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Water Quality and Possible Sources of Nitrate in the Cimarron Terrace Aquifer, Oklahoma, 2003

Scientific Investigations Report 2004–5221

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

Cover: Photos, clockwise from upper left:

Tractor and plow near Dover, Oklahoma. Photo by Jason R. Masoner, July 2003.

A well owner, right, helps USGS staff locate a well near Waynoka, Oklahoma. Photo by S. Jerrod Smith, July 2003.

Center-pivot irrigation of corn near Ringwood, Oklahoma. Photo by S. Jerrod Smith, July 2003.

Grain silos near Ringwood, Oklahoma. Photo by Jason R. Masoner, July 2003.

Center photo:

Horses near Cleo Springs, Oklahoma, with petroleum pump jack and storage tanks, background. Photo by Shana L. Mashburn, July 2003.
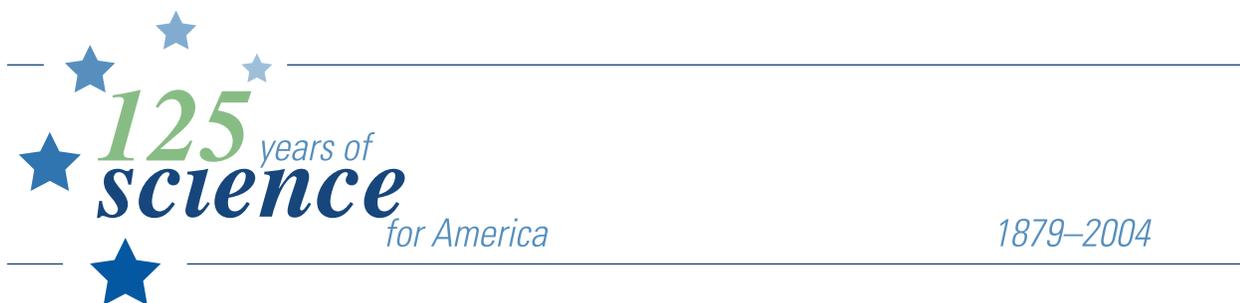
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By Jason R. Masoner and Shana L. Mashburn

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

U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
Charles G. Groat, Director

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Conversion Factors and Datum

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
kilometer (km)	0.6214	mile (mi)
Area		
acre	4,047	square meter (m^2)
Volume		
gallon (gal)	3,785	milliliter (mL)
cubic inch (in^3)	0.01639	liter (L)
liter (L)	0.2642	gallon (gal)
Mass		
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F = (1.8 × °C) + 32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C = (°F - 32) / 1.8

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88).

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

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (μg/L).

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Abstract

Water from the Cimarron terrace aquifer in northwest Oklahoma commonly has nitrate concentrations that exceed the maximum contaminant level of 10 milligrams per liter of nitrite plus nitrate as nitrogen (referred to as nitrate) set by the U.S. Environmental Protection Agency for public drinking water supplies. Starting in July 2003, the U.S. Geological Survey, in cooperation with the Oklahoma Department of Environmental Quality, conducted a study in the Cimarron terrace aquifer to assess the water quality and possible sources of nitrate. A qualitative and quantitative approach based on multiple lines of evidence from chemical analysis of nitrate, nitrogen isotopes in nitrate, pesticides (indicative of cropland fertilizer application), and wastewater compounds (indicative of animal or human wastewater) were used to indicate possible sources of nitrate in the Cimarron terrace aquifer.

Nitrate was detected in 44 of 45 ground-water samples and had the greatest median concentration (8.03 milligrams per liter) of any nutrient analyzed. Nitrate concentrations ranged from <0.06 to 31.8 milligrams per liter. Seventeen samples had nitrate concentrations exceeding the maximum contaminant level of 10 milligrams per liter. Nitrate concentrations in agricultural areas were significantly greater than nitrate concentrations in grassland areas.

Pesticides were detected in 15 of 45 ground-water samples. Atrazine and deethylatrazine, a metabolite of atrazine, were detected most frequently. Deethylatrazine was detected in water samples from 9 wells and atrazine was detected in samples from 8 wells. Tebuthiuron was detected in water samples from 5 wells; metolachlor was detected in samples from 4 wells; prometon was detected in samples from 4 wells; and alachlor was detected in 1 well. None of the detected pesticide concentrations exceeded the maximum contaminant level or health advisory level set by the U.S. Environmental Protection Agency.

Wastewater compounds were detected in 28 of 45 ground-water samples. Of the 20 wastewater compounds detected, 11 compounds were from household chemicals, 3 compounds were hydrocarbons, 2 compounds were industrial chemicals, 2 compounds were pesticides, 1 compound was of animal source, and 1 compound was a detergent compound. The most frequently detected wastewater compound was phenol, which was detected in 23 wells. N,N-diethyl-meta-toluamide (DEET) was detected in water samples from 5 wells. Benzophenone, ethanol-2-butoxy-phosphate, and tributylphosphate were detected in water samples from 3 wells.

Fertilizer was determined to be the possible source of nitrate in samples from 13 of 45 wells sampled, with $\delta^{15}N$ values ranging from 0.43 to 3.46 permil. The possible source of nitrate for samples from the greatest number of wells (22 wells) was from mixed sources of nitrate from fertilizer, septic or manure, or natural sources. Mixed nitrate sources had $\delta^{15}N$ values ranging from 0.25 to 9.83 permil. Septic or manure was determined as the possible source of nitrate in samples from 2 wells. Natural sources were determined to be the possible source of nitrate in samples from 7 wells, with $\delta^{15}N$ values ranging from –0.83 to 9.44 permil.

