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Waste-Indicator and Pharmaceutical Compounds in Landfill-Leachate-Affected Ground Water near Elkhart, Indiana, 2000–2002

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Abstract Four wells downgradient from a landfill near Elkhart, Indiana were sampled during 2000–2002 to evaluate the presence of waste-indicator and pharmaceutical compounds in landfill-leachate-affected ground water. Compounds detected in leachate-affected ground water included detergent metabolites (*p*-nonylphenol, nonylphenol monoethoxylate, nonylphenol diethoxylate, and octylphenol monoethoxylate), plasticizers (ethanol-2-butoxy-phosphate and diethylphthalate), a plastic monomer (bisphenol A), disinfectants (1,4-dichlorobenzene and triclosan), an antioxidant (5-methyl-1H-benzotriazole), three fire-retardant compounds (tributylphosphate and tri(2-chloroethyl)phosphate, and tri(dichlorisopropyl)phosphate), and several pharmaceuticals and metabolites (acetaminophen, caffeine, cotinine, 1,7-dimethylxanthine, fluoxetine, and ibuprofen). Acetaminophen, caffeine, and cotinine detections confirm prior indications of pharmaceutical and nicotinate disposal in the landfill.

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Landfill leachate is a mixed wastewater derived from the interaction of infiltrating water with fluids, solids, and gases within the buried waste. As analytical chemical capabilities have increased, so has the diversity of organic compounds detected in landfill leachate (Eganhouse et al. 2001; Holm et al. 1995; Oman and Hynning 1993; Murray and Beck 1990). Many contaminants in industrial and household wastewater (waste-indicators) and human and veterinary pharmaceuticals (Kolpin et al. 2002; Glassmeyer et al. 2005; Barnes et al. 2004) have been detected in wastewater-affected surface water and ground water but are not typically analyzed during regulatory monitoring of leachate-affected ground water. Analysis and study of waste-indicator and pharmaceutical compounds in landfill-leachate-affected ground water are needed to determine their potential presence and concentrations so that risks to human health can be assessed and remedial actions at landfills can be designed with knowledge of the concentrations of these compounds.

The Himco Dump is an unlined, 60 acre landfill northwest of Elkhart, Indiana that was used for disposal of commercial, industrial, and medical waste, and general refuse on the land surface or in 10–15 feet deep trenches from 1960 to 1976; it is listed on the US Environmental Protection Agency (USEPA) National Priority List (US Environmental Protection Agency 2002). The aquifer beneath the landfill is in unconsolidated glacial outwash deposits and is part of the St. Joseph aquifer system, a USEPA-designated sole-source aquifer. The aquifer typically is separated into upper and lower units by a confining unit of silt and clay; near the landfill the confining unit is

