Hyperion Plant Biosolids Land Application and Effect on Groundwater Quality

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ABSTRACT: From 1994, the City of Los Angeles applied Class B biosolids from the Hyperion Treatment Plant (HTP) at its Green Acres Farm in Kern County, California. In response to local regulations, since October 2002 HTP has produced Exceptional Quality (EQ) biosolids by thermophilic anaerobic digestion. EQ biosolids comply with the most stringent limits in the U.S. EPA 40 CFR Part 503 Rule for pollutants (503.13), pathogen reduction (503.32) and vector attraction reduction (503.33) and are considered to be as safe as any other fertilizer. In a further effort to protect the public and the environment, the City of Los Angeles conducted an evaluation of the potential impact of biosolids land application on the groundwater quality. A literature review of the fate and mobility in soil of biosolids constituents indicated a potential for the leaching of nitrate from biosolids. However, this potential is minimal because of the Part 503 Biosolids Rule requirement of land application of biosolids at nitrogen-based agronomic rates. Leaching of other biosolids constituents to groundwater is relatively insignificant because of immobilization in soil (phosphorus, heavy metals, some organic pollutants), biodegradation or volatilization to the atmosphere (some organic pollutants), or inactivation (pathogens). This was confirmed by a review of groundwater monitoring data from several land application sites in the USA with over 10 years of biosolids application. Elevated nitrate concentrations in groundwater were sometimes observed, however, an unequivocal correlation between nitrate in groundwater and the land application of biosolids could not be established. The presence of other biosolids constituents in groundwater has never been reported. Groundwater monitoring at the Green Acres Farm in Kern County over 1990–2002 did not indicate any effect of biosolids land application on the groundwater quality. This can possibly be attributed to a combination of two factors: a) low concentrations of pollutants in HTP biosolids; b) limitation of the biosolids application rate to the agronomic rate as calculated from the nitrogen needs of the crops cultured on the Green Acres Farm. Overall, this study confirms the findings of the 2002 reviews of the Part 503 Biosolids Rule by the National Research Council that there is no scientific evidence that the Part 503 Biosolids Rule has failed to protect public health or the environment. However, additional scientific work has been recommended.

INTRODUCTION

THE City of Los Angeles applied Class B biosolids from the Hyperion Treatment Plant (HTP) at its Green Acres Farm in Kern County, California, from 1994. The biosolids were produced by mesophilic anaerobic digestion. In response to Kern County's regulations, since October 2002 HTP has produced Exceptional Quality (EQ) biosolids by thermophilic anaerobic digestion. EQ biosolids comply with the most stringent limits for pollutants (503.13), pathogen reduction (503.32) and vector attraction reduction (503.33) in the U.S. EPA Part 503 Biosolids Rule and are considered to be as safe as any other fertilizer (U.S. EPA, 1993 and 1994). Although the City of Los Angeles received Kern County's permit for land application of EQ biosolids after conducting several full-scale tests at HTP (Iranpour et al., 2002, 2003a and b, 2004a and b), there still is concern about the potential impact of biosolids land application on the groundwater quality. Biosolids constituents that may have an impact on groundwater include nutrients such as nitrogen and phosphorus, heavy metals, organic pollutants and pathogens (WERF, 2002a).

The risk assessments for the Part 503 Biosolids Rule analyzed the risks to humans, animals, plants, and soil organisms from exposure to pollutants in biosolids

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through 14 different exposure pathways (U.S. EPA, 1995c). Exposure pathway 14 considered exposure of humans to pollutants through groundwater (e.g., biosolids → soil → groundwater → human). This pathway assumed a depth to groundwater of one meter, which can be considered conservative because groundwater levels often are deeper. Pathway 14 was not the limiting pathway in establishing the current limits of Part 503 Biosolids Rule because other exposure pathways potentially had a greater risk.

The U.S. EPA requested the National Research Council (NRC) to conduct independent evaluations of the methods and approaches used in establishing the chemical and pathogen standards for biosolids. This was in response to the Clean Water Act requirement to periodically reassess the scientific basis of the Part 503 Biosolids Rule and to address increasing public health concerns. In relation to groundwater contamination, a 1996 study concluded that land application of biosolids according to existing guidelines and regulations will not have a significant impact on groundwater (NRC, 1996). A 2002 study evaluated leaching calculations and predictions of groundwater concentrations conducted by the U.S. EPA (NRC, 2002). This study identified several limitations:

- The partition coefficients used by EPA were not necessarily representative of the range of conditions that exist in the U.S.
- The model did not account for rapid transport of biosolids contaminants through preferential flow paths in soil and for enhanced transport of contaminants bound to organic constituents in soil particles.
- Some dilution and attenuation factors used by U.S. EPA were found to be inaccurate.

In spite of these uncertainties, it was concluded that there was no documented scientific evidence that the Part 503 Biosolids Rule has failed to protect public health. However, it was also concluded that additional scientific work is needed to reduce persistent uncertainty about the potential for adverse human health effects from exposure to biosolids.