Introduction

Water from the Cimarron terrace aquifer in northwestern Oklahoma (fig. 1) commonly has nitrate concentrations that exceed the maximum contaminant level (MCL) of 10 milligrams per liter (mg/L) of nitrite plus nitrate as nitrogen (referred to as nitrate in subsequent discussions due to low nitrite concentrations) set by the U.S. Environmental Protection Agency (USEPA) for public drinking water supplies (U.S. Environmental Protection Agency, 2002a). Fifty of 161 ground-water samples (31 percent) collected from the Cimarron terrace aquifer from 1985 through 1993 had nitrate concentrations that exceeded the MCL (Becker, 1994). Eighty percent of ground-water samples collected in the Cimarron terrace aquifer at or near confined animal feeding operations (CAFOs) in 2001 had nitrate concentrations exceeding the MCL for nitrate (Becker and others, 2002). Consumption of nitrate concentrations greater than 4 mg/L in water from community wells has been associated with an increased risk of cancer (Ward and others, 1996). Elevated nitrate concentrations also have been linked to hypertension (Malberg and others, 1978), diabetes (Parslow and others, 1997), methemoglobinemia (blue-baby syndrome), and possible birth defects (National Governors' Association, 1991).

The Cimarron terrace aquifer is a shallow, unconfined aquifer that may have moderate to high vulnerability to contamination from land-use activities (Osborn and others, 1998, Appendix B, pg. B-9). Land uses overlying the Cimarron terrace aquifer include raising of livestock and production of feed-
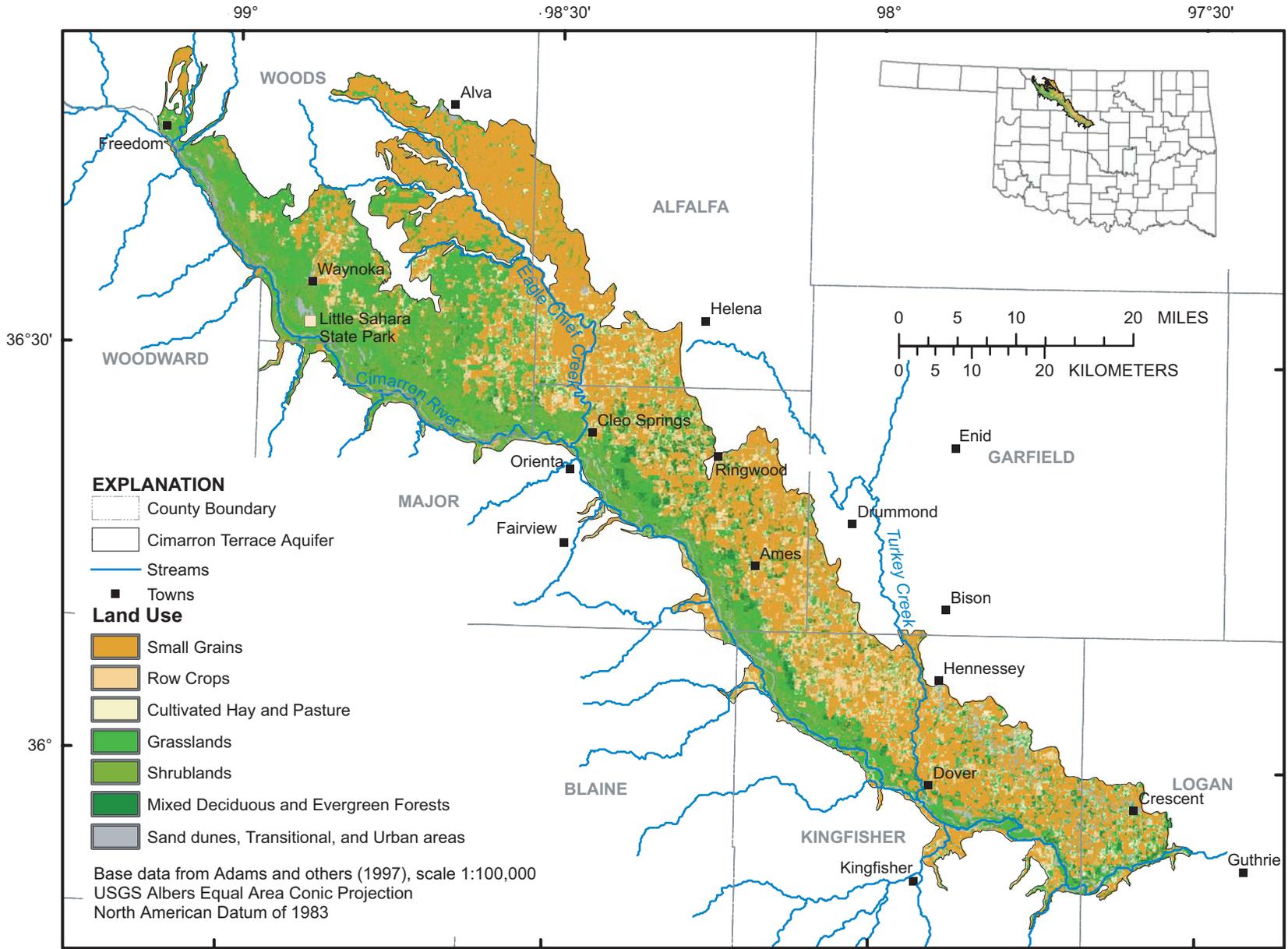
Figure 1. Location of study area and major land-use determinations from the 1992 National Land Cover Dataset overlying the Cimarron terrace aquifer (U.S. Geological Survey, 2002).

grain crops such as wheat, corn, and soybeans (Bloyd and Shepler, 2001). Agricultural activities are commonly associated with elevated nitrate concentrations in ground water, particularly where row crops are irrigated (Mueller and Helsel, 1996).

