the treatment of residual municipal waters depends on their physicochemical and microbiological characteristics. Careful management of biosolids can minimize risks and hazards. Depending upon waste quality, characteristics of the application site and the intended use of the material, the following safeguards may be necessary:

- Pretreatment methods to ensure a safe biosolid product
- Monitoring of soils, groundwater, and surface runoff
- Limitations on heavy metal application
- Limitations on public access to application sites

The municipal wastewater treatment byproduct of biosolids is both a resource and a nuisance. Households and industries introduce quantities of toxic materials into municipal sludge and human wastes also possess harmful organisms such as disease-causing bacteria, viruses and parasites. Therefore, sludge must be scientifically managed in its disposal and utilization.

REFERENCES

Avery, L.M., Killham, K., and Jones, D.L. (2005) Survival of E. coli O157:H7 in Organic Wastes Destined for Land Application. *Journal of Applied Microbiology.* April 2005 v98 i4 p814-822.

Brown, Sally (2005) Trends in Class A Biosolids Production, Biocycle, 46, 4, 30.

Center for Disease Control and Pollution (CDC 2005): Division of Bacterial and Mycotic Diseases *Escherichia Coli O157:H7*, <http://www.cdc.gov/ncidod/dbmd/diseaseinfo/escherichiacoli_g.htm>

Garrido, S., Martin Del Campo, G., Esteller, M. V., Vaca, R., and Lugo, J. (2005) Heavy Metals in Soil Treated with Sewage Sludge Composting, Their Effect on Yield and Uptake of Broad Bean Seeds (*Vicia faba L.*) Water, Air and Soil Pollution 166, 1, 303.

Hope, Jane (1986) Sewage Sludge Disposal and Utilization Study. Washington State Institute of Public Policy, 86-01-4101.

Jones, D.L. (1999) Potential Health Risks Associated with the Persistence of *Escherichia Coli O157* in Agricultural Environments. Soil Use and Management 15, 1, 76.

Lindeman, W.C., D.L. Lindsey, and P.R. Fresquez. 1984. Amendment of Mine Soil to Increase the Number and Activity of Microorganisms. Soil Sci. Soc. Am. J. 48, 1, 574.

Lyberatos, G.; Klimantos, P.; Vassilakis, I.; and Kornaros, M. (2004) On the Impact of Land Application of Secondary Sludge. Water, Air and Soil Pollution: Focus 4, 4, 349.

Metcalf and Eddy (2003) Wastewater Engineering Treatment and Reuse. New York, New York.

Quilbe, Renaud; Serreau, Christophe; Wicherek, Stanislas; Bernard, Claude; Tomas, Yolene; and Oudinet, Jean-Paul (2005) Nutrient Transfer by Runoff from Sewage Sludge Amended Soil Under Simulated Rainfall. Environmental Monitoring and Assessment, 100, 1, 177.

Reuter, Ron (1997) Sewage Sludge as an Organic Amendment for Reclaiming Surface Mine Wastes. Department of Horticultural Science, University of Minnesota. <http://horticulture.coafes.umn.edu/>

United States Environmental Protection Agency (1999) Biosolids Generation, Use, and Disposal in the United States. EPA530-R-99-009, Washington, D.C.

United States Environmental Protection Agency (2000) Guide to Field Storage of Biosolids, EPA/832-B-00-007, Washington, D.C.

United States Environmental Protection Agency (2005), Biosolids. <http://www.epa.gov/owm/mtb/biosolids/index.htm> Last updated on Friday, June 24th, 2005, Washington, D.C.