Early field studies focused on the effect of biosolids application on the quality of run-off water from agricultural land (Duningan and Dick, 1980; Bruggeman and Mostaghimi, 1993). Recent studies have focused on several factors potentially relevant to groundwater contamination by biosolids constituents:

- nitrogen availability (WERF, 2002a);
- mineralization of organic nitrogen from biosolids after land application (NRC, 1996; Crohn, Internet document; Sanden, Internet document);
- nitrogen-based application rates of biosolids (Moss et al., 2002; U.S. EPA, 1995b; U.S. EPA, 1995c; WERF, 2002a);
- phosphorus availability (Binder et al., 2001; Jenkins et al., 2000; Moss et al., 2002; NRC, 1996; WERF, 2002a and b);
- immobilization of heavy metals in the topsoil layer (Emmerich et al., 1982; Joshua et al., 1998; NRC, 1996; WERF, 2002a; Yingming and Corey, 1993);
- immobilization of organic pollutants bound to the organic matter present in biosolids (NRC, 1996); sorption of pathogens to biosolids and soil organic matter and/or destruction in soil (NRC, 1996; U.S. EPA, 1995a and 2000).

The general goal of this review was to evaluate laboratory experiments and field trials regarding the impact of constituents typically present in biosolids on groundwater. The specific objectives were to determine and evaluate:

- the fate and mobility of biosolids pollutants/constituents in soil;
- the impact of biosolids land application on groundwater at sites with long-term land application programs;
- the potential impact of land application of HTP's EQ biosolids on the groundwater quality at the Green Acres Farm.

APPROACH

The first part of this review is a literature survey of the mechanisms of transport and immobilization of constituents typically found in biosolids. Information was categorized per class of constituents, i.e., macronutrients (nitrogen and phosphorus), heavy metals, organic pollutants, and pathogens. Also, a 1993 WERF study of ten long-term biosolids programs in the U.S. was reviewed and summarized. Six of these biosolids programs extensively monitored the groundwater and the agencies were requested to provide additional and more recent groundwater data.

The second part of this review is an evaluation of the biosolids land application program at the City of Los Angeles' Green Acres Farm. This included evaluation of thirteen years of groundwater quality data (BSK, 2002), and the contents of pollutants, pathogens, and nutrients present in HTP biosolids, which are analyzed on a monthly basis.

RESULTS

Literature Review

Biosolids versus other soil amendments. The amounts of biosolids produced and land applied are very small compared to the amounts of manures and fertilizers (Table 1). Biosolids are currently applied to less than 1% of the U.S. agricultural acreage. Consequently, the contribution of biosolids to the total amount of nitrogen or phosphate supplied to agricultural land is negligible (Table 1). Although biosolids land application is strictly regulated by the Part 503 Biosolids Rule (Iranpour et al., 2004c), similar regulations do not exist or are still being developed for manures and fertilizers (Table 2).

Heavy metals. Laboratory studies have demonstrated that heavy metals from biosolids form insoluble, stable complexes with organic matter, carbonates and other components in soil, which minimizes their potential for leaching to groundwater (Emmerich et al., 1982). Metals in general accumulate in the upper soil layer, and transport of heavy metals to groundwater is very unlikely (NRC, 1996; WERF, 2002a). This has been confirmed in field studies (e.g., Figure 1). Metal immobilization is a long-term process (Binder et al., 2001; Joshua et al., 1998; Yingming and Corey, 1993).

Organic pollutants. The National Research Council (NRC, 1996) reported that organic pollutants are not likely to contaminate groundwater because their concentrations in biosolids are low, because they are volatilized (PCBs) or biodegraded (phthalates, detergents and surfactants) after land application, or because they are strongly sorbed to soil (PCBs, phthalates).

An AMSA survey in 2001 indicated that the average concentration of dioxins in biosolids was 48.5 ppt TEQs (WERF, 2002a). Table 3 shows that this is in the same range of the dioxins content found in mineral fertilizers. No information is available on dioxins in manure. Due to the strong sorption of dioxins to humic substances in soil, it is expected that only minimal amounts of dioxins may leach to groundwater from biosolids-amended soil, unless soil particles containing dioxins are themselves transported through erosion, channeling, and movements through cracks and fissures (Carpenter, 2000). In addition, on October 17, 2003, U.S. EPA has made a final decision not to regulate dioxins in land-applied biosolids. After five years of study, including outside peer review, it was determined that dioxins from land applied biosolids do not pose a significant risk to human health or the environment (U.S. EPA, 2003).

Recently, some have expressed concern on the presence of brominated diphenyl ethers, pharmaceuticals, and endocrine disruptors (surfactants and estrogens) in biosolids (WERF, 2002a). However, there is no evidence that these constituents have contaminated groundwater under fields where biosolids have been applied.

Pathogens. The presence of pathogens in biosolids is only relevant for Class B biosolids, since Class A biosolids are pathogen-free. In general, the possibility of contamination of groundwater with pathogens such as viruses, bacteria, and helminth ova is insignificant because pathogens are strongly sorbed to biosolids or destroyed in soil (NRC, 1996; U.S. EPA, 2000). In addition, helminth cysts are probably too large to be trans-

Table 1. Production and land application of soil amendments in the U.S. (WERF, 2002a).