Starting in July 2003, the U.S. Geological Survey, in cooperation with the Oklahoma Department of Environmental Quality, conducted a study in the Cimarron terrace aquifer to assess the water quality, land uses, and possible sources of nitrate. An understanding of the water quality and possible sources of nitrate in the Cimarron terrace aquifer will help water-resources managers and local residents better protect the water resources of the Cimarron terrace aquifer.

Purpose and Scope

The purpose of this report is to describe the water quality and possible sources of nitrate in the Cimarron terrace aquifer. Forty-five ground-water wells in the Cimarron terrace aquifer were randomly selected. Wells were grouped into two land-use categories, areas of agricultural use, referred to as agricultural areas, and grassland areas not disturbed by agriculture, referred to as grassland areas. Wells were sampled for nutrients, nitrogen isotope ratios in nitrate, pesticides, and wastewater compounds during July and August 2003.

Concentrations of nutrients, nitrogen isotope ratios in nitrate, pesticides, and wastewater compounds sampled from wells in agricultural and grassland areas were statistically and graphically analyzed. A qualitative and quantitative approach based on multiple lines of evidence from chemical analysis of nitrate, nitrogen isotopes in nitrate, commonly applied pesticides (indicative of fertilizer application), and wastewater compounds (indicative of animal or human waste) was used to indicate possible sources of nitrate in the Cimarron terrace aquifer.

Description of Study Area

The study area consists of 1,305 square miles (mi^2) and includes Quaternary-age terrace deposits located north of the Cimarron River floodplain extending from Freedom to Guthrie in northwest Oklahoma (fig. 1). The Cimarron terrace aquifer lies within the Cimarron River drainage basin, which has a drainage area of approximately 18,927 mi^2 (Adams and Bergman, 1996). Average annual precipitation in the study area ranges from 26 inches in the northwest to 32 inches in the southeast (Johnson and Duchon, 1995).

Ground water in the Cimarron terrace aquifer is an important economic resource for northwest Oklahoma. Approximately 63 percent of ground-water withdrawals in Alfalfa, Garfield, Kingfisher, Major, and Woods Counties in 2000 were withdrawn from the Cimarron terrace aquifer. The Cimarron terrace aquifer produced over 4.27 billion gallons of water for public supply in 2000. More than 4.40 billion gallons of water from the aquifer were used for irrigation and livestock purposes in 2000 (Phyllis Robertson, Oklahoma Water Resources Board, written commun., 2003).

Hydrogeology

The Cimarron terrace aquifer is underlain by Permian-age units that crop out along the study area boundary (Adams and Bergman, 1996). Cimarron terrace sediments were originally deposited by the southward migration of the ancestral Cimarron River (Adams and Bergman, 1996). Since deposition, these terrace sediments have been reworked by water and wind that creates sand dunes. The terrace deposits consist of interfingered lenses of clay, sandy clay, and cross-bedded poorly-sorted sand and gravel and range from 0 to 120 feet (ft) (Adams and Bergman, 1996). The Cimarron terrace sediments are composed of quartz, feldspar, ferruginous shale, and quartzitic sandstone (Reed and others, 1952). Most dunes in the study area are stabilized by vegetation. However, a field of large, active dunes located within and around Little Sahara State Park, 4 miles south of Waynoka (fig. 1), are unvegetated and can reach heights as high as 70 ft (Adams and Bergman, 1996).

Ground-water flow in the Cimarron terrace aquifer is generally southeast to southwest flowing towards the Cimarron River, except where flow direction is influenced by perennial tributaries to the Cimarron River (Adams and Bergman, 1996). Potentiometric surface maps shown in Adams and Bergman (pg, 20-22, 1996) indicate that surface water is not a major source of recharge to the aquifer. The two greatest sources of recharge to the Cimarron terrace aquifer are infiltration of precipitation and irrigation return flow (Adams and Bergman, 1996).

Land Use

Agriculture is the predominant land use in the study area (fig. 1). Agriculture in this report refers to areas that have been planted or are intensely managed for the production of livestock for food. Agricultural land use overlying the aquifer consists of 41.4 percent small grains, 7.0 percent row crops, and 6.3 percent cultivated hay and pasture (fig. 2) (U.S. Geological Survey, 2002). Additional land-use types overlying the aquifer are grasslands (27.1 percent), shrublands (11.0 percent), mixed deciduous and evergreen forest (4.4 percent), and other less prevalent land uses (2.8 percent). The development of modern irrigation systems has facilitated an increase in the cultivation of wheat, corn, and oats in the Cimarron terrace aquifer (U.S. Department of Agriculture, 1996). Numerous CAFOs have been established since 1994 overlying the Cimarron terrace aquifer (Becker and others, 2002; Oklahoma Department of Environmental Quality, 2003). Oil and gas production and related petroleum service oriented companies are the predominant industry in the Cimarron terrace aquifer area (Mark Gregory, Oklahoma State University, written commun., 1988).

