USGS
science for a changing world

Prepared in cooperation with the Minnesota Pollution Control Agency

Pharmaceutical Compounds in Shallow Groundwater in Non-Agricultural Areas of Minnesota—Study Design, Methods, and Data, 2013

Data Series 878

U.S. Department of the Interior
U.S. Geological Survey

Cover photograph. Water-level measurement in a monitoring well near Elk River, Minnesota, October 2013. Photograph by Sarah M. Elliott, U.S. Geological Survey.

Pharmaceutical Compounds in Shallow Groundwater in Non-Agricultural Areas of Minnesota—Study Design, Methods, and Data, 2013

By Sarah M. Elliott and Melinda L. Erickson

Prepared in cooperation with the Minnesota Pollution Control Agency

Data Series 878

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

Suggested citation:
Elliott, S.M., and Erickson, M.L., 2014, Pharmaceutical compounds in shallow groundwater in non-agricultural areas of Minnesota—Study design, methods, and data, 2013: U.S. Geological Survey Data Series 878, 11 p., *http://dx.doi.org/10.3133/ds878*.

ISSN 2327-638X (online)

Contents

Figures

Tables

Conversion Factors

Inch/Pound to SI (used for well characteristics)

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)

SI to Inch/Pound (used for analytical methods)

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
millimeter (mm)	0.03937	inch (in)
micrometer (μm)	0.00003937	inch (in)
	Volume	
liter (L)	0.2642	gallon (gal)
milliliter (mL)	0.0338	ounce, fluid (fl. oz)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Concentrations of chemical constituents in water are given nanograms per liter (ng/L).

Abbreviations

E	estimated
EAC	endocrine active compound
HPLC	high-performance liquid chromatograph
IDS	isotope dilution standard
MPCA	Minnesota Pollution Control Agency
MRM	multiple reaction-monitoring
NFM	National Field Manual for the Collection of Water-Quality Data
NWIS	National Water Information System
NWQL	National Water Quality Laboratory
PCFF	Personal Computer Field Forms
®	registered trademark
RSD	relative standard deviation
USGS	U.S. Geological Survey

Acknowledgments

David Duffey and Sophia Vaughan (MPCA) collected the groundwater samples for this study. Sharon Kroening, MPCA's ambient groundwater monitoring project coordinator, is acknowledged for providing guidance and coordination for this study. In November 2008, Minnesota voters approved a three-eighths of 1 percent increase in the State sales tax rate under the Clean Water, Land and Legacy Amendment. Approximately 33 percent of the funds were dedicated to a Clean Water Fund to protect, enhance, and restore water quality in lakes, rivers, streams, and groundwater. Funding for this study was provided by the State of Minnesota's Clean Water Fund and the U.S. Geological Survey's Cooperative Water Program.

Pharmaceutical Compounds in Shallow Groundwater in Non-Agricultural Areas of Minnesota—Study Design, Methods, and Data, 2013

By Sarah M. Elliott and Melinda L. Erickson

Abstract

The U.S. Geological Survey, in cooperation with the Minnesota Pollution Control Agency, completed a study on the occurrence of pharmaceutical compounds and other contaminants of emerging concern in shallow groundwater in non-agricultural areas of Minnesota during 2013. This report describes the study design and methods for the study on the occurrence of pharmaceuticals and other contaminants of emerging concern, and presents the data collected on pharmaceutical compounds. Samples were analyzed by the U.S. Geological Survey National Water Quality Laboratory for 110 pharmaceutical compounds using research method 9017. Samples from 21 of 45 wells had detectable concentrations of at least one of the 110 compounds analyzed. One sample contained detectable concentrations of nine compounds, which was the most detected in a single sample. Fewer than five compounds were detected in most samples. Among all samples, 27 of the 110 compounds were detected in groundwater from at least one well. Desmethyldiltiazem and nicotine were the most frequently detected compounds, each detected in 5 of 46 environmental samples (one well was sampled twice so a total of 46 environmental samples were collected from 45 wells). Caffeine had the highest detectable concentration of all the compounds at 2,060 nanograms per liter.

Introduction

Several recent studies have documented endocrine active compounds (EACs) and other contaminants of emerging concern in surface water in Minnesota (Lee and others, 2004; Lee, Schoenfuss, and others, 2008; Lee, Yaeger, and others, 2008). Additionally, these contaminants have been detected in groundwater in Minnesota (Erickson, 2012; Lee and others, 2004; Tornes and others, 2007) and nationwide (Zogorski and others, 2006; DeSimone and others, 2009). Understanding the occurrence and distribution of these compounds in groundwater in Minnesota is important for source-water protection efforts and to better understand the connections between land use and water quality. Wastewater treatment systems, including domestic septic systems, are not designed to remove these types of compounds (Herberer, 2002; Ternes and others, 2002), potentially providing a transport path for these compounds to groundwater.

Lee and others (2004) collected samples from 11 monitoring or production wells, which were located in a variety of land-use settings, including sewered residential, commercial/industrial, residential septic, landfill, and feedlot. Although few groundwater sites were sampled, the detections of pharmaceuticals, antibiotics, disinfectants, personal-care products (such as sunscreen, insect repellant, and fragrances), plasticizers, pesticides, solvents, detergents, flame retardants, and polycyclic aromatic hydrocarbons in the groundwater samples were notable.

The U.S. Geological Survey (USGS), in cooperation with the Minnesota Pollution Control Agency (MPCA), completed a study on the occurrence of pharmaceuticals and other contaminants of emerging concern in shallow groundwater in non-agricultural areas of Minnesota using wells within the MPCA ambient groundwater monitoring network. The compounds analyzed include steroidal hormones, pharmaceuticals, antibiotics, and organic wastewater compounds. As part of this study, the MPCA collected 46 groundwater samples from 45 wells during 2013 (two environmental samples were collected from one of the wells). These samples were analyzed for 110 pharmaceutical compounds, including steroidal hormones, human-use pharmaceutical compounds, human- and animal-use antibiotics, and a broad suite of organic compounds associated with wastewater, by the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado, or the USGS Organic Geochemistry Research Laboratory in Lawrence, Kansas.

The purposes of this report are to describe the study design and methods of sample collection and laboratory analysis for the study on the occurrence of pharmaceuticals and other contaminants of emerging concern, and present quality-assurance and analytical data for 110 pharmaceutical compounds in 46 groundwater samples collected from 45 wells during 2013. The samples analyzed for pharmaceutical compounds included in this report were analyzed by the USGS NWQL using research method 9017 for pharmaceuticals in filtered water.