Soil Amendment	Produced (Million dry tons/year)	Applied (Million dry tons/year)		
		Product	Nitrogen	Phosphorus
Manure	133	120	6	3.6
Fertilizer	50	50	11	4.4
Biosolids	6.9	2.8	negligible	negligible

Table 2. Regulations on soil amendments (WERF, 2002a).

Criterion	Soil Amendments			
	Biosolids	Manures	Macronutrient Fertilizers	Micronutrient Fertilizers
Pathogen Limits	Established Regulations	None	Not applicable	Not applicable
Metal Limits	Established Regulations	Developing Regulations	Developing Regulations	Developing Regulations
N-based Application Rates	Established Regulations	Developing Regulations	None	None
P-based Application Rates	None	Developing Regulations	None	None

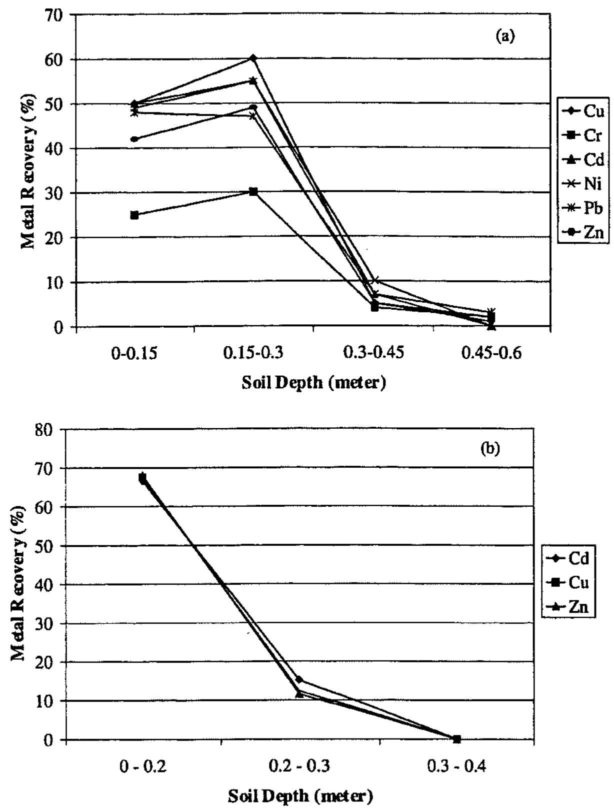

Figure 1. Metal recovery in soil from land applied biosolids (a): Sloan et al., 1998; (b); Yingming and Corey, 1993).

ported through soil (NRC, 1996). Overall, pathogen contamination of groundwater by biosolids has not been demonstrated (WERF, 2002a).

Nitrogen. An important issue with regard to nitrogen content in biosolids is that most of nitrogen is present in an organic form, which must be mineralized before it is available to plants. The conversion of organic nitrogen to ammonium and nitrate is a gradual process, which is why nitrogen from biosolids is sometimes referred to as "slow release" (WERF, 2002a). Another important issue is the difference in mobility of ammonium and nitrate through soil. When water infiltrates the soil, nitrate from biosolids moves readily with water to deeper parts, thereby possibly contaminating underground waters. Conversely, ammonium, being a cation, would be held at exchange sites on soil colloids.

Table 3. Dioxins concentration in soil amendments (WERF, 2002a).

Metal	Dioxins (ppt TEQ)
Manures	NA
Fertilizers	
Bulk/packaged (11 products)	0–35
Micronutrients (14 products)	0–27
Micronutrients (2 products)	140–340
Biosolids (average)	48.5

TEQ: toxic equivalent;
NA: not available
Note: On 10-17-2003, U.S. EPA announced not to regulate dioxins in biosolids, because dioxins in biosolids do not pose a significant risk to human health or the environment.

Several field studies have demonstrated the ability of nitrate to infiltrate soil. In a field trial in Goulburn, Australia, dewatered sludge cake was applied to three types of soils (Joshua et al., 1998). Movement of nitrate to a depth of 50 cm in duplex soils and 70 cm in sandy Red Earths was observed over a period of one and a half years. However, the biosolids application rates in these trials were 2 to 10 times higher than the usual rate of about 10 dry tons/ha.year. In another field study, biosolids land application for over 10 years caused 50 mg/l nitrate in the groundwater down to 15 m below the surface (Welby, Internet document). Nitrate concentrations further increased for two more years after stopping land application. Elevated nitrate concentrations reported by Welby seemed to be correlated to the presence of irregularly distributed shallow groundwater in the studied field.

The Part 503 Biosolids Rule requires that biosolids are land applied at nitrogen-based agronomic rates in order to prevent leaching of nitrate to groundwater. The studies reported by Joshua et al. (1998) and by Welby (Internet document) did not specify whether biosolids application was indeed at nitrogen-based agronomic rates. In contrast, very little leaching of nitrate and penetration of only 1.2 m deep were observed during application of biosolids at agronomic rates in a field test conducted in Nebraska (Binder et al., 2001).