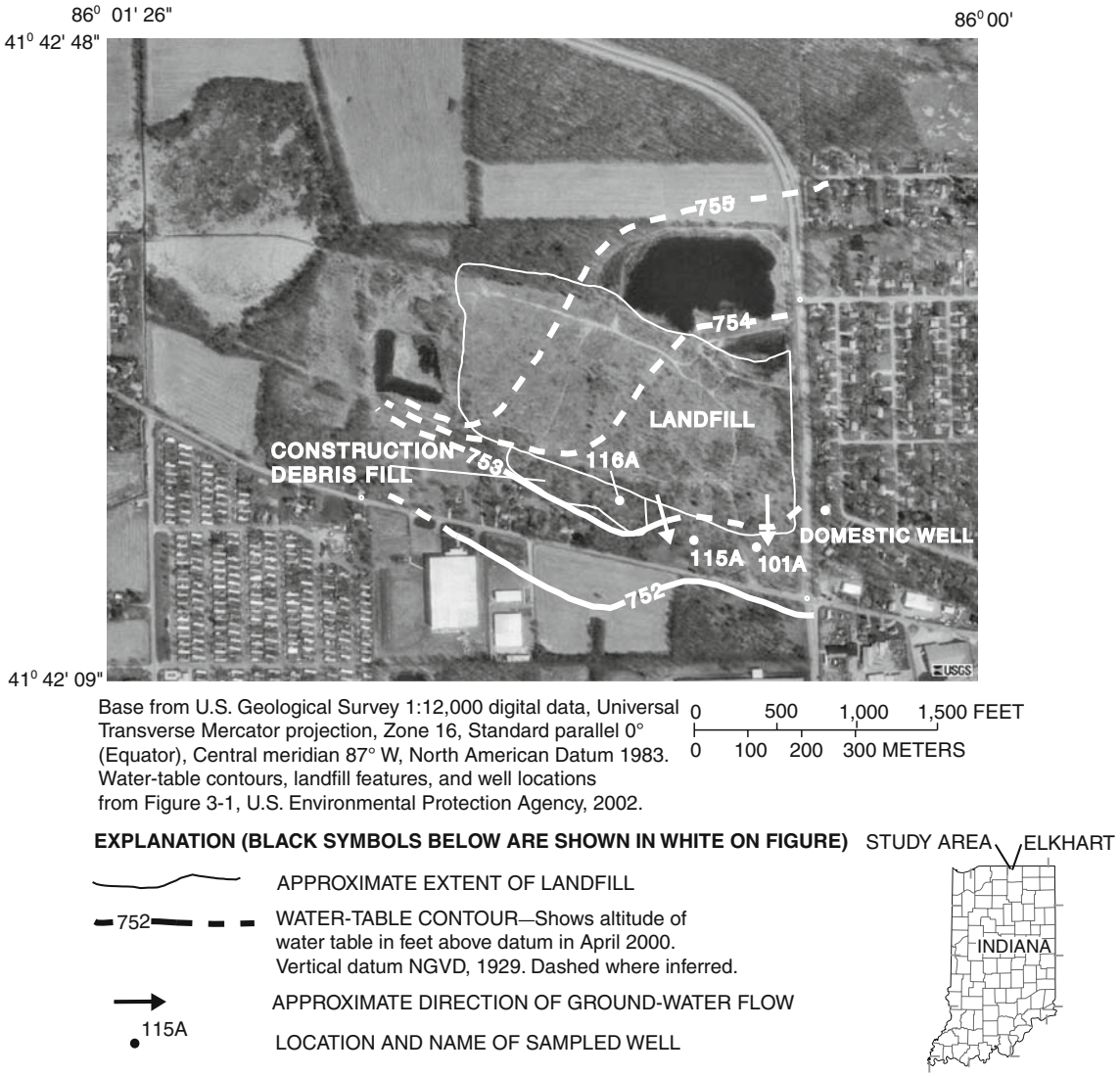

Fig. 1 Location of study area and sampled wells near Elkhart, Indiana, USA (2000 and 2002), and water-table configuration, April 2000

absent (Duwelius and Silcox 1991). Ground-water flow in the shallow aquifer near the landfill is south-southeast (Fig. 1) and toward the St. Joseph River (Duwelius and Silcox 1991) except for an area of south-southwesterly flow along the southern landfill boundary. A plume of leachate-related bromide in ground water was mapped in 1980 and 1982 as extending about 1 mile south-southeast of the landfill toward a public-supply-well field (Duwelius and Silcox 1991). USEPA sampling from 1984 through 1995 detected volatile organic compounds (VOCs), semi-VOCs, and metals in water from wells at and near the landfill. Water from domestic wells in a neighborhood east of the landfill contained concentrations of benzene, chloroform, 1,2-dichloroethane, vinyl chloride, 1,1-dichloroethane, arsenic, sodium, and calcium that indicated leachate contamination. Ground water downgradient from the landfill was sampled in 2000 and 2002 for this study to identify whether waste-indicator and pharmaceutical compounds could be present in landfill-leachate-affected ground water.

Materials and Methods

Water samples were collected from three wells completed in the aquifer downgradient from the landfill on November 15–16, 2000; two observation wells (101A and 116A) and a domestic well (Fig. 1; Table 1). Samples were collected from two wells on October 31, 2002 (115A and 116A) to expand and verify the results of the 2000 sampling. Well 101A was dry during sampling in 2002; nearby observation well 115A, also completed in the aquifer downgradient from the landfill, was substituted. Sampling personnel abstained from selected personal care and food products including insect repellents, colognes, perfumes, caffeinated

Table 1 Characteristics of wells sampled for analysis of waste-indicator and pharmaceutical contaminants near a landfill at Elkhart, Indiana, USA