Study Design

The study was designed to determine the magnitude of concentrations of pharmaceutical compounds and other organic contaminants of emerging concern in shallow groundwater in non-agricultural areas of Minnesota. The MPCA's ambient groundwater monitoring network (hereafter called the network) (Minnesota Pollution Control Agency, 2009) targets wells completed in the sand and gravel aquifers and vulnerable bedrock aquifers, such as the Prairie du Chien-Jordan aquifer, in areas that are sensitive to pollution, as described by the Minnesota Department of Natural Resources and others (Falteisek, 2013). Wells within the MPCA network represent typical urban land-use settings in large and small urban areas throughout Minnesota; wells are primarily screened near the water table. Approximately 40 of the 200 network wells are sampled annually for EACs and other contaminants of emerging concern on a rotating basis. MPCA staff, in consultation with other State agencies (Departments of Natural Resources, Health, and Agriculture) and the USGS, selected a subset of 45 wells from the State's ambient groundwater monitoring network for sampling as part of the 2013 sampling season, the fourth year of this study. Results of the study's findings from 2009–2012 are presented in Erickson (2012) and Erickson and others (2014).

Pharmaceutical compounds analyzed in groundwater samples for this study include compounds typically found in wastewater, including steroidal hormones, pharmaceuticals, antibiotics, and other organic compounds. Methods and analytical results of research method 9017 are included in this report. Analytical results for a subset of samples analyzed at the NWQL using schedule 2080, which analyzes 14 pharmaceutical compounds in common with research method 9017, also are included in this report. Methods for schedule 2080 are described in Furlong and others (2008). Although analytical methods are different between research method 9017 and schedule 2080, a comparison of analytical results from the two analytical methods provides information regarding precision and capabilities of research method 9017.

The 45 sampled wells (fig. 1; table 1) are located primarily in non-agricultural areas in proximity to human alterations, such as housing developments or industrial activities. Water samples were collected during the months April through June 2013. Samples were sent to the USGS NWQL in Denver, Colorado, or the USGS Organic Geochemistry Research Laboratory in Lawrence, Kansas, for analysis. Analytical results for hormones, antibiotics, and wastewater compounds in samples analyzed by the NWQL or Organic Geochemistry Research Laboratory using approved methods (Furlong and others, 2008; Meyer and others, 2007; Zaugg and others, 2006), are published in the USGS National Water Information System (NWIS) (U.S. Geological Survey, 2014), and are not included in this report. These analytical results for hormones, antibiotics, and wastewater compounds can be obtained from NWIS using the station numbers given in table 1.

Methods

This section of the report describes the methods used to collect the groundwater samples and the analytical methods for the analysis of 110 pharmaceutical compounds. Quality-assurance and quality-control samples collected for this study also are described.

Groundwater Sample Collection

USGS staff provided training to MPCA hydrologic technicians on USGS sampling protocols and the use of the USGS Personal Computer Field Forms (PCFF) computer program, which is used to record field data. MPCA staff collected samples from 45 of the wells in the State's ambient network during the period April through June 2013. One of the 45 wells (site 24, fig. 1) was sampled twice in 2013 (April 29 and May 20). Water samples were collected by MPCA staff according to the USGS National Field Manual for the Collection of Water-Quality Data (NFM) (U.S. Geological Survey, variously dated). USGS staff verified sample integrity and labeling, shipped all samples to the USGS laboratories, and entered necessary site and sample information into USGS databases.

Each monitoring well was purged using a submersible or peristaltic pump and Teflon® tubing. Field properties, such as water temperature, pH, and specific conductance, were measured and recorded in PCFF as specified in the NFM. Samples for analysis by research method 9017 were collected using USGS protocols for organic contaminants (section 5.6.1.F of Wilde and others, 2004), except that the samples were contained in new 125-milliliter amber glass bottles. Samples for analysis by research method 9017 and all other analyses were filtered in the field using the procedure summarized in Wilde and others (2004). Samples were stored at 4 degrees Celsius (ºC) or less, until analysis. Sampling equipment was decontaminated between sampling sites using, in sequence, Liqui-Nox®, tap water, deionized water, methanol, and organic-free blank water. Sampling personnel refrained from using personal-care products (for example, mosquito repellant containing *N*,*N*-diethyl-*meta*-toluamide [DEET]) and participating in activities which may introduce compounds of interest (for example, smoking or drinking coffee) to avoid contamination of the samples during collection.

Analytical Methods for Pharmaceutical Compounds

Groundwater samples were analyzed for 110 pharmaceutical compounds using research method 9017, which was under method research development at the USGS NWQL in 2013. Because this USGS research method was under development, long-term quality-assurance information was not available during the time of this study. The method was approved in 2014 as NWQL schedule 2440, and is briefly described in this section and in more detail in Furlong and others (2014).