The calculation of biosolids application rates should consider the mineralization of organic nitrogen. Nitrogen mineralization is a slow process taking place over several years, hence, the mineralization rate is difficult to accurately estimate. A U.S. EPA manual provides calculations for estimating the rate of mineralization of organic nitrogen as well as calculations for leaching of nitrate as a function of various parameters (U.S. EPA, 1995b). However, a field study conducted in the San Joaquin Valley, California, indicated that nitrogen mineralization in land applied biosolids is highly variable and probably site-specific (Sanden, Internet document). Land application sites would need to be assessed on an individual basis for proper management regarding maximizing the crop yield and minimizing the possibility of groundwater pollution by nitrate. The potential for excess nitrogen application can further be reduced by use of Nutrient Management Plans that better predict nitrogen application requirements (CWEA, 1998; Moss et al., 2002).

Another concern is the potential of nitrate leaching from biosolids field storage, which can impact local wells or cause pollution of surface waters. In a field study conducted in a gravel pit reclamation site, stockpiling of biosolids contributed significantly to groundwater contamination with nitrate, but biosolids land application at the same site did not (McDowell et al., 2002). In order to prevent nitrate leaching from biosolids field storage, water management practices that include impermeable lining and catch basins have been recommended by U.S. EPA (2000).

Phosphorus. Phosphorus in biosolids is in excess over nitrogen. Therefore, there is a possibility of phosphorus accumulation in the topsoil layer because inorganic phosphorus is relatively water insoluble. This may cause phosphorus contamination of surface waters by soil erosion and runoff (Binder et al., 2001; NRC, 1996; WERF, 2002a). Phosphorus from biosolids also is less soluble in water than phosphorus from inorganic fertilizers (Moss, 2002; WERF, 2002b). Jenkins et al. (2000) hypothesized that the amount of leachable and extractable phosphorus in biosolids and biosolids/soil mixtures is controlled by the formation of insoluble aluminum phosphate ($AlPO_4$) and iron phosphate ($FePO_4$). Thus, based on this hypothesis, the leachable phosphorus in biosolids is strongly related to the [P]/([Al] + [Fe]) molar ratio. Figure 2 shows that there is a linear relationship between the amount of leachable phosphorus and this molar ratio. The additions of aluminum and iron to enhance sedimentation and the addition of iron to control H_2S during anaerobic digestion may decrease the leachability of phosphorus from biosolids (WERF, 2002b), and, consequently, the possibility of phosphorus contamination of groundwater.

It should also be noted that phosphorus leaching from biosolids is not as relevant as nitrogen, because phosphorus in drinking water is not a health concern as is nitrate (U.S. EPA, 2000). Nutrient Management Plans recommended by U.S. EPA (2000) will also help to prevent phosphate leaching from biosolids.

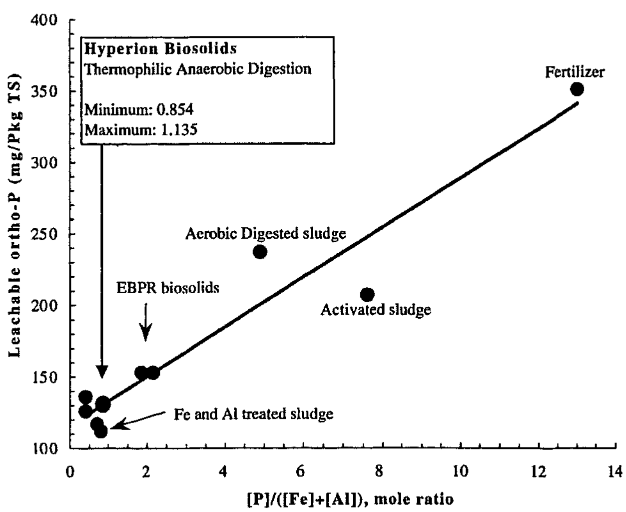

Figure 2. Leachable phosphorous as a function of [P]/([Fe]+[Al]) molar ratio (Derived from Kyle and McClintock (1995) by Jenkins et al. (2000)).

WERF field study. This study documented 10 biosolids programs with over 10 years of land application (WERF, 1993). Geographic locations and summaries of these programs are provided in Figure 3 and Table 4, respectively. Six programs with extensive groundwater monitoring provided additional and more recent data (up to 2002), which have also been included in Table 4. In general, these field studies confirmed the general results found in the literature review:

- Groundwater pollution by organic contaminants and heavy metals from biosolids has not been reported.
- Migration of pathogens to groundwater has not been reported.
- Elevated levels of nitrate in groundwater have been found at a few locations, sometimes causing exceedance of the nitrate limit for drinking water (10 ppm as nitrate-N). However, it was not possible to establish an unequivocal correlation between the high levels of nitrate and the land application of biosolids.

HTP Biosolids and Green Acres Farm Studies

The Green Acres Farm with almost 5,000 acres is located in Kern County, California, about 27 km miles

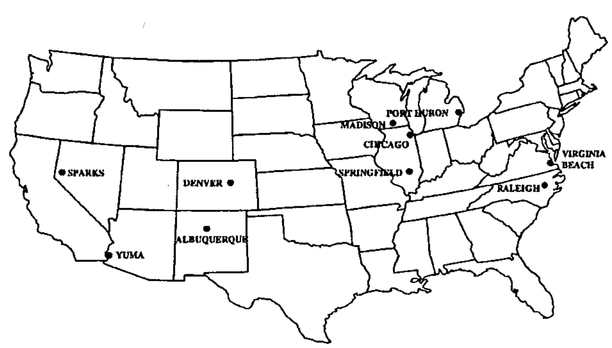

Figure 3. Geographic locations of Biosolids Land Application Programs (WERF, 1993).