Historical Pesticide Use

According to pesticide-use estimates for counties included in the study area, dimethoate, 2,4-D, bromoxynil, and ethyl-par-
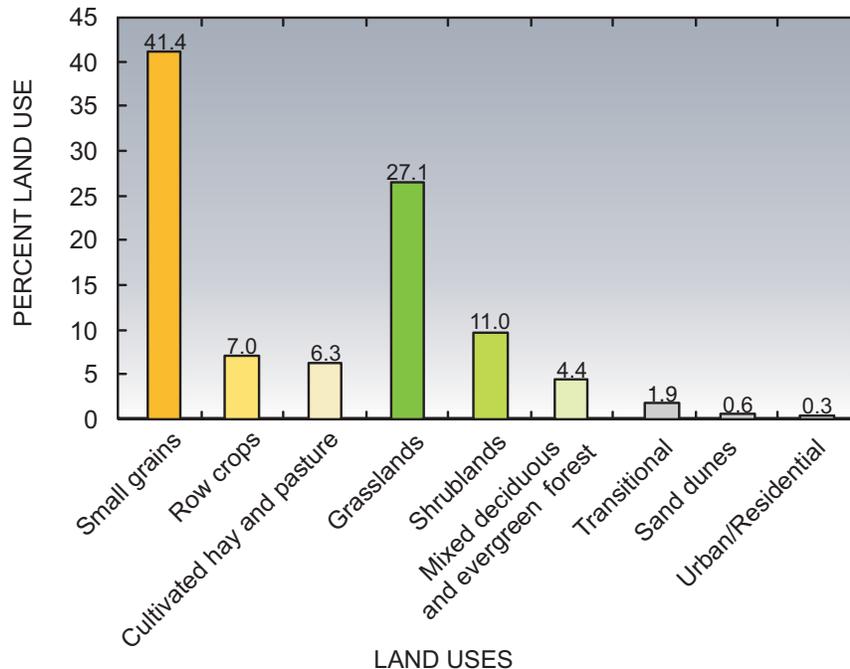
Figure 2. Land-use proportions in the study area overlying the Cimarron terrace aquifer (U.S. Geological Survey, 2002).

athion were the most abundantly applied pesticide compounds from 1992 to 1995 (G.P. Thelin, U.S. Geological Survey, written commun., 2001). Dimethoate and ethyl-parathion are insecticides commonly applied on wheat, alfalfa, corn, sorghum, cotton, sunflowers, soybeans, barley, oats, and rye (Thelin and Gianessi, 2000). Bromoxynil and 2,4-D are herbicides commonly applied on common forage crops, wheat, corn, barley, sorghum, and oats (G.P. Thelin, U.S. Geological Survey, written commun., 2001). For counties included in the study area, Garfield County had the greatest total pesticide use, followed by pesticide use in Alfalfa and Woods Counties (table 1).

Acknowledgments

The authors thank the homeowners and landowners who allowed access to domestic and stock wells; to the cities of Alva, Enid (located east of study area), and Waynoka; and the Major County Rural Water District for allowing access to public water-supply wells. Additional thanks to U.S. Geological Survey employees and volunteers, Martin Schneider, Chris Neel, Jerrod Smith, and Martyn McMurphy, who assisted in data collection and to Mike Sughru who helped to combine Geographic Information System (GIS) data bases.

Methods

This section describes the methodology used to select sampling locations within the Cimarron terrace aquifer. Information about the techniques of ground-water sampling, chemical analysis, and statistical analysis also are provided.

Selection of Sampling Sites

Well-location data stored in the U.S. Geological Survey Ground Water Information System (GWSI) and the Oklahoma Water Resources Board (OWRB) data bases were combined into a single GIS data set. Land-use data from the National Land Cover Dataset (NLCD) (U.S. Geological Survey, 2002) were used to categorize land uses overlying the Cimarron terrace aquifer into two general categories, agricultural areas and grassland areas, because those were the most predominant land uses (fig. 3). NLCD land-use categories small grains, row crop, and cultivated pasture or hay were grouped into one land-use category, defined agricultural. NLCD land-use categories grassland, shrubland, forested areas, sand dunes, and transitional areas were grouped into one land-use category, defined in this report as grasslands. While sampling sites were grouped into two general categories, most of the sampled wells were located in rural homesteads, which could be considered a separate land-use category within the larger more general NLCD land-use categories.

Table 1. Pesticide-use estimates for the 30-most commonly applied pesticide compounds for counties included in the Cimarron terrace aquifer, 1992-1995, derived from county pesticide-use information (G.P. Thelin, U.S. Geological Survey, written commun., 2001)

[all units are in pounds of active ingredient; -, indicates pesticide was not applied in county or the amount applied was less than amount needed to be in the top 30 most applied]