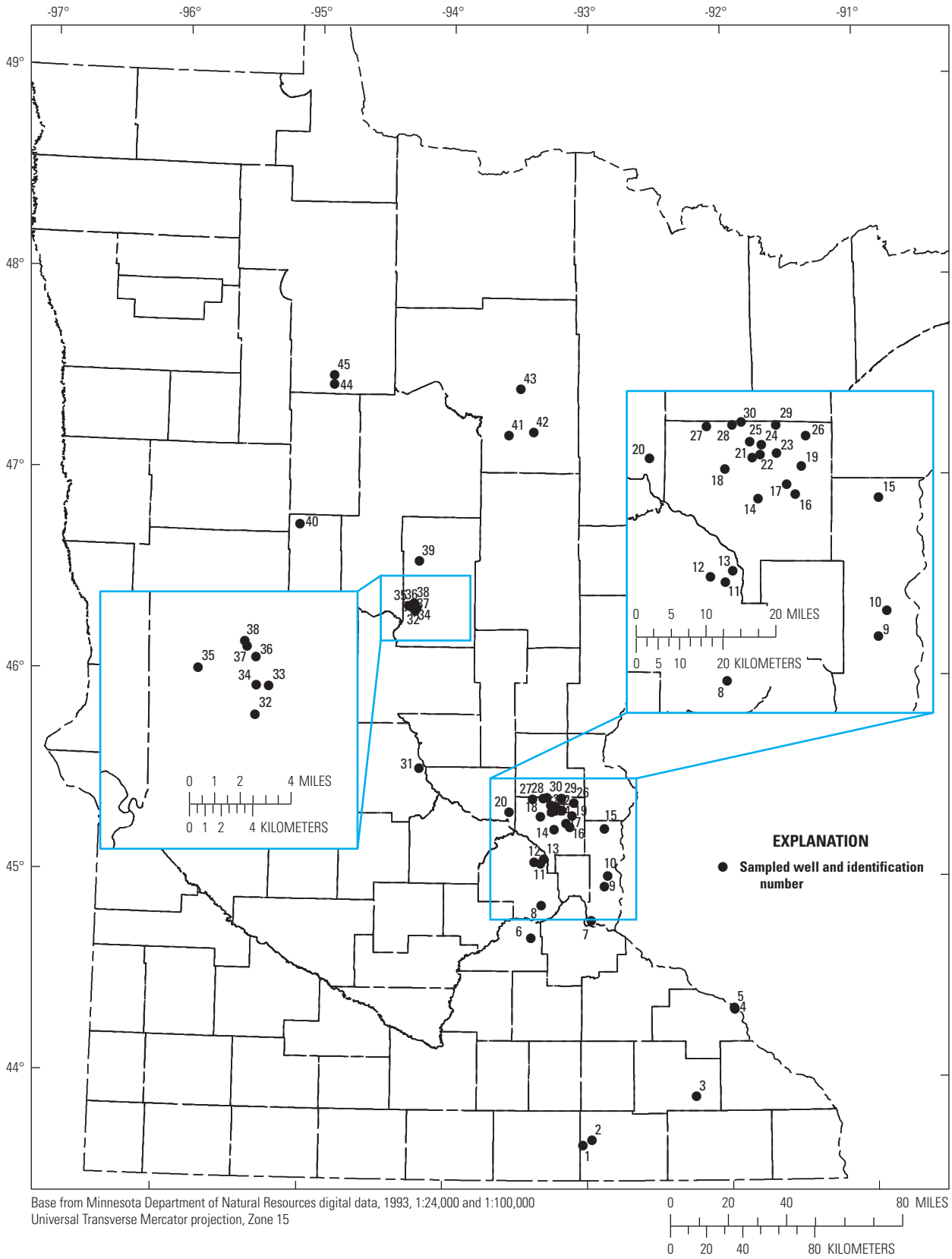

Figure 1. Location and identification numbers of wells sampled, 2013.

Table 1. Selected information for sampled wells.

[ID, identification; MUN, Minnesota unique well number; ft bgs, feet below ground surface; USGS, U.S. Geological Survey; GLEN, Galena Dolomite; QRNR, Quaternary System; MN040, Minnesota County Well Index; GSSG, glacial surficial sand or gravel; JRDN, Jordan Sandstone; DMDF, Des Moines drift]

Agency code	Station number	Site ID number (fig. 1)	MUN	Well type	Aquifer	Well depth (ft bgs)	Open or screened interval of well (ft bgs)
USGS	434036093014701	1	651822	Domestic	GLEN	330	253–330
USGS	434214092580001	2	562727	Domestic	GLEN	340	210–340
USGS	435512092145201	3	55W0000143	Domestic	GLEN	80	Unknown
USGS	442112091582401	4	612403	Domestic	QRNR	66	62–64
USGS	442149091583901	5	474571	Domestic	QRNR	57	53–57
MN040	444230093233901	6	207563	Domestic	GSSG	98	93–98
MN040	444751092582301	7	121063	Domestic	JRDN	190	170–190
USGS	445228093193101	8	789992	Monitoring	QRNR	34	24–34
USGS	445807092525301	9	778354	Monitoring	GSSG	43	33–43
USGS	450116092512501	10	783301	Monitoring	GSSG	75	65–75
USGS	450447093195101	11	660018	Monitoring	QRNR	26	21–26
USGS	450524093223201	12	560414	Monitoring	GSSG	18	13–18
USGS	450611093183101	13	560412	Monitoring	GSSG	13.5	8.5–13.5
USGS	451513093140701	14	785652	Monitoring	QRNR	26	16–26
USGS	451525092525001	15	512008	Domestic	JRDN	160	148–160
USGS	451543093073301	16	789993	Monitoring	QRNR	13	3–13
USGS	451701093090501	17	789994	Monitoring	QRNR	15	5–15
USGS	451855093195901	18	245653	Monitoring	GSSG	27.6	17.6–27.6
USGS	451918093063001	19	786975	Monitoring	QRNR	18	8–18
USGS	452013093332001	20	649956	Monitoring	GSSG	48	43.5–48.5
USGS	452019093151201	21	789995	Monitoring	QRNR	15	5–15
MN040	452043093134801	22	148184	Domestic	JRDN	109	90–109
USGS	452056093105401	23	783316	Monitoring	QRNR	14	4–14
USGS	452153093133501	24	W30009	Monitoring	GSSG	18	15–18
USGS	452219093153901	25	783315	Monitoring	QRNR	14	4–14
USGS	452304093054601	26	783317	Monitoring	QRNR	28	18–28
USGS	452412093231801	27	783312	Monitoring	GSSG	16	6–16
USGS	452423093184501	28	783313	Monitoring	GSSG	19	9–19
USGS	452426093110201	29	785070	Monitoring	GSSG	15	5–15
USGS	452444093171201	30	786974	Monitoring	QRNR	14	4–14
USGS	453303094114501	31	783233	Monitoring	QRNR	22.7	12.7–22.7
USGS	462002094142301	32	775496	Monitoring	QRNR	15	5–15
USGS	462101094134401	33	786964	Monitoring	QRNR	18	8–18
USGS	462102094142101	34	785661	Monitoring	QRNR	14	4–14
USGS	462137094171401	35	786963	Monitoring	QRNR	18	8–18
USGS	462200094142301	36	785659	Monitoring	QRNR	19	9–19
USGS	462223094145001	37	792440	Monitoring	QRNR	14	4–14
USGS	462232094145701	38	785658	Monitoring	QRNR	12	2–12
USGS	463507094125301	39	792441	Monitoring	QRNR	30	20–30
USGS	464538095050101	40	438559	Domestic	GSSG	40	36–40
USGS	471254093342001	41	468403	Domestic	QRNR	38	33–38
USGS	471353093233601	42	708434	Domestic	QRNR	68	64–68
USGS	472652093291601	43	778359	Monitoring	QRNR	30	20–30
USGS	472740094512700	44	243267	Monitoring	DMDF	12.5	10.5–12.5
USGS	473017094512901	45	243344	Monitoring	QRNR	27	22–27