Table 4. ***Summary of biosolids land application programs (WERF (1993) and City of Los Angeles Bureau of Sanitation).***

Agency		Biosolids					Land Application	
Applicator	Location	Year Started	Biosolids Quality	% TS	Dry tons/day	Type	Application Method	Rate (dry ton/ha/yr)
AG-TECH	Yuma, AZ	1980	–	–	78	various	–	7–17
Albuquerque	Albuquerque, NM	1981	Class B	3.5	26	anaerobically digested	subsurface injection	30–35
Hamton Roads Sanitation District	Virginia Beach, VA	1984	Class B	20	18	anaerobically digested	surface application	5–10
Madison Metropolitan Sewer District	Madison, WI	1974	Class B	5.5	20	anaerobically digested	subsurface injection	4–5
Metro Wastewater Reclamation District	Denver, CO	1979	Class B	16	70	anaerobically digested	surface application	2–25
Metropolitan Water Reclamation District of Greater Chicago	Chicago, IL	1970	Class B	63	550	anaerobically digested	surface application	4–5
Port Heron	Port Heron, MI	1982	Class A	10	5	lime stabilized	subsurface injection	7–12
Raleigh	Raleigh, NC	Class B - 1980, Cass A - 1995	30% Class B 70% Class A	5 (Class B) 75 (Class A)	16	aerobically digested	injection (Class B) surface (Class A)	–
Springfield Metro Sanitary District	Springfield, IL	1974	Class B	2.5	1.8	aerobically digested	surface application	0.2–1.2
Truckee Meadows Water Reclamation Facility	Sparks, NV	1979	Class B	19–24	15	anaerobically digested	surface application	22–67
Los Angeles Bureau of Sanitation	Kern County, CA	1994	Class B - 1994, Class A - 2003	30	240	anaerobically digested meso/thermo	surface application	33

Table 4 (continued). Summary of biosolids land application programs (WERF (1993) and City of Los Angeles Bureau of Sanitation).

Agency		Soil	Groundwater			
Applicator	**Location**	**Type or Soil Property**	**Groundwater Monitoring**	**Average Depth of Groundwater (m)**	**Monitoring Frequency**	**Status**
AG-TECH	Yuma, AZ	–	–	–	–	No information
Albuquerque	Albuquerque, NM	–	yes	260	once/yr	No impact on groundwater except for sodium (65-> 110 mg/L)
Hamton Roads Sanitation District	Virginia Beach, VA	heavy clay, sandy	yes	–	–	No impact on groundwate, high background nitrate and ammonium concentrations
Madison Metropolitan Sewer District	Madison, WI	moderate permiability	yes	18–30	once/yr	Increases in nitrate and chloride, but no significant differences to other sites using commercial fertilizer and animal manure
Metro Wastewater Reclamation District	Denver, CO	clay sandy soil	no	5–183	–	High in nitrate, but source of contamination could not be established
Metropolitan Water Reclamation District of Greater Chicago	Chicago, IL	moderate permiability	yes	12–23	4 times/yr	No change in groundwater quality related to biosolids application
Port Heron	Port Heron, MI	fine textured, heavy clay	no	–	–	No information
Raleigh	Raleigh, NC	clay	yes	generally >3	3 times/yr	2800 kg of N per hectare in cummulative application over 8 years resulted in nitrate leaching
Springfield Metro Sanitary District	Springfield, IL	silt clay loams	yes	6–9	4 times/yr	High in nitrate and chloride with peaks in fall and winter
Truckee Meadows Water Reclamation Facility	Sparks, NV	silt clay (lake sediment)	no	27–45	–	High in nitrate and chloride, but could not be correlated to biosilids application
Los Angeles Bureau of Sanitation	Kern County, CA	slightly alkaline	yes	30	once/yr	No impact on groundwater

southwest of Bakersfield and about 1.5 km northeast of Lake Buena Vista (Figure 4). The farm was acquired by the City of Los Angeles in Spring 2000 from private ownership. Since 1994, the farm has received biosolids from the City of Los Angeles Hyperion Treatment Plant, and reclaimed water from the City of Bakersfield for the cultivation of wheat, corn, alfalfa, and sudan grass. Biosolids application rates are calculated on the basis of the agronomic nitrogen requirements of the crops as determined by an independent contractor. Additional information on the Green Acres Farm biosolids program is included in Table 4. In the following sections the characteristics of the HTP biosolids is discussed, followed by a discussion of the groundwater studies conducted at the Green Acres Farm.

HTP Biosolids quality. The City of Los Angeles routinely monitors the biosolids quality to evaluate compliance with the Part 503 Biosolids Rule and the Kern County Ordinance. In this section, HTP biosolids quality data obtained from January 2002 to August 2003 are presented.