Pesticides	Alfalfa	Garfield	Kingfisher	Logan	Major	Woods
Dimethoate	52,235	73,892	44,666	16,415	32,128	39,944
2,4-D	21,585	30,651	25,360	18,369	24,527	38,484
Bromoxynil	19,212	27,525	16,581	6,073	11,777	14,836
Ethyl-parathion	20,354	13,518	9,763	4,681	8,326	9,131
Methyl-parathion	18,422	8,841	7,159	3,849	6,610	6,821
Permethrin	4,470	4,626	2,973	1,211	2,278	2,701
MCPA	2,548	3,628	2,191	842	1,633	1,951
Dicamba	2,145	3,070	2,738	2,201	2,774	4,404
Glyphosate	1,995	2,845	1,724	641	1,304	1,541
Chlorpyrifos	2,986	2,574	1,718	806	1,571	1,585
Malathion	5,437	1,356	1,486	1,009	1,613	1,485
Carbofuran	5,280	1,326	1,463	973	1,710	1,452
Tebuthiuron	887	1,217	1,198	-	1,389	2,468
Chlorsulfuron	817	1,170	705	258	502	631
Picloram	455	639	637	576	709	1,219
Propiconazole	272	390	234	87	167	210
Carbaryl	1,191	296	324	290	356	323
Atrazine	420	286	249	362	1,322	336
Hexazinone	989	247	270	180	293	270
Triasulfuron	148	212	128	-	91	115
2,4-DB	791	197	216	144	235	216
Metolachlor	209	142	147	180	654	168
Metsulfuron	-	135	81	-	58	73
Methomyl	201	55	-	78	83	61
Alachlor	-	43	65	55	273	51
Chlorothalonil	160	-	-	609	225	6
Terbufos	-	-	-	-	246	29
Disulfoton	-	-	112	-	677	14
Fonofos	-	-	63	-	89	-
Cyanazine	-	-	44	-	273	-
Total	163,209	178,881	122,295	59,889	103,893	130,525
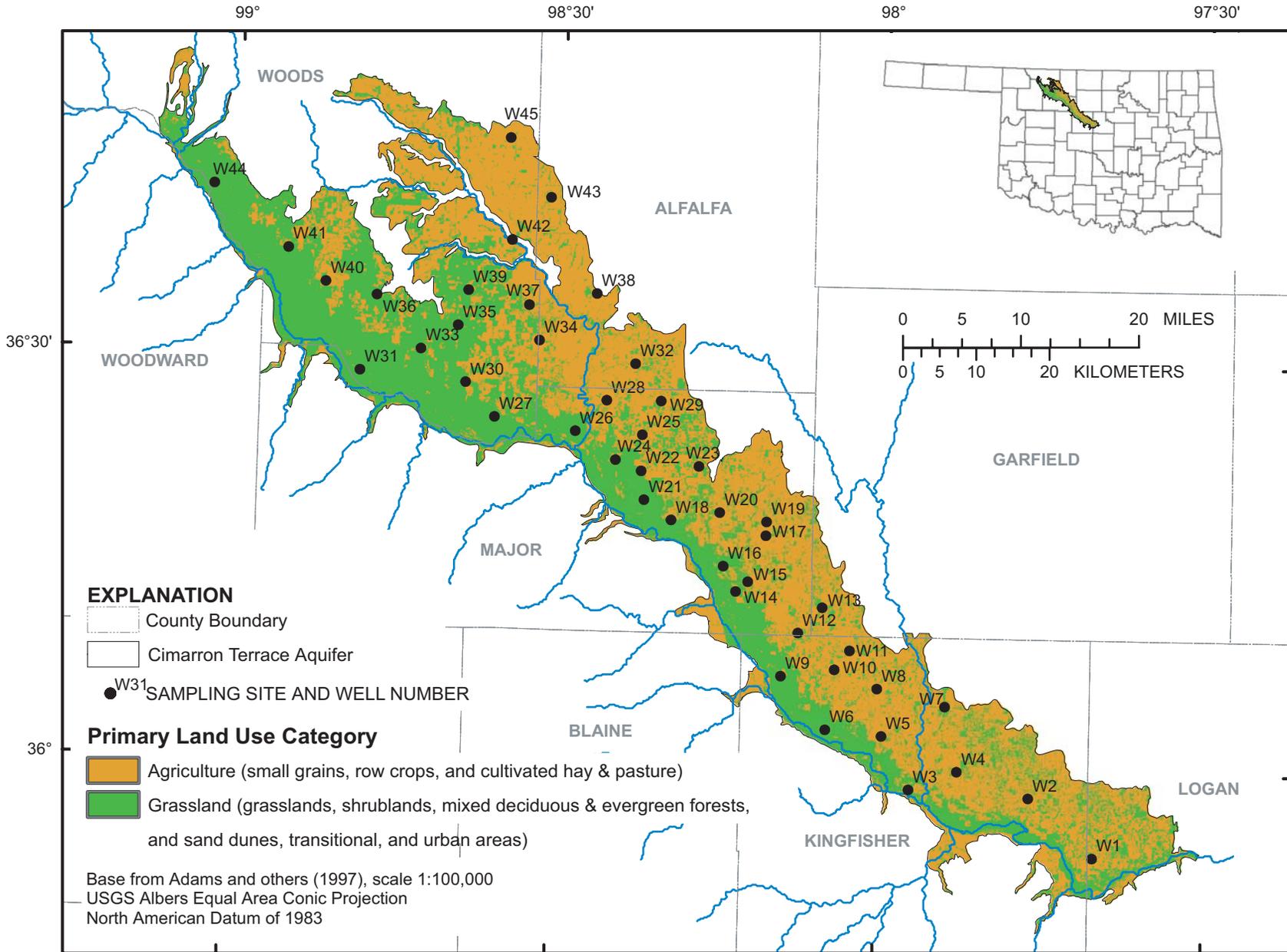
Figure 3. Locations of wells and reclassification of National Land Cover Dataset into two general land-use categories (U.S. Geological Survey, 2002).

Forty-five ground-water sampling locations were selected randomly (table 2) using a computerized stratified random selection algorithm (Scott, 1990). A modification to a simple random selection of wells was implemented to ensure an equal-area distribution of selected wells in the agricultural and grass-land areas. Agricultural and grassland areas were divided into 10-kilometer grid cells and one or more wells were randomly selected within each grid cell. Ultimately, 28 wells were selected in the agricultural areas and 17 wells were selected in the grassland areas (fig. 3). Wells that overlaid an agriculture land use were designated an agricultural well, and wells that overlaid a grassland land use were designated a grassland well. More wells were selected in agricultural areas, because the majority land use was agriculture. The owners of the selected wells were contacted to gain permission to include their well in the study. There were instances where permission could not be obtained. In those cases, a replacement well was located in the same or adjacent cell. Two of the 45 wells, W9 and W31, were selected to represent background nitrate concentrations in the study area. These wells were located in remote grassland areas more than 6 miles away from agricultural activities or septic systems. W9 is a well located in a remote area in Kingfisher County near the Cimarron River. W31 is a water-supply well used by the Oklahoma Department of Transportation to supply water needed for temporary road maintenance and construction purposes located in Major County. Although W31 was not near any major nutrient sources, a 5-acre area starting 20 ft east of the well was used as a staging ground for heavy-duty and light-duty vehicles used for road construction.

Ground-Water Sampling and Analysis Methods

Fifty-two water samples were collected from 45 wells in the Cimarron terrace aquifer in July and August 2003. Seven samples were collected for quality-control purposes, which are described in Appendix 1. Field measurements of specific conductance, pH, water temperature, and dissolved oxygen were recorded every 3 minutes with a calibrated multi-probe meter in a sealed flow-through cell to monitor changes in water quality while purging. After three well volumes had been purged and field measurements had stabilized, samples were collected using U.S. Geological Survey protocols (Wilde and others, 1998, Table 6.0-1, pg. 6).