Well identifier	USGS site number	Latitude	Longitude	Well depth (feet below ground surface)	Water level (depth in feet below ground surface; date in month/day/year)	Casing diameter and material	Aquifer type
116A	414216086001701	41° 42′16″ N	86° 00′17″ W	12.8	11.35 (11/16/2000);11.61 (10/31/2002)	2 in. ID PVC	Unconfined
101A	414215086001702	41° 42′16″ N	86° 00′17″ W	18.8	10.11 (11/16/2000)	2 in. ID PVC	Unconfined
115A	414217086002301	41° 42′16″ N	86° 00′22″ W	17.4	14.33 (10/31/2002)	2 in. ID PVC	Unconfined
Domestic well	414218086001101	41° 42′18″ N	86° 00′12″ W	–	–	Unknown	Unconfined

USGS, U.S. Geological Survey; °: degree; ′: minute; ″: second; in., inch; ID, inside diameter; PVC, polyvinylchloride; –, could not measure

products, and tobacco for 3 days prior to sampling and throughout sample collection and processing. Ground-water samples were produced using a stainless steel submersible pump equipped with polytetrafluoroethylene gear-drive, hose, and fittings. Decontamination was done before and between samples by sequentially flushing the sample pump and tubing with a diluted laboratory-grade detergent rinse; a deionized-water rinse; and 4 L of laboratory-grade, organic-free water. Water was sampled when probe-measured pH, specific conductance (SC), and temperature of water from the wells had stabilized in sequential, flow-cell based measurements. Water samples were collected in amber, baked-glass bottles, chilled immediately after collection, and sent to the USGS National Water Quality Laboratory in Denver, Colorado. In 2000, a field-process-blank sample was prepared by pouring laboratory-grade, organic-free water into a clean sample bottle before collecting the sample from the domestic well. In 2002, a field-process-blank sample was prepared by pumping laboratory-grade, organic-free water through the sampling pump and tubing after decontamination and before collecting water from well 116A. Samples were filtered at the laboratory before extraction through a glass-fiber filter with a 0.7 μm pore size.

Three methods were used to prepare samples for analysis and measure concentrations of the target compounds (Focazio et al. 2008). Samples for waste-indicator compound analysis were preserved with 60 g NaCl to "salt out" hydrophilic compounds (Zaugg et al. 2002) and extracted using continuous liquid-liquid extraction with methylene chloride at pH 2. Waste-indicator compounds were determined by capillary-column gas chromatography/selected-ion monitoring (SIM) mass spectrometry (MS). Human prescription and nonprescription drugs and selected metabolites were extracted using SPE cartridges that contained 0.5 g of Oasis Hydrophilic-Lipophilic-Balance (HLB), then separated and measured by high-performance liquid chromatography coupled to an electrospray ionization, quadrupole MS in SIM mode (Cahill et al. 2004). Antibiotic compounds were extracted and analyzed using tandem solid-phase extraction (SPE) and single quadrapole, liquid chromatography/electrospray-MS in positive-ion mode using SIM (Meyer et al. 2007). The tandem SPE used an Oasis HLB cartridge (60 mg), followed in sequence by a mixed mode, HLB-cation exchange cartridge (60 mg) (Waters Inc., Milford, Massachusetts). Data were reported using the conventions of Focazio et al. (2008).

Results and Discussion

Concentrations of contaminants in water from the sampled wells were similar to leachate-affected ground water (Table 2). Water from wells 115A and 116A had concentrations of bromide similar to those in a leachate plume from the landfill as classified using data from Duwelius and Silcox (1991). Similar concentrations of sulfate, 1,1-dichloroethane, 1,2-dichloropropane, and dichlorodifluoromethane were detected in water from the observation wells and the domestic well. The SC of water from the three observation wells was similar to the SC of landfill-leachate-affected ground water from other local observation wells.

Several waste-indicator compounds were detected in water from the observation wells (Table 3), including detergent metabolites (*p*-nonylphenol, nonylphenol monoethoxylate, nonylphenol diethoxylate, and octylphenol monoethoxylate), plasticizers (ethanol-2-butoxy-phosphate and diethylphthalate), a plastic monomer (bisphenol A), disinfectants (1,4-dichloro-benzene and triclosan), an antioxidant (5-methyl-1H-benzotriazole), three fire-retardant compounds (tributylphosphate, tri(2-chloroethyl)-phosphate, and tri(dichlor-isopropyl)phosphate), a wood preservative (p-cresol), and an insect repellent (*N*,*N*-diethyltoluamide). Recoveries of several waste-indicator compounds from fortified laboratory blank samples were low (30%–63%), indicating that concentrations of these compounds in water samples may be greater than listed in Table 3. Antibiotics and several waste-indicator and pharmaceutical compounds were not detected in ground-water samples; these results can be accessed using the instructions in footnote 1 of Table 3.