Pollutants. Table 5 shows that the average concentrations of heavy metals in HTP biosolids are well below the limits specified in the Part 503 Biosolids Rule and the Kern County Ordinance for EQ biosolids. Hence, the possibility of groundwater contamination by metals from HTP EQ biosolids is very unlikely. Although PCBs and dioxins in biosolids are not regulated in the Part 503 Biosolids Rule, the Kern County Ordinance has set limits of 50 ppm and 10 ppb, respectively. The concentrations of dioxins and PCBs in HTP biosolids were well below these limits as both chemicals were below the limit of detection limits (<0.026 ppm and

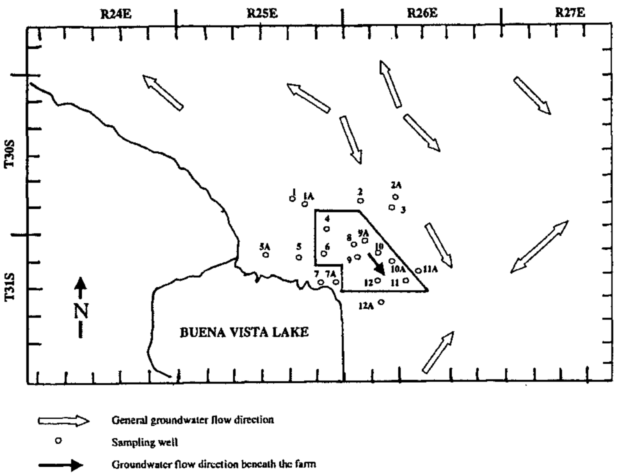

Figure 4. Sampling wells and groundwater flow at Green Acres Farm location (Kern County, CA).

Table 5. Pollutant concentrations in HTP biosolids.

Pollutant	HTP mg/dry kg[1]	Part 503 Limits[4] mg/dry kg	Kern County Ordinance Requirement
Heavy metals			Same as Part 503 limits
Arsenic	7.12	41	Same as Part 503 limits
Cadmium	14.4	39	Same as Part 503 limits
Chromium	104	n.a.	Same as Part 503 limits
Copper	844	1500	Same as Part 503 limits
Lead	38.7	300	Same as Part 503 limits
Mercury	2.23	17	Same as Part 503 limits
Molybdenum	23.0	n.a.	Same as Part 503 limits
Nickel	82.4	420	Same as Part 503 limits
Selenium	7.46	100	Same as Part 503 limits
Zinc	1030	2800	Same as Part 503 limits
Organic Pollutants			
Dioxin (2,3,7,8-TCDD)	ND[1][2]	n.a.	10 ppb
PCBs	ND[1]	n.a.	50 ppm
Pathogens/Indicators			
Salmonella	<1.7 MPN/4 g dry wt[3]	3 MPN/4 g dry wt OR	3 MPN/4 g dry wt AND
Fecal Coliforms	<22 MPN/g dry wt[3]	1,000 MPN/g dry wt	1,000 MPN/g dry wt
Enteric viruses	<1 PFU/4 g dry wt[3]	<1 PFU/4 g dry wt	<1 PFU/4 g dry wt
Viable helminth ova	<1 ova/4 g dry wt[3]	<1 ova/4 g dry wt	<1 ova/4 g dry wt

[1] Average concentration: January – December, 2002
[2] Monthly analyses ranged from <0.011 ppb (<11 ppt TEQ) to <0.084 ppb (<84 ppt TEQ)
[3] Observed densities: January - August 2003
[4] 40 CFR 503.13 (Table 3)
n.a. = not applicable
ND = not detected

<0.034 ppb, respectively). The low pollutant levels in HTP biosolids can be attributed to the Industrial Discharge Pre-treatment Program implemented by the City of Los Angeles. As an example, the heavy metal discharge in HTP's effluent has steadily been reduced over the past 25 years (Figure 5).

Pathogens. Class B biosolids were applied at the Green Acres Farm from 1994 to September 2002. However, as discussed in the previous section, pathogens are not a significant concern for groundwater because they are sorbed to organic matter or rapidly destroyed in soil. Also, the restrictions for land use of Class B biosolids, specified in the Part 503 Biosolids Rule, assure that pathogens are inactivated in the environment before human exposure to land applied biosolids. Furthermore, since October 2002, HTP biosolids fully met the Class A limits for fecal coliforms, *Salmonella* sp., enteric viruses and viable helminth ova (Table 5). It should be emphasized that the bacteriological requirements in the Kern County Ordinance are stricter than those in the Part 503 Biosolids Rule since it requires compliance with both bacteriological criteria. Since HTP biosolids do not contain pathogens, contamination of groundwater by pathogens is no longer an issue.

Nutrients. Table 6 shows that the total nitrogen and phosphorus concentrations measured in HTP biosolids are about the same as in most other types of biosolids. The biosolids application rate at the Green Acres Farm is calculated from the actual nitrogen content in HTP biosolids and the agronomic nitrogen requirements, as required by the Part 503 Biosolids Rule. Agronomic phosphorus requirements are yet not defined as they are currently being developed. Phosphorus leaching from HTP biosolids, however, may strongly be reduced by the addition of iron in several processes at HTP, as discussed in the previous section. The [P]/([Al] + [Fe]) molar ratio in HTP biosolids is by estimation 0.972. In Figure 2 it can be seen that at such low a ratio the leachability of phosphorus is minimal.