A 100-microliter aliquot of the filtered water sample is directly injected into a high-performance liquid chromatograph (HPLC) coupled to a triple quadrupole mass spectrometer using an electrospray ionization source operated in the positive ion mode. Separation of the pharmaceutical compounds is completed using a reversed-phase gradient of formic acid/ammonium formate-modified water and methanol. When possible, a specific isotope dilution standard (IDS) pharmaceutical with chemical similarity to an unlabeled pharmaceutical of interest is added to the sample prior to analysis (table 2). Each pharmaceutical compound is then identified using multiple reaction-monitoring (MRM) of two fragmentations of the protonated molecular ion of each pharmaceutical to two unique product ions. The primary MRM precursor-product ion transition is quantified for each pharmaceutical relative to that of a specific IDS pharmaceutical. This direct injection analysis method results in method detection limits ranging from 0.45 to 94.1 nanograms per liter (ng/L) for the analyzed compounds. An assessment of method performance for each pharmaceutical was conducted to determine the applicability of the method in different matrices. Recovery of a suite of pharmaceuticals spiked into reagent, surface, and drinking water; groundwater; and wastewater influent and treated effluent typically was greater than 90 percent (Furlong and others, 2014).

Table 2. Pharmaceutical compound and corresponding isotope dilution standard used for its quantification in filtered water samples by U.S. Geological Survey National Water Quality research method 9017.

[*d*, deuterium; ^{13}C, carbon-13]

Pharmaceutical compound	Isotope dilution standard
acetaminophen	acetaminophen-d_3
albuterol	albuterol-d_9
amphetamine	amphetamine-d_6
caffeine	caffeine-$^{13}C_3$
codeine	codeine-d_6
cotinine	cotinine-d_3
diazepam	diazepam-d_5
diltiazem	diltiazem-d_3
diphenhydramine	diphenhydramine-d_3
fluoxetine	fluoxetine-d_6
hydrocodone	hydrocodone-d_3
methadone	methandone-d_9
norfluoxetine	norfluoxetine-d_6
oxycodone	oxycodone-d_3
pseudoephedrine	pseudoephedrine-d_3
sulfamethoxazole	sulfamethoxazole-$^{13}C_6$
temazepam	temazepam-d_5
thiabendazole	thiabendazole-d_4
trimethoprim	trimethoprim-d_9

Because research method 9017 is an "information-rich" method, as are other mass spectrometry methods the NWQL provides (Childress and others, 1999), qualitatively identified compounds for which calculated concentrations are less than the interim reporting level or less than the lowest calibration standard are reported by NWQL as estimated and noted with the "E" remark code. Compounds that are not detected are reported as less than the interim reporting level.

Quality Assurance and Control

Quality-assurance plans were established to evaluate laboratory and field sampling techniques, assess possible sources of contamination, and assure representative samples. All field personnel were familiar with study design and sampling protocols before field sampling or data processing to assure sample integrity.

Field quality-assurance samples were collected consistent with the USGS NFM (U.S. Geological Survey, variously dated). The collected field quality-assurance samples included replicates and blanks (table 3). Field equipment-blank samples were collected at 4 of the 45 wells to characterize any contamination potentially introduced during field activities. Field replicates were collected at three wells during the 2013 sampling. Analytical results of the field quality-assurance samples are presented in table 4 as a Microsoft Excel spreadsheet (*http://pubs.usgs.gov/ds/2014/878/downloads/table4.xls*).

Potential contamination of water samples during sample collection, processing, and laboratory analysis was assessed with field equipment-blank samples. Field equipment-blank samples were prepared at selected sites before a scheduled field sample. Field equipment-blank samples were prepared by processing HPLC organic-free grade water (certified by the USGS to be free of the compounds of interest) through the same equipment used to collect and process field samples. Four field blank samples were collected and analyzed to assess contamination introduced during sample collection and processing and laboratory analysis for water samples. At least one compound was detected in three of the four field equipment-blank samples. Nine compounds were detected among all field blank samples (table 4). Seven compounds were detected in one of the field equipment-blank samples, the most detections in any one field blank. Three (one-third) of the compounds detected in field equipment-blank samples were detected in two of the blank samples (1,7-dimethylxanthine, caffeine, and lidocaine); six (two-thirds) of the compounds detected in field equipment-blank samples were detected in one blank sample. Piperonyl butoxide and pseudoephedrine were each detected in one field equipment-blank sample, but were not detected in environmental samples. Several compounds detected in field equipment-blank samples were also detected in environmental samples. However, compounds detected in field blank samples did not correspond to associated environmental samples collected on the same day. Despite the lack of association between field blank and environmental sample detections,

Table 3. Field quality-assurance sample descriptions.

[ID, identification; hh, hours; mm, minutes; OAQ, field equipment-blank quality-assurance sample, artificial water; WGQ, groundwater quality-assurance sample]

Station number	Site ID number (fig. 1)	Date sampled	Time sampled, in hhmm	Medium code	Sample description
452412093231801	27	04/16/2013	1000	OAQ	Field equipment-blank.
451513093140701	14	04/30/2013	1020	WGQ	Replicate of environmental sample collected at 1015.
450116092512501	10	05/07/2013	1130	OAQ	Field equipment-blank.
445807092525301	9	05/07/2013	1519	WGQ	Matrix spike.
445807092525301	9	05/07/2013	1520	WGQ	Matrix spike duplicate of sample collected at 1519.
462200094142301	36	05/14/2013	1300	OAQ	Field equipment-blank.
451855093195901	18	05/20/2013	1338	WGQ	Matrix spike.
451855093195901	18	05/20/2013	1339	WGQ	Matrix spike duplicate of sample collected at 1338.
472740094512700	44	06/03/2013	1600	OAQ	Field equipment-blank.
471353093233601	42	06/04/2013	1152	WGQ	Replicate of environmental sample collected at 1150.
445228093193101	8	06/07/2013	0956	WGQ	Replicate of environmental sample collected at 0955.

environmental sample concentrations that were less than 10 times any field equipment-blank concentration were assigned a 'v' code in table 4 and are not counted as detections in this report. Future interpretation of these data warrants consideration of the compound detections in field equipment-blank samples.