Table 2 Ground-water chemistry from sampled wells, 2000 and 2002, and from prior sampling of leachate-affected ground water and water from upgradient wells in the study area near Elkhart, Indiana, USA

Characteristic or chemical name	Measurement units	Water chemistry from wells sampled for this study (sequential duplicate sample results in parentheses)					Water chemistry from prior sampling of ground water in the study area		
		Domestic well	Observation wells downgradient from the landfill				Leachate-affected ground water, Reference 1	Leachate-affected ground water, range, Reference 2 (number of samples in parenthesis)	Water from upgradient wells, range, Reference 2 (number of samples in parenthesis)
			101A	115A	116A	116A			
Date sampled	mm/dd/yyyy or range of years	11/15/2000	11/16/2000	10/31/2002	11/16/2000	10/31/2002	09/13/1979	1980–89	1980–89
Field characteristics									
pH	Standard units	7.24	7.01	8.88	6.70	9.44	6.1	6.4–8.2 (72)	7.5–8.4 (53)
Specific conductance	µS/cm	711	1,220	1,512	3,386	3,302	9,220	248–2,200 (72)	290–540 (53)
Inorganic constituents									
Date sampled	mm/dd/yyyy or range of years	03/15/2000	05/03/2000	10/31/2002	05/03/2000	10/31/2002	9/13/1979	1980–1989	1980–1989
Bromide	mg/L	0.07	0.001 (0.001)	0.78	2.38 (2.42)	2.96 (2.96)	7.1	<0.01–4.7 (72)	0.01–0.7 (52)
Boron	µg/L	–	–	164	–	548 (558)	580	–	–
Sulfate	mg/L	171	218 (215)	274	1,260 (1,250)	497 (502)	620	–	–
Calcium	mg/L	177	258 (242)	359	666 (685)	564 (578)	1,200	–	–
Sodium	mg/L	44.4	66.8 (65.2)	40.8	161 (160)	153 (157)	570	–	–
Organic compounds									
Date sampled	Month/day/year	04/19/2000	5/3/2000	10/31/2002	5/3/2000	10/31/2002	–	–	–
1,1–Dichloroethane	µg/L	3	8	<4.4	8 (7)	11 (12)	–	–	–
1,2–Dichloropropane	µg/L	8	<1	<4.4	1 (1)	<4.4 (<4.4)	–	–	–
Benzene	µg/L	<1	2	11	<1 (<1)	<4.7 (<4.7)	–	–	–
Dichlorodifluoromethane	µg/L	4	4	–	7	–	–	–	–
Tetrahydrofuran	µg/L	–	–	6.3	–	7.4 (8.7)	–	–	–
1,4–Dioxane	µg/L	–	–	11	–	9.2 (32)	–	–	–

mm month, dd day, yyyy year, µS/cm microsiemen per centimeter, – not analyzed in sample, mg/L milligrams per liter, µg/L micrograms per liter, < less than

References of prior sampling results: 1. Imbrigiotta and Martin (1981, p. 126, well M1); 2. Duwelius and Silcox (1991, p. 27–28)

Table 3 Selected waste-indicator, pharmaceutical, and pharmaceutical metabolite compounds in leachate-affected ground water from wells near Elkhart, Indiana, USA, 2000 and 2002