Nutrients, nitrogen isotopes, pesticides, and wastewater compounds were analyzed from samples collected mostly from domestic or public-supply wells equipped with submersible pumps. Thirty-one of the 45 wells were domestic wells, 10 were public water-supply wells, 3 were irrigation wells, and 1 was a low-volume general water-supply well leased by the Oklahoma Department of Transportation. Samples were collected through Teflon tubing attached to spigots at or near the wellhead. All samples were collected inside a sealed preservation chamber to limit exposure from potential sources of contamination in the atmosphere (Horowitz and others, 1994). Water for nutrient compounds was filtered in the field through a 0.45-micron disposable capsule filter and collected in 125-milliliter brown polyethylene bottles. Water for nitrogen isotope samples and wastewater compounds was not filtered. Samples for nitrogen isotopes were collected in 1-liter polyethylene bottles with poly-seal caps. Water for pesticide compounds was filtered in the field using an aluminum plate-filter assembly with a glass-fiber filter with a 0.7-micrometer (μm) nominal pore size, baked at 450 degrees Celsius, collected in 1-liter baked amber glass bottles sealed with Teflon-lined caps. Samples of wastewater compounds were collected in 1-liter baked amber glass bottles sealed with Teflon-lined caps. All samples upon collection at each well were immediately submersed in ice and chilled to less than 4 degrees Celsius. Nutrients, pesticide, and wastewater compound samples were shipped submersed in ice to the laboratory for analysis within 48 hours of sample collection. Nitrogen isotope samples were frozen within 24 hours of sample collection and were shipped to the laboratory 3 weeks later, after all samples had been collected.

Water samples collected during this study were sent to two laboratories. Samples were analyzed at the U.S. Geological Survey National Water Quality Laboratory (NWQL) in Lakewood, Colorado, for 6 nutrients (table 3), 52 pesticides (table 4), and 72 wastewater compounds (table 5). Nitrogen-isotope samples were analyzed at the University of Nebraska Water Sciences Laboratory in Lincoln, Nebraska.

Nutrients were analyzed according to methods presented in Fishman (1993). Pesticides were extracted at the NWQL by solid-phase extraction and were analyzed by selected ion monitoring with gas chromatography/mass spectrometry (Zaugg and others, 1995). Wastewater compounds were extracted at the NWQL by continuous liquid-liquid extraction using methylene chloride solvent and were analyzed by full scan capillary-column gas chromatography/mass spectrometry (Steven Zaugg, U.S. Geological Survey, written commun., 2003).

Preparation for nitrogen isotope analysis involves steam distillation, and a quantitative conversion to nitrogen gas that is purified and collected on a high vacuum preparation system. Nitrogen isotope analysis was done using isotope ratio mass spectrometer (Daniel Snow, University of Nebraska Water Sciences Laboratory, written commun., 2003).

There are instances when a concentration value is reported as an estimated concentration (E). An estimated concentration value has been confirmed during the laboratory analysis, but the actual concentration is reported as an estimate for one or more of the following reasons: (1) the calculated concentration is greater than or equal to the long-term method detection level (LT-MDL) but less than the lowest calibration standard (LS), or (2) the calculated concentration is greater than or equal to the LT-MDL but less than the laboratory reporting level (LRL) (Childress and others, 1999). The unquantified result of "M" is preferable in instances of very low concentrations below the reporting level when material has been detected and verified.

Table 2. Location and well information for 45 wells sampled in the Cimarron terrace aquifer, July and August 2003

[-, not measured, well casing inaccessible; ID, identification number]

Well number (fig. 3)	U.S. Geological Survey station ID	County	Depth of well (feet)	Depth to water (feet)	Date measured	Land use
W1	355351097400301	Logan	57.3	25.2	08/07/03	Agriculture
W2	355812097460001	Kingfisher	61.5	33.7	07/18/03	Agriculture
W3	355842097570001	Kingfisher	29.8	13.5	07/16/03	Grassland
W4	360004097523601	Kingfisher	70.0	15.3	07/15/03	Agriculture
W5	360236097593501	Kingfisher	43.0	22.9	07/15/03	Agriculture
W6	360300098044601	Kingfisher	52.0	11.9	07/15/03	Grassland
W7	360451097534801	Kingfisher	98.0	37.8	07/11/03	Agriculture
W8	360605098000401	Kingfisher	58.0	18.7	07/15/03	Agriculture
W9	360653098085601	Kingfisher	-	-	07/16/03	Grassland
W10	360726098040101	Kingfisher	97.0	11.6	07/11/03	Agriculture
W11	360851098023901	Kingfisher	108	12.9	07/08/03	Agriculture
W12	361005098072601	Major	62.0	20.1	07/16/03	Agriculture
W13	361159098051501	Garfield	109	12.8	07/08/03	Agriculture
W14	361303098131501	Major	51.1	15.2	07/10/03	Grassland
W15	361347098120901	Major	65.0	9.80	07/10/03	Agriculture
W16	361454098142601	Major	65.0	25.0	07/09/03	Grassland
W17	361712098103401	Major	108	33.6	07/08/03	Agriculture
W18	361812098192101	Major	60.0	9.50	07/09/03	Agriculture
W19	361813098103201	Major	76.8	21.3	07/08/03	Agriculture
W20	361850098145201	Major	-	-	07/10/03	Agriculture
W21	361939098215301	Major	60.0	42.2	07/09/03	Grassland
W22	362146098215401	Major	65.0	40.1	07/16/03	Agriculture
W23	362212098165201	Major	55.0	21.9	07/16/03	Agriculture
W24	362233098243601	Major	40.6	28.6	08/07/03	Grassland
W25	362426098221001	Major	65.1	34.8	07/16/03	Agriculture
W26	362435098282201	Major	52.6	24.2	07/09/03	Grassland
W27	362530098355201	Woods	-	9.70	07/03/03	Grassland
W28	362655098253101	Major	50.0	19.6	07/17/03	Agriculture
W29	362657098203101	Major	69.4	25.4	08/08/03	Agriculture
W30	362800098383701	Woods	87.5	30.4	07/02/03	Grassland
W31	362842098482401	Woods	26.4	9.70	07/02/03	Grassland
W32	362939098225701	Alfalfa	75.0	35.0	07/17/03	Agriculture
W33	363023098424801	Woods	60.0	16.1	07/16/03	Grassland
W34	363113098315201	Alfalfa	33.0	7.90	07/11/03	Agriculture
W35	363211098392401	Woods	59.8	6.60	07/03/03	Grassland
W36	363330098470001	Woods	29.0	6.60	07/08/03	Grassland
W37	363348098325401	Woods	40.4	6.30	07/09/03	Agriculture
W38	363445098264001	Alfalfa	48.0	16.4	07/23/03	Agriculture