Replicate samples are used to quantify the variability of detections and corresponding concentrations that result from sample processing (sample splitting, filtration, and transport) and laboratory techniques. Three replicate samples were collected at three different wells. Replicate sample pairs consisted of a primary environmental field sample and a replicate sample collected immediately after the environmental sample; the two samples should be nearly identical in composition. Concentrations of detected compounds in replicate samples were compared by calculating the relative standard deviation (RSD) for each detected compound. The RSD is calculated by dividing the standard deviation of the samples by the mean of the samples, and then multiplying by 100. None of the three sequential replicate sample pairs that were collected had detections of the same compounds and therefore, it was not possible to calculate RSD for those samples. No compounds were detected in the environmental or replicate sample collected from site 42 (fig. 1; table 4). One compound (caffeine) was detected in the replicate sample collected from site 14 (fig. 1); however, that compound was not detected in the associated environmental sample. The concentration of caffeine in the replicate samples was less than 10 times the concentration detected in a field equipment-blank sample, so the value was assigned a 'v' code in table 4. Compound detections in paired samples collected from site 8 (fig. 1; table 4) also were not consistent between the samples. Two compounds, acetaminophen and metaxalone, were detected in the environmental sample, but not in the replicate sample. The concentration of acetaminophen was less than 10 times the concentration detected in a field equipment-blank sample, so the value was assigned a 'v' code in table 4. The concentration of metaxalone in the environmental sample was reported as an estimated (E) value because it was less than the interim reporting level.

Five samples were analyzed for pharmaceutical compounds using schedule 2080 and research method 9017. Analytical results from the two methods allowed for comparison between the old (schedule 2080) and new (research method 9017) analytical methods for pharmaceutical compounds.

Laboratory quality-control samples were used to validate and interpret the environmental data. Laboratory quality-control samples included laboratory reagent blanks, reagent spikes, matrix spikes, and surrogates. At least one fortified laboratory reagent spike sample and one laboratory reagent blank sample were analyzed with each set of 10–16 environmental samples. Laboratory reagent blanks are samples of reagent water that are assumed to be void of the compounds of interest. Laboratory reagent blank samples were used to assess potential sample contamination. Several pharmaceutical compounds were detected in the laboratory reagent blank samples at concentrations greater than the interim reporting level. At least one pharmaceutical compound was detected in every laboratory reagent blank sample. Two of the 13 laboratory reagent blank samples included in analyses had detections of 15 pharmaceutical compounds, which was the greatest number of detections in laboratory blanks. Fexofenidine was the most frequently detected compound in laboratory reagent blank samples, detected in all but one laboratory reagent blank sample. Chlorpheniramine was detected in more than one-half of all laboratory reagent blank samples. Despite detections in laboratory reagent blanks, neither fexofenadine nor chlorpheniramine were detected in any environmental samples. Warfarin was the only compound detected in both an environmental

sample and associated laboratory reagent blank; the environmental sample concentration was E13.9 ng/L (table 4), which was less than 10 times the laboratory reagent blank concentration, so it was assigned a 'v' code and not counted as a detection in this report (U.S. Geological Survey, 2011).

Recoveries for compounds spiked into reagent water (laboratory reagent spike samples) and for surrogate compounds spiked into environmental samples indicate the general proficiency of the laboratory methods. Laboratory reagent spikes are samples of reagent water that are spiked (fortified) in the laboratory with a known concentration of selected compounds. Average recoveries of compounds in laboratory reagent spike samples ranged from 77 percent (cimetidine) to 112 percent (pseudoephedrine). For research method 9017, surrogate compounds were added to samples before analysis to monitor method performance, as described in the "Analytical Methods for Pharmaceutical Compounds" section. Surrogates are chemicals that have similar properties to the analytes of interest, but do not interfere with quantitation of the compounds of interest. Average recovery of surrogate compounds in environmental samples ranged from 81 percent (pseudoephedrine-d_3) to 112 percent (hydrocodone-d_3). Recovery of compounds and surrogates were within acceptable ranges of 50–150 percent (Furlong and others, 2014) indicating general good recovery of pharmaceutical compounds using this analytical method.

Matrix interference was to be assessed by laboratory matrix spikes in groundwater samples. Two matrix spike samples with associated duplicate samples were collected at two wells and shipped to the NWQL for assessment of matrix interference. In cases when the environmental sample concentration was less than the method detection limit, a concentration of zero was used to estimate percent recovery of the spiked analyte. Recoveries of target analytes spiked into sample matrices ranged from 26 to 471 percent, indicating the sample matrix may have interfered with recovery of some analytes. Orlistat had the overall lowest recovery, ranging from 26 to 76 percent. Recoveries of two compounds, lamivudine and penciclovir, were greater than 200 percent in all spiked samples, indicating that environmental concentrations may be biased high. Compound recoveries generally were consistent between duplicate matrix spike samples.

Pharmaceutical Compounds in Groundwater

The concentration data for the 110 pharmaceutical compounds in 46 groundwater samples collected from 45 wells in Minnesota during 2013 are presented in table 4, along with the associated percent recoveries for IDS pharmaceuticals. Environmental samples from 21 wells had detectable concentrations of at least one of the 110 pharmaceutical compounds analyzed using USGS NWQL research method 9017 (table 4, Microsoft® Excel spreadsheet; figs. 2 and 3). Fewer than 5 compounds were detected in most samples. One sample contained detectable concentrations of nine compounds (site 25, fig. 1; table 4), which was the most compounds detected in one sample. Twenty-seven of the 110 compounds analyzed were detected in at least one groundwater sample. Twelve of the 27 detected compounds were detected in more than one sample and are shown in figure 3. The remaining 15 of 27 detected compounds were detected in only one groundwater sample. Most detected compounds were detected in fewer than four samples. Desmethyldiltiazem and nicotine were the most frequently detected compounds (detected in 5 of 46 environmental samples). Detectable concentrations of all compounds ranged from 0.43 to 2,060 ng/L, with caffeine having the highest detectable concentration.