Parameter or compound name	Reporting limit and units	Domestic well (result from duplicate sample in parenthesis)	Observation wells downgradient from the landfill				Compound recoveries from fortified laboratory blank samples, in percent (number of samples in parenthesis)		Compounds detected in other blank samples; (year detected in parenthesis)	
			116A	116A	101A	115A	2000 samples	2002 samples	Field-process blank	Laboratory (organic-free water) blank
Collection date	mm/dd/yyyy	11/15/2000	11/16/2000	10/31/2002	11/16/2000	10/31/2002	NA	NA	NA	NA
Waste-indicator compounds (analyzed by method of Zaugg et al. 2002)										
Benzophenone	0.5 µg/L	–	–	<0.5	–	*UC*	–	98 (1)	None	None
5-methyl-1H-benzotriazole	2 µg/L	<2 (<2)	*UC*	<2	*UC*	<2	30, 38 (2)	78 (1)	None	None
p-Cresol	1 µg/L	<1 (<1)	*UC*	<1	*UC*	<1	47, 54 (2)	90 (1)	None	None
Cumene	0.5 µg/L	–	–	*UC*	–	<0.5	–	52 (1)	None	None
1,4-Dichlorobenzene	0.5 µg/L	<5 (<0.5)	*UC*	*UC*	*UC*	<0.5	45, 62 (2)	70 (1)	None	None
N,N-Diethyltoluamide (DEET)	0.5 µg/L	<5 (<0.5)	*0.5*	*UC*	*UC*	*UC*	56, 62 (2)	103 (1)	None	None
Ethyl citrate	0.5 µg/L	–	–	<0.5	–	*UC*	–	95 (1)	None	None
Galaxolide (HHCB)	0.5 µg/L	–	–	<0.5	–	*UC*	–	102 (1)	None	None
Menthol	0.5 µg/L	–	–	<0.5	–	*UC*	–	96 (1)	None	None
Bisphenol A	1 µg/L	<1 (<1)	*1.3*	*Q, UC*	*UC*	*Q, UC*	45, 60 (2)	82 (1)	*UC* (2002)	None
Nonylphenol monoethoxylate	5 µg/L	<5 (<5)	*UC*	<5	*UC*	*UC*	42, 43 (2)	96 (1)	None	None
Nonylphenol diethoxylate	5 µg/L	<5 (<5)	<5	<5	*UC*	*UC*	32, 47 (2)	98 (1)	None	*UC* (2002)
Octylphenol monoethyoxylate	1 µg/L	<1 (<1)	*UC*	<1	*UC*	*Q, UC*	50, 54 (2)	109 (1)	None	None
p-Nonylphenol	5 µg/L	<5 (<5)	*UC*	<5	*UC*	*UC*	60, 61 (2)	97 (1)	None	*UC* (2000)
Triclosan	1 µg/L	*UC (UC)*	<1	<1	*UC*	*UC*	50, 55 (2)	92 (1)	None	None
Tonalide (AHTN)	0.5 µg/L	–	–	<0.5	–	*UC*	–	96 (1)	None	None
Polynuclear aromatic hydrocarbons (analyzed by method of Zaugg et al. 2002)										
Anthracene	0.5 µg/L	<.5 (<.5)	*UC*	<0.5	<0.5	<0.5	53, 60 (2)	91 (1)	None	None
Fluoranthene	0.5 µg/L	<.5 (<.5)	<0.5	*UC*	<0.5	<0.5	63 (2)	94 (1)	None	None
Fire retardants (analyzed by method of Zaugg et al. 2002)										
Tributylphosphate	0.5 µg/L	–	–	*0.64*	–	*UC*	–	104 (1)	None	None
Tri(2-chloroethyl)phosphate	0.5 µg/L	*0.65 (0.74)*	*UC*	*UC*	*UC*	*UC*	50, 55 (2)	90 (1)	None	None
Tri(dichlorisopropyl)phosphate	0.5 µg/L	<0.5 (<0.5)	<0.5	*UC*	<0.5	<0.5	48, 49 (2)	86 (1)	None	None
Plasticizers (analyzed by method of Zaugg et al. 2002)										
Ethanol-2-butoxy-phosphate	0.5 µg/L	<0.5 (<0.5)	*1.0*	*0.9*	*UC*	*UC*	41, 45 (2)	89 (1)	None	None
Diethylphthalate	0.5 µg/L	–	–	<0.5	–	*1.2*	–	103 (1)	None	None