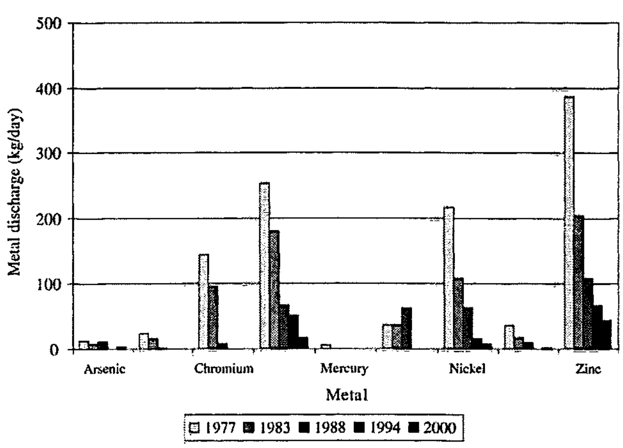

Figure 5. *Metal discharges in HTP effluent (1977–2000).*

Table 6. Nutrient concentrations in biosolids.

Biosolids	Total Nitrogen (% dry weight)	Total Phosphorus (% dry weigth)
HTP[(1)]		
Therm. Anaerobic digestion	4.7	3.5
AMSA 1998 Survey[(2)]		
Alkaline stabilized (class A)	1	0.4
Alkaline and digested liquid	5.3	2.2
Alkaline and digested cake	4.1	1.9
Heat dried	6	3.1

[(1)]Average concentration: December 2001–November 2002
[(2)]WERF (2002a)

Groundwater description. Since 1990, the groundwater at the Green Acres Farm has routinely been monitored by several local and state agencies, including the City of Bakersfield, Kern Delta Water District (KDWD), Kern County Water Agency (KCWA), and California Department of Water Resources (DWR). In addition, an extensive survey of the groundwater conditions at the farm and its vicinity has been conducted in 2002. Locations of the wells are shown in Figure 4.

Regional groundwater. Based on KCWA Spring 2001 data, the depth to groundwater in the 780 km^2 region surrounding the farm ranged from approximately 10.7 m below ground surface (bgs) to greater than 61 m bgs. The depth to the aquifer generally decreased from north-central to southwest-central parts of the region. The groundwater surface elevation in the region surrounding the farm ranged from approximately 46 m above mean sea level (msl) to greater than 88 m above msl in Spring 2001. The groundwater surface elevation decreased laterally from a hydraulically upgradient ridge, extended from the west-central to the northeast of the region. The groundwater surface elevation also decreased laterally toward hydraulically downgradient areas near the southeast, east central and northwest portion of the region. The groundwater flow direction beneath the region was generally toward hydraulically downgradient areas at the southeast and northwest portions of the region (Figure 4).

Site groundwater. The depth to groundwater beneath the farm in Spring 2001 generally ranged from between 18–21 m bgs at the northwest part of the field to between 36–40 m bgs at the southeast part. The groundwater surface elevation ranged between 55 (southeast) and 73 m above msl (northwest). The groundwater flow direction beneath the farm in Spring 2001 was generally from hydraulically upgradient areas near the northwest portion of the farm toward downgradient areas at the southeast portion of the site (Figure 4).

Site shallow groundwater. The subsurface geological and geochemical data did not allow for a differentiation between near-surface groundwater associated with the aquifer and accumulations of groundwater whose downward movement is restricted by strata of low permeability (commonly referred as "perched" water). However, contamination of shallow groundwater was not a concern because piezometric data indicated a consistent absence of shallow groundwater at the farm since 1991.

Groundwater quality. Groundwater samples were collected from five wells in July 2002. The results in Table 7 indicate that nitrate was below the detection limit (0.2 mg/l N-NO_3) in most of the samples. One out of five groundwater samples contained nitrate, but at a concentration of 1.1 mg/l, which still is almost ten times below the Primary Maximum Contaminant Level (MCL) drinking water standard of 10 mg nitrate-N/l adopted by the California Department of Health Services (DHS), Title 22 California Code of Regulations (CCR) §64431. The 2002 data also demonstrate that:

1. none of the groundwater samples contained chloride at a concentration that equaled or exceeded the upper Secondary MCL drinking water standard for chloride of 500 mg/l (California DHS , 22 CCR 64449);
2. none of the groundwater samples had an electrical conductivity (EC) equal or above the upper Secondary MCL drinking water standard of 1600 micromhos (California DHS, 22 CCR 64449).