One well (site 24) was sampled twice approximately one month apart in 2013. Although this set of samples is not being considered as a replicate pair, they provide important information regarding temporal variation in the groundwater chemistry and how representative a one-time sampling of these wells may be. The two samples collected at site 24 (station number 452153093133501, site 24, fig. 1) on May 20 and June 25 contained detectable concentrations of carisoprodol and meprobamate with RSDs of 59 and 14, respectively.

Five samples were analyzed with both USGS NWQL research method 9017 and schedule 2080. Schedule 2080 analyzes the presence of 14 pharmaceuticals in samples using solid-phase extraction and liquid chromatography-mass spectrometry methods (Furlong and others, 2008). Percent recovery of surrogates generally was greater using research method 9017 compared to schedule 2080, although different surrogates were used between the two methods. Average recoveries for the two surrogates used in schedule 2080 were 51 and 70 percent for carbamazepine-d_{10} and ethylnicotinate-d_4, respectively. Research method 9017 includes analysis of 19 surrogates (IDS pharmaceuticals) for which average recoveries ranged from 81 to 112 percent. Table 5 shows a comparison of results between the two pharmaceutical methods, research method 9017 and laboratory schedule 2080. Laboratory reporting limits used for schedule 2080 are up to 10-fold higher compared to interim reporting limits used for research method 9017. Three pharmaceuticals were detected with schedule 2080. Sulfamethoxazole was detected in two samples, and acetaminophen and carbamazepine were detected in one sample. Five pharmaceuticals were detected when samples were analyzed with research method 9017, although three of those detections were associated with detections in laboratory equipment-blank samples and were coded with a 'v' in tables 4 and 5. Two detections were in common between schedule 2080 and research method 9017: carbamazepine and sulfamethoxazole (in one of two paired samples with a detection using schedule 2080).

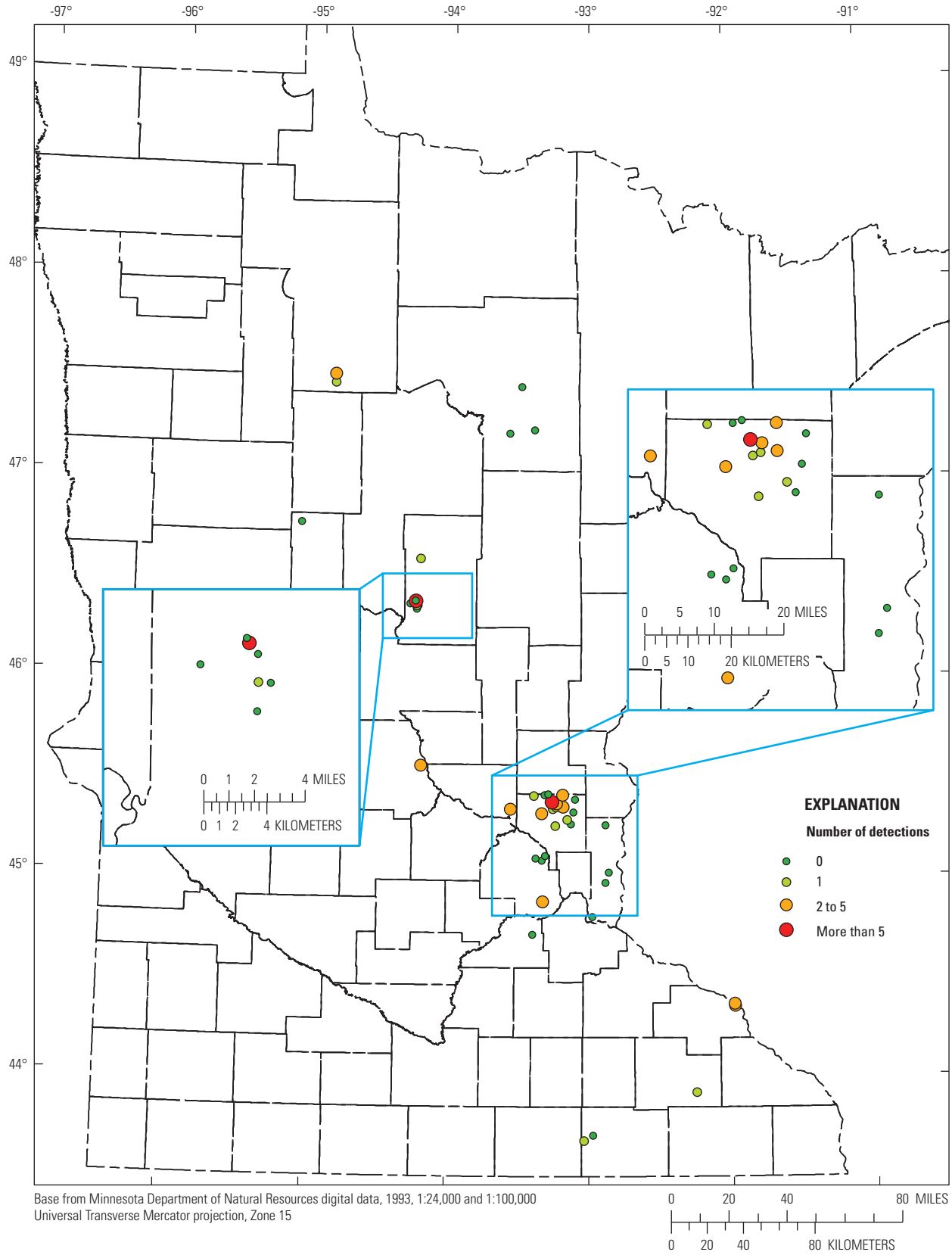

Figure 2. Sampled well locations and number of pharmaceuticals detected in groundwater samples from non-agricultural areas of Minnesota, 2013.