Table 2. Location and well information for 45 wells sampled in the Cimarron terrace aquifer, July and August 2003—Continued

[-, not measured, well casing inaccessible; ID, identification number]

Well number (fig. 3)	U.S. Geological Survey station ID	County	Depth of well (feet)	Depth to water (feet)	Date measured	Land use
W39	363452098384301	Woods	50.0	4.50	07/08/03	Grassland
W40	363510098514601	Woods	70.0	17.0	07/02/03	Agriculture
W41	363735098551801	Woods	40.0	12.0	07/11/03	Grassland
W42	363834098343801	Woods	70.0	18.0	07/09/03	Agriculture
W43	364519098311701	Alfalfa	32.0	11.9	07/09/03	Agriculture
W44	364258099000801	Woods	30.0	6.00	07/08/03	Grassland
W45	364605098350001	Woods	89.0	19.5	07/11/03	Agriculture

Table 3. Nutrients and interim reporting levels as of 2003, U.S. Geological Survey National Water Quality Laboratory Schedule 2752

[method reference: Fishman (1993); mg/L, milligrams per liter]

Constituent	Interim reporting levels	Unit
Nitrogen, nitrite	0.008	mg/L
Nitrogen, nitrite plus nitrate[1]	0.060	mg/L
Nitrogen, ammonia	0.04	mg/L
Nitrogen, ammonia plus organic nitrogen	0.10	mg/L
Phosphorus	0.004	mg/L
Phosphorus, orthophosphate	0.018	mg/L

[1]Referred to as nitrate in this report

Table 4. Pesticides and reporting levels as of 2003, U.S. Geological Survey National Water Quality Laboratory Schedule 2001

[method reference: Zaugg and others (1995); µg/L, micrograms per liter; Irl, interim reporting level; Mrl, minimum reporting level]

Pesticide	Reporting levels	Unit	Reporting level type	Use
2,6-Diethylaniline	0.006	µg/L	Irl	Fungicide
Acetochlor	0.006	µg/L	Irl	Herbicide
Alachlor	0.005	µg/L	Irl	Herbicide
alpha-HCH	0.005	µg/L	Mrl	Insecticide
Atrazine	0.007	µg/L	Irl	Herbicide
Azinphos-methyl	0.05	µg/L	Irl	Insecticide
Benfluralin	0.01	µg/L	Irl	Herbicide
Butylate	0.002	µg/L	Irl	Herbicide
Carbaryl	0.041	µg/L	Irl	Insecticide
Carbofuran	0.02	µg/L	Irl	Insecticide
Chlorpyrifos	0.005	µg/L	Irl	Insecticide
cis-Permethrin	0.006	µg/L	Irl	Insecticide
Cyanazine	0.018	µg/L	Irl	Herbicide
Dacthal	0.003	µg/L	Irl	Herbicide
Deethylatrazine (metabolite)	0.006	µg/L	Irl	Herbicide
Desulfinylfipronil	0.004	µg/L	Irl	Insecticide
Desulfinylfipronil amide	0.009	µg/L	Irl	Insecticide
Diazinon	0.005	µg/L	Mrl	Insecticide
Dieldrin	0.005	µg/L	Irl	Insecticide
Disulfoton	0.021	µg/L	Irl	Insecticide
EPTC	0.002	µg/L	Irl	Herbicide
Ethalfluralin	0.009	µg/L	Irl	Herbicide
Ethoprophos	0.005	µg/L	Irl	Insecticide
Fipronil	0.007	µg/L	Irl	Insecticide
Fipronil sulfide	0.005	µg/L	Irl	Insecticide
Fipronil sulfone	0.005	µg/L	Irl	Insecticide
Fonofos	0.003	µg/L	Irl	Insecticide
Lindane	0.004	µg/L	Irl	Insecticide
Linuron	0.035	µg/L	Irl	Herbicide
Malathion	0.027	µg/L	Irl	Insecticide

Table 4. Pesticides and reporting levels as of 2003, U.S. Geological Survey National Water Quality Laboratory Schedule 2001—Continued

[method reference: Zaugg and others (1995); µg/L, micrograms per liter; Irl, interim reporting level; Mrl, minimum reporting level]