Table 3 continued

Parameter or compound name	Reporting limit and units	Domestic well (result from duplicate sample in parenthesis)	Observation wells downgradient from the landfill				Compound recoveries from fortified laboratory blank samples, in percent (number of samples in parenthesis)		Compounds detected in other blank samples; (year detected in parenthesis)	
			116A	116A	101A	115A	2000 samples	2002 samples	Field-process blank	Laboratory (organic-free water) blank
Hormones (analyzed by method of Zaugg et al. 2002)										
3B-Coprostanol	2 µg/L	<2 (<2)	<2	*UC*	<2	*UC*	34, 43 (2)	79 (1)	None	None
Cholesterol	2 µg/L	<2 (<2)	<2	*UC*	<2	*UC*	38, 44 (2)	70 (1)	None	None
Beta-sitosterol	2 µg/L	–	–	<2	–	*UC*	30, 39 (2)	71 (1)	None	None
Pharmaceuticals and pharmaceutical metabolites (analyzed by method of Cahill et al. 2004)										
Acetaminophen	0.009 µg/L	*0.38*	<0.009	<0.009	*P 0.022*	<0.009	89, 118 (2)	52, 62 (2)	*UC* (2000)	None
Caffeine	0.014 µg/L	*Q 0.13*	<0.014	<0.014	*UC*	<0.014	85, 90 (2)	73, 75 (2)	*UC* (2000)	*UC* (2002)
Cotinine	0.023 µg/L	*UC*	<0.023	<0.023	< 0.023	*0.10*	61, 66 (2)	69, 70 (2)	None	None
1,7-Dimethylxanthine	0.018 µg/L	*Q 0.045*	<0.018	<0.018	*Q 0.057*	<0.018	142, 165 (2)	82, 107 (2)	None	None
Fluoxetine	0.018 µg/L	<0.018	<0.018	<0.018	*UC*	<0.018	28, 51 (2)	5, 36 (2)	None	None
Ibuprofen	0.018 µg/L	<0.018	<0.018	<0.018	*3.1*	<0.018	87, 90 (2)	36, 40 (2)	None	None

mm/dd/yyyy month, day and year, NA Not applicable, – not analyzed µg/L micrograms per liter, < less than, UC compound detected at concentration less than reporting limit, Q Concentration was from 2 to less than 10 times the concentration in an associated blank, P concentration was less than 2 times the concentration in an associated blank, compound detections are in *italics*

Qualified detections (Q, P) may indicate a false positive for method contaminants. Full analytical results for the ground-water samples from landfill wells can be accessed using their USGS site numbers (Table 1) to retrieve data through the Web site http://nwis.waterdata.usgs.gov/in/nwis/qwdata

Pharmaceuticals and pharmaceutical metabolites in water from the observation wells included acetaminophen, caffeine, cotinine (a nicotine metabolite), 1,7-dimethylxanthine (a caffeine metabolite), fluoxetine, and ibuprofen. The domestic well water analysis may have been affected by water from nearby septic systems; it had larger concentrations of acetaminophen and caffeine than water from the observation wells. About 69 kg/day of caffeine, 7 kg/day of acetaminophen and 0.1 kg/day methyl nicotinate were disposed in 1976 with the firm that managed the landfill (*David Lamm, Indiana State Board of Health, written commun. 1976*). Small concentrations of acetaminophen, caffeine, and 1,7-dimethylxanthine in leachate-affected ground water (Table 3) are consistent with their short persistence in simulated soil columns (Cordy et al. 2004). The cotinine detections in ground water may relate to environmental degradation of methyl nicotinate or human metabolism of nicotine. The ibuprofen detection in water from well 101A (3.1 μg/L) may relate to disposal of prescription or preproduction residues in the landfill.

Waste-indicator compound detections from landfill-leachate-affected ground water in this study (Table 3) are similar to those in leachate-affected ground water at a landfill near Norman, Oklahoma (Barnes et al. 2004). Frequently detected compounds from both sites include a fire retardant (tri(2-chloroethyl)-phosphate), a plasticizer (ethanol-2-butoxy-phosphate), a plastic monomer (bisphenol A), detergents (nonylphenol mono-ethoxylate, nonylphenol diethoxylate, octylphenol monoethoxylate, and *p*-nonylphenol) and an insect repellant (*N*,*N*-diethyltoluamide). The diversity of pharmaceuticals and pharmaceutical metabolites detected in ground-water samples in this study was greater than that reported for ground water near the Norman landfill. These results indicate the importance of additional analyses of leachate affected ground water from other sites for waste-indicator and pharmaceutical compounds to evaluate their potential occurrence and persistence in ground water. These results and conclusions are based on 2000 and 2002 data from this study and prior published results. Additional data collection is planned in 2008 by the USEPA during design of the final cleanup plan for this landfill (*Rosauro Delrosario, U.S. Environmental Protection Agency, written commun. 2008*).