Figures 6, 7 and 8 show the average nitrate and chloride concentrations and the electrical conductivity of groundwater samples from 1990 to 2002. These parameters have been well below the standards for drinking water. It is also clear that land application of biosolids, initiated in 1994, has not promoted an increase of nitrate concentrations in the groundwater below the farm. In fact, by comparing the average data of summer months in 1990 and 2002, it appears that the groundwater quality has slightly improved. For example, the average N-NO_3 concentration in groundwater samples has decreased by at least 20%, from 0.5 mg/L in 1990 to

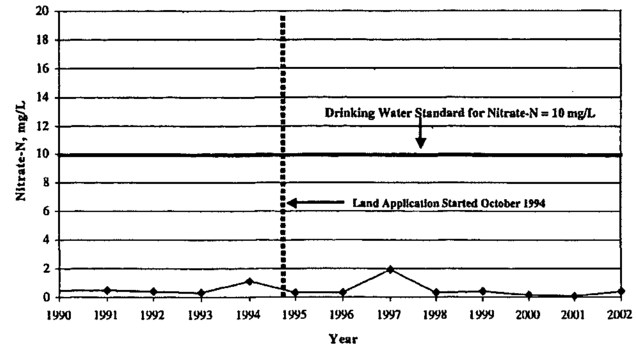

Figure 6. Nitrate concentrations in groundwater at Green Acres Farm.

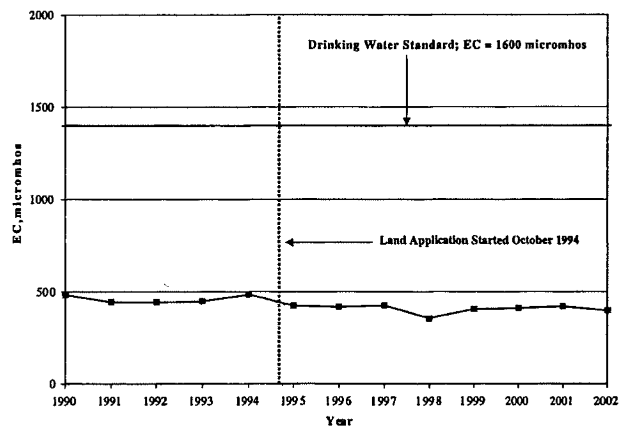

Figure 7. Electrical conductivity in groundwater at the Green Acres Farm.

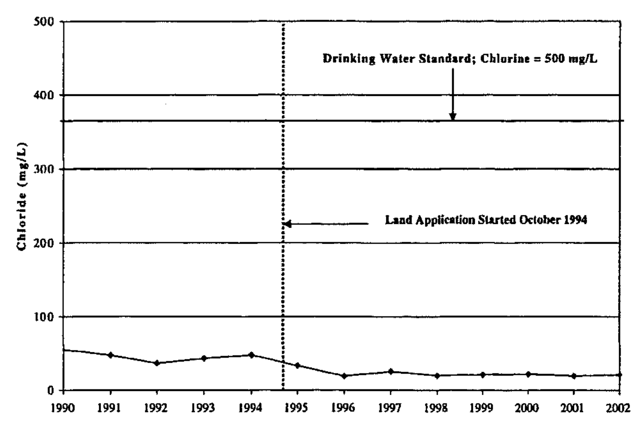

Figure 8. Chloride concentrations in groundwater at the Green Acres Farm .

Table 7. Analytical results of groundwater samples collected at and near the Green Acres Farm (well locations in Figure 4; July 16, 2002).

Well Number	Cl	NO_3 (as N)	pH	EC
3	15	ND	9.1	250
7	38	1.1	7.6	700
9	18	ND	8.8	370
10	16	ND	9.1	330
10A	19	ND	8.9	340

ND: Not Detected

less than 0.4 mg/L in 2002. Similarly, the average EC and chloride concentration have decreased over the same period of time by 18% and 62%, respectively.

CONCLUSIONS

1. Groundwater parameters at the Green Acres Farm (e.g., nitrate, chloride, pH, and electrical conductivity) indicate that 8 years of continuous biosolids land application have not impacted the quality of groundwater.
2. The possibility of groundwater pollution by HTP EQ biosolids land application at the Green Acres Farm is in general minimal:
   - The industrial discharge pre-treatment program conducted of the City of Los Angeles has greatly reduced the concentrations of heavy metals and organic pollutants in HTP biosolids.
   - HTP EQ biosolids do not contain pathogens and fecal coliform levels are very low (about 100 times less than the Class A limit).
   - The addition of iron during the wastewater treatment processes at HTP may cause the formation of insoluble phosphates (FePO4), thereby minimizing the possibility of groundwater contamination by phosphorus.
   - HTP biosolids application at agronomic rates eliminates the possibility of nitrate leaching.
3. The literature review supported the conclusions of the evaluations at the Green Acres Farm:
   - Nitrogen-based application rates of biosolids are an important factor to prevent leaching of nitrate.
   - Implementation of improved nutrient management programs, that account for field-specific mineralization of organic nitrogen, will further reduce the possibility of nitrate leaching.
   - Phosphorus is less water-soluble than nitrogen and accumulates in the topsoil layer.
   - Addition of Al and Fe during wastewater treatment processes may cause the formation of insoluble phosphates ($AlPO_4$, $FePO_4$), thereby further reducing the possibility of groundwater contamination by phosphate.
   - Heavy metals accumulate in the topsoil layer through long-term immobilization mechanisms.
   - Organic pollutants may be present in biosolids, but in very low concentrations and they are strongly bound to the organic matter.
   - The possibility of contamination of groundwater with pathogens is very unlikely since they are strongly retained by the biosolids organic matter or they are destroyed in soil.

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