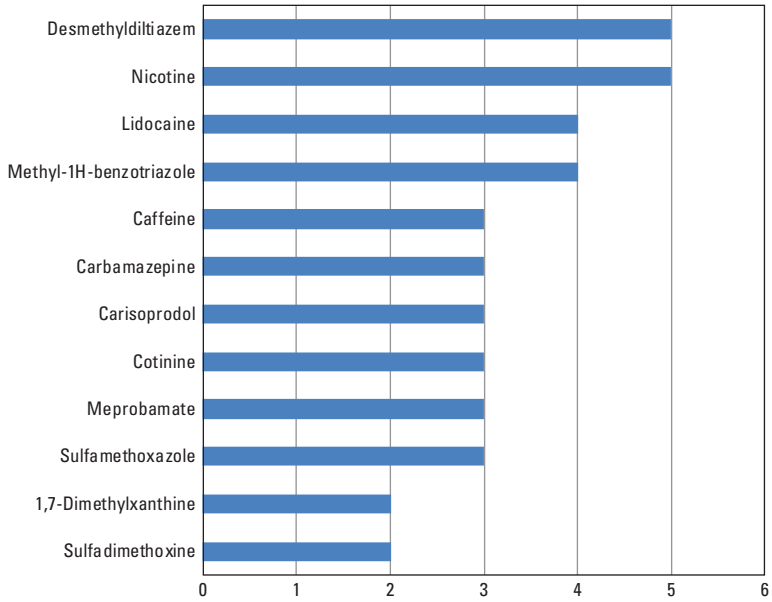

Figure 3. Number of detections of selected pharmaceutical compounds in groundwater samples from non-agricultural areas of Minnesota, 2013.

Table 5. Concentrations of pharmaceutical compounds in environmental samples analyzed at the U.S. Geological Survey National Water Quality Laboratory using two different analytical methods.

[Samples were analyzed using research method 9017 and schedule 2080 for filtered water samples. Only compounds in common with both analytical methods are included. ID, identification; hh, hours; mm, minutes; <, less than interim reporting level; E, estimated value; v, concentration is less than 10 times greater than laboratory blank or field blank concentration]

Station number	Site ID number (fig. 1)	Date sampled	Time sampled, in hhmm	Analytical method	Concentration, in nanograms per liter						
					1,7-Dimethylxanthine	Acetaminophen	Albuterol	Caffeine	Carbamazepine	Codeine	Cotinine
445807092525301	9	5/7/2013	1510	2080	<100	<120	<80	<60	<60	<46	<38
				9017	<87.7	<7.13	<6.06	<90.7	<4.18	<88.3	<6.37
451855093195901	18	5/20/2013	1330	2080	<100	E438	<80	<60	<5	<46	<38
				9017	<87.7	<7.13	<6.06	<90.7	<4.18	<88.3	v7.82
452013093332001	20	6/17/2013	1050	2080	<100	<120	<80	<60	<5	<46	<38
				9017	v142	<7.13	<6.06	v146	<4.18	<88.3	<6.37
452153093133501	24	6/25/2013	1005	2080	<100	<120	<80	<60	<60	<46	<38
				9017	<87.7	<7.13	<6.06	<90.7	<4.18	<88.3	v4.31
452043093134801	22	6/11/2013	1435	2080	<100	<120	<80	<60	92	<46	<38
				9017	<87.7	<7.13	<6.06	<90.7	103	<88.3	<6.37

Station number	Site ID number (fig. 1)	Date sampled	Time sampled, in hhmm	Analytical method	Concentration, in nanograms per liter						
					Dehydronifedipine	Diltiazem	Diphenhydramine	Sulfamethoxazole	Thiabendazole	Trimethoprim	Warfarin
445807092525301	9	5/7/2013	1510	2080	<80	<60	<58	<91	<60	<34	<80
				9017	<24.5	<10.2	<5.79	<26.1	<4.1	<19.0	<6.03
451855093195901	18	5/20/2013	1330	2080	<80	<60	<58	<91	<60	<5	<80
				9017	<24.5	<10.2	<5.79	<26.1	<4.1	<19.0	<6.03
452013093332001	20	6/17/2013	1050	2080	<80	<60	<58	E9	<60	<5	<80
				9017	<24.5	<10.2	<5.79	E24.4	<4.1	<19.0	<6.03
452153093133501	24	6/25/2013	1005	2080	<80	<60	<58	<91	<60	<34	<80
				9017	<24.5	<10.2	<5.79	<26.1	<4.1	<19.0	<6.03
452043093134801	22	6/11/2013	1435	2080	<80	<60	<58	E11	<60	<5	<80
				9017	<24.5	<10.2	<5.79	<26.1	<4.1	<19.0	<6.03

Summary

The U.S. Geological Survey, in cooperation with the Minnesota Pollution Control Agency, completed a study on the occurrence of pharmaceutical compounds and other contaminants of emerging concern in shallow groundwater in non-agricultural areas of Minnesota during 2013. This report describes the study design and methods for the study on the occurrence of pharmaceuticals and other contaminants of emerging concern, and presents the data collected on pharmaceutical compounds. A total of 46 environmental samples and 11 quality-control samples were collected from 45 wells as part of this study. Samples were analyzed by the U.S. Geological Survey National Water Quality Laboratory for 110 pharmaceutical compounds using research method 9017. Environmental samples from 21 wells had detectable concentrations of one or more pharmaceutical compounds. One sample contained detectable concentrations of nine compounds, which was the most detected in one sample. Fewer than 5 compounds were detected in most samples. Among all samples, 27 of 110 pharmaceutical compounds were detected in at least one sample. Detectable concentrations of all compounds ranged from 0.43 to 2,060 nanograms per liter, with caffeine having the highest detectable concentration. Desmethyldiltiazem and nicotine were the most frequently detected compounds (detected in 5 of 46 environmental samples).

References Cited

DeSimone, L.A., Hamilton, P.A., and Gilliom, R.J., 2009, Quality of water from domestic wells in principal aquifers of the United States, 1991–2004—Overview of major findings: U.S. Geological Survey Circular 1332, 49 p. (Also available at *http://pubs.usgs.gov/circ/circ1332/*.)

Childress, C.J.O., Foreman, W.T., Connor, B.F., and Maloney, T.J., 1999, New reporting procedures based on long-term method detection levels and some considerations for interpretations of water-quality data provided by the U.S. Geological Survey National Water Quality Laboratory: U.S. Geological Survey Open-File Report 99–193, 19 p. (Also available at *http://pubs.er.usgs.gov/publication/ofr99193*.)

Erickson, M.L., 2012, Steroidal hormones and other endocrine active compounds in shallow groundwater in nonagricultural areas of Minnesota—Study design, methods, and data, 2009–10: U.S. Geological Survey Data Series 663, 9 p., last accessed December 26, 2013, at *http://pubs.usgs.gov/ds/663/*.

Erickson, M.L., Langer, S.K., Roth, J.L., and Kroening, S.E., 2014, Contaminants of emerging concern in ambient groundwater in urbanized areas of Minnesota, 2009–12: U.S. Geological Survey Scientific Investigations Report 2014–5096, 38 p., with appendix, *http://dx.doi.org/10.3133/sir20145096*.