References

Barnes KK, Christenson SC, Kolpin DW, Focazio MJ, Furlong ET, Zaugg SD, Meyer MT, Barber LB (2004) Pharmaceuticals and other organic waste water contaminants within a leachate plume downgradient of a municipal landfill. Ground Water Monit R 24:119–126. doi:10.1111/j.1745-6592.2004.tb00720.x

Cahill JD, Furlong ET, Burkhardt MR, Kolpin DW, Anderson LG (2004) Determination of pharmaceutical compounds in surface- and ground-water samples by solid-phase extraction and high-performance liquid chromatography—electrospray ionization mass spectrometry. J Chromatogr A 1041:171–180. doi:10.1016/j.chroma.2004.04.005

Cordy G, Duran N, Bouwer H, Rice R, Kolpin DW, Furlong ET, Zaugg SD, Meyer MT, Barber LB (2004) Do pharmaceuticals, pathogens, and other organic waste water compounds persist when waste water is used for recharge? Ground Water Monit R 24:58–69. doi:10.1111/j.1745-6592.2004.tb00713.x

Duwelius RF, Silcox CA (1991) Ground-water levels, flow, and quality in northwestern Elkhart County, Indiana, 1980–89. US Geological Survey Water-Resources Investigations Report 91–4053:66 p. U.S. Geological Survey, Reston, VA, USA

Eganhouse RP, Cozzarelli IM, Scholl MA, Matthews LL (2001) Natural attenuation of volatile organic compounds in the leachate plume of a municipal landfill using alkylbenzenes as process probes. Ground Water 39:192–202. doi:10.1111/j.1745-6584.2001.tb02300.x

Focazio MJ, Kolpin DW, Barnes KK, Furlong ET, Meyer MT, Zaugg SD, Barber LB, Thurman ME (2008) A national reconnaissance for pharmaceuticals and other organic wastewater contaminants in the United States—II—Untreated drinking water sources. Sci Total Environ 402:201–206. doi:10.1016/jscitoenv.2008.02.021

Glassmeyer ST, Furlong ET, Kolpin DW, Cahill JD, Zaugg SD, Warner SL, Meyer MT, Kryak DD (2005) Transport of chemical and microbial compounds from known wastewater discharges: potential for use as indicators of human fecal contamination. Environ Sci Technol 39:5157–5169. doi:10.1021/es048120k

Holm JV, Ruegge K, Bjerg PJ, Christensen TH (1995) Occurrence and distribution of pharmaceutical organic compounds in the groundwater downgradient of a landfill (Grindsted, Denmark). Environ Sci Technol 29:1415–1420. doi:10.1021/es00005a039

Imbrigiotta TE, Martin A (1981) Hydrologic and chemical evaluation of the ground-water resources of northwest Elkhart County Indiana. US Geological Survey Water-Resources Investigations Report 81–53:140 p. U.S. Geological Survey, Reston, VA, USA

Kolpin DW, Furlong ET, Meyer MT, Thurman EM, Zaugg SD, Barber LB, Buxton HT (2002) Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999–2000. A national reconnaissance: Environ Sci Technol 36:1202–1211. doi:10.1021/es011055j

Meyer MT, Lee EA, Ferrell GF, Bumgarner JE, Varnes J (2007) Evaluation of tandem off-line and on-line solid-phase extraction with liquid chromatography/electrospray ionization-mass spectrometry for the analysis of antibiotics in ambient water and comparision to an independent method. US Geological Survey Scientific Investigations Report 2007–5021:28 p

Murray HE, Beck JN (1990) Concentrations of synthetic organic chemicals in leachate from a municipal landfill. Environ Pollut 67:195–203. doi:10.1016/0269-7491(90)90186-G

Oman C, Hynning PA (1993) Identification of organic compounds in municipal landfill leachates. Environ Pollut 80:265–271. doi:10.1016/0269-7491(93)90047-R

US Environmental Protection Agency (2002) Supplemental site investigations/site characterization report, Himco Dump Superfund site, Elkhart, Indiana, Dec 2002 vol 1

Zaugg SD, Smith SG, Schroeder MP, Barber LB, and Burkhardt MR (2002) Methods of analysis by the US geological survey national water quality laboratory—Determination of wastewater compounds by polystyrene-divinylbenzene solid-phase extraction and capillary-column gas chromatography/mass spectrometry. U.S. Geological Survey Water-Resources Investigations Report 01-4186:37 p