Falteisek, Jan, 2013, County Atlas - Regional Assessment Program: Minnesota Department of Natural Resources, accessed May 3, 2013, at *http://www.dnr.state.mn.us/waters/groundwater_section/mapping/index.html*.

Furlong, E.T., Kanagy, C.J., Kanagy, L.K., Coffey, L.J., and Burkhardt, M.R., 2014, Determination of human-use pharmaceuticals in filtered water by direct aqueous injection-high-performance liquid chromoatography/tandem mass spectrometry: U.S. Geological Survey Techniques and Methods, book 5, chap. B10, 49 p., accessed June 13, 2014, at *http://dx.doi.org/10.3133/tm5B10*.

Furlong, E.T., Werner, S.L., Anderson, B.D., and Cahill, J.D., 2008, Determination of human-health pharmaceuticals in filtered water by chemically modified styrene-divinylbenzene resin-based solid-phase extraction and high-performance liquid chromatography/mass spectrometry: U.S. Geological Survey Techniques and Methods, book 5, sec. B, chap. B5, 56 p., accessed June 13, 2014, at *http://pubs.usgs.gov/tm/tm5b5/*.)

Herberer, Thomas, 2002, Occurrence, fate, and removal of pharmaceutical residues in the aquatic environment—A review of recent research data: Toxicology Letters, v. 131, p. 5–17. (Also available at *http://dx.doi.org/10.1016/S0378-4274(02)00041-3*.)

Lee, K.E., Barber, L.B., Furlong, E.T., Cahill, J.D., Kolpin, D.W., Meyer, M.T., and Zaugg, S.D., 2004, Presence and distribution of organic wastewater compounds in wastewater, surface, ground, and drinking waters, Minnesota, 2000–02: U.S. Geological Survey Scientific Investigations Report 2004–5138, 47 p. (Also available at *http://pubs.usgs.gov/sir/2004/5138/*.)

Lee, K.E., Schoenfuss, H.L., Jahns, N.D., Brown, G.K., and Barber, L.B., 2008, Alkylphenols, other endocrine-active chemicals, and fish responses in three streams in Minnesota—Study design and data, February–September 2007: U.S. Geological Survey Data Series 405, 44 p., accessed November 30, 2011, at *http://pubs.usgs.gov/ds/405/*.

Lee, K.E., Yaeger, C.S., Jahns, N.D., and Schoenfuss, H.L., 2008, Occurrence of endocrine active compounds and biological responses in the Mississippi River—Study design and data, June through August 2006: U.S. Geological Survey Data Series 368, 27 p., accessed November 30, 2011, at *http://pubs.usgs.gov/ds/368/*.

Meyer, M.T., Lee, E.A., Ferrell, G.M., Bumgarner, J.E., and Varns, Jerry, 2007, Evaluation of offline tandem and online solid-phase extraction with liquid chromatography/electrospray ionization-mass spectrometry for analysis of antibiotics in ambient water and comparison to an independent method: U.S. Geological Survey Scientific Investigations Report 2007–5021, 28 p. (Also available at *http://pubs.usgs.gov/sir/2007/5021/*.)

Minnesota Pollution Control Agency, 2009, MPCA's ambient ground water monitoring strategy proposal for the Clean Water Land and Legacy Amendment: 2 p., accessed December 1, 2011, at *http://www.pca.state.mn.us/index.php/view-document.html?gid=3883*.

Ternes, T.A., Meisenheimer, Martin, McDowell, Derek, Sacher, Frank, Branch, H.J., Hsiate-Gulde, Brigette, Preuss, Gudrun, Wilme, Uwe, and Zulei-Seibert, Ninette, 2002, Removal of pharmaceuticals during drinking water treatment: Environmental Science and Technology, v. 36, no. 17, p. 3,855–3,863. (Also available at *http://dx.doi.org/10.1021/es015757k*.)

Tornes, L.H., Stark, J.R., Hoard, C.J., and Smith, E.A., 2007, Anthropogenic organic compounds in ground water and finished water of community water systems in the Greater Twin Cities metropolitan area, Minnesota and Wisconsin, 2004–05: U.S. Geological Survey Scientific Investigations Report 2007–5273, 42 p. (Also available at *http://pubs.usgs.gov/sir/2007/5273/*.)

U.S. Geological Survey, 2011, Application of the result-level 'v' value qualifier code and 'E' remark code to selected organic results reported by the National Water Quality Laboratory (NWQL): U.S. Geological Survey Office of Water Quality Technical Memorandum 2012.01, accessed June 13, 2014, at *http://water.usgs.gov/admin/memo/QW/qw12.01.pdf*.

U.S. Geological Survey, 2014, National Water Information System—USGS water-quality data for Minnesota: last accessed March 14, 2014, at *http://waterdata.usgs.gov/mn/nwis/qw*.

U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1–A9. (Also available at *http://pubs.water.usgs.gov/twri9A*.)

Wilde, F.D., Radtke, D.B., Gibs, Jacob, and Iwatsubo, R.T., eds., 2004, Processing of water samples (ver. 2.2): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A5, accessed November 29, 2011, at *http://pubs.water.usgs.gov/twri9A5/*.

Zaugg, S.D., Smith, S.G., Schroeder, M.P., Barber, L.B., and Burkhardt, M.R., 2006, Methods of analysis by the U.S. 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 2001–4186, 37 p. (Also available at *http://pubs.usgs.gov/wri/wri014186/*.)

Zogorski, J.S., Carter, J.M., Ivahnenko, Tamara, Lapham, W.W., Moran, M.J., Rowe, B.L., Squillace, P.J., and Toccalino, P.L., 2006, The quality of our Nation's waters—Volatile organic compounds in the Nation's ground water and drinking-water supply wells: U.S. Geological Survey Circular 1292, 101 p. (Also available at *http://pubs.usgs.gov/circ/circ1292/*.)

Publishing support provided by:
Rolla Publishing Service Center

For more information concerning this publication, contact:
Director, USGS Minnesota Water Science Center
2280 Woodale Drive
Mounds View, Minnesota 55112
(763) 783–3100

Or visit the Minnesota Water Science Center Web site at:
http://mn.water.usgs.gov/

ISSN 2327-638X (online)
http://dx.doi.org/10.3133/ds878