Pesticide	Reporting levels	Unit	Reporting level type	Use
Metolachlor	0.013	µg/L	Irl	Herbicide
Metribuzin	0.006	µg/L	Irl	Herbicide
Molinate	0.002	µg/L	Irl	Herbicide
Napropamide	0.007	µg/L	Irl	Herbicide
p,p'-DDE	0.003	µg/L	Irl	Insecticide
Parathion	0.01	µg/L	Irl	Insecticide
Parathion-methyl	0.006	µg/L	Irl	Insecticide
Pebulate	0.004	µg/L	Irl	Herbicide
Pendimethalin	0.022	µg/L	Irl	Herbicide
Phorate	0.011	µg/L	Irl	Insecticide
Prometon	0.015	µg/L	Irl	Herbicide
Propachlor	0.025	µg/L	Irl	Herbicide
Propanil	0.011	µg/L	Irl	Herbicide
Propargite	0.023	µg/L	Irl	Insecticide
Propyzamide	0.004	µg/L	Irl	Herbicide
Simazine	0.005	µg/L	Irl	Herbicide
Tebuthiuron	0.016	µg/L	Irl	Herbicide
Terbacil	0.034	µg/L	Irl	Herbicide
Terbufos	0.017	µg/L	Irl	Insecticide
Thiobencarb	0.005	µg/L	Irl	Herbicide
Tri-allate	0.002	µg/L	Irl	Herbicide
Trifluralin	0.009	µg/L	Irl	Herbicide

Table 5. Wastewater compounds and minimum reporting levels as of 2003, U.S. Geological Survey National Water Quality Laboratory custom lab code 8033

[method reference: Steven Zaugg, U.S. Geological Survey, written commun., 2003; µg/L, micrograms per liter; %, percent; >, greater than; UV, ultraviolet]

Wastewater compounds	Minimum reporting level	Unit	Effluent categories	Use
1,4-Dichlorobenzene	0.5	µg/L	Household	Moth repellent, fumigant, deodorant
17-beta-Estradiol	5	µg/L	Animal	Estrogen replacement therapy, estrogen metabolite
1-Methylnaphthalene	0.5	µg/L	Hydrocarbon	2-5% of gasoline, diesel fuel, or crude oil
2,6-Dimethylnaphthalene	0.5	µg/L	Hydrocarbon	Present in diesel/kerosene (trace in gasoline)
2-Methylnaphthalene	0.5	µg/L	Hydrocarbon	2-5% of gasoline, diesel fuel, or crude oil
3,4-dichlorophenyl isocyanate	1	µg/L	Industrial	Dyes
3-beta-Coprostanol	2	µg/L	Animal	Carnivore fecal indicator
3-tert-butyl-4-hydroxy anisole (BHA)	5	µg/L	Household	Antioxidant, general preservative
4-Cumylphenol	1	µg/L	Detergent	Nonionic detergent metabolite
4-n-Octylphenol	1	µg/L	Detergent	Nonionic detergent metabolite
4-tert-Octylphenol	1	µg/L	Detergent	Nonionic detergent metabolite
5-Methyl-1H-benzotriazole	2	µg/L	Industrial	Antioxidant in antifreeze and deicers
Acetophenone	0.5	µg/L	Household	Fragrance in detergent and tobacco, flavor in beverages
Acetyl hexamethyl tetrahydronaphthalene (AHTN)	0.5	µg/L	Household	Musk fragrance
Anthracene	0.5	µg/L	Hydrocarbon	Wood preservative, component of tar, diesel, or crude oil
Anthraquinone	0.5	µg/L	Household	Manufacture dye/textiles, seed treatment, bird repellent
Benzo[a]pyrene	0.5	µg/L	Household	Used in cancer research
Benzophenone	0.5	µg/L	Household	Fixative for perfumes and soaps
Beta-Sitosterol	2	µg/L	Animal	Plant sterol
beta-Stigmastanol	2	µg/L	Animal	Plant sterol
Bisphenol A	1	µg/L	Household	Plasticizer, resin
Bromacil	0.5	µg/L	Pesticide	Herbicide, >80% noncrop usage on grass/brush
Bromoform	0.5	µg/L	Household	Ozonation byproduct, military/explosives
Caffeine	0.5	µg/L	Household	Beverages, diuretic
Camphor	0.5	µg/L	Household	Flavor, odorants, ointments
Carbaryl	1	µg/L	Pesticide	Insecticide, crop and garden usage
Carbazole	0.5	µg/L	Household	Manufacture dyes, explosives, and lubricants

Table 5. Wastewater compounds and minimum reporting levels as of 2003, U.S. Geological Survey National Water Quality Laboratory custom lab code 8033—Continued

[method reference: Steven Zaugg, U.S. Geological Survey, written commun., 2003; μg/L, micrograms per liter; %, percent; >, greater than; UV, ultraviolet]

Wastewater compounds	Minimum reporting level	Unit	Effluent categories	Use
Chlorpyrifos	0.5	μg/L	Pesticide	Insecticide, domestic pest and termite control
Cholesterol	2	μg/L	Animal	Fecal indicator and plant sterol
Cotinine	1	μg/L	Household	Primary nicotine metabolite
Diazinon	0.5	μg/L	Pesticide	Insecticide, > 40% nonagricultural usage, ants, flies
d-Limonene	0.5	μg/L	Household	Fungicide, antimicrobial, antiviral, fragrance in aerosols
Dichlorovs	1	μg/L	Pesticide	Insecticide, pet collars, flies
Diethylhexyl phthalate	0.5	μg/L	Household	Celluloid, cosmetics, varnishes, and dopes. Plasticizer for cellulose ester plastics. Insecticide sprays
Equilenin	5	μg/L	Animal	Hormone replacement drug therapy
Estrone	5	μg/L	Animal	Biogenic hormone
Ethanol-2-butoxy-phosphate	0.5	μg/L	Household	Plasticizers
Ethynyl estradiol	5	μg/L	Animal	Oral contraceptive
Fluoranthene	0.5	μg/L	Hydrocarbon	Component of coal tar and asphalt
Galaxolide	0.5	μg/L	Household	Musk Fragance
Hexahydro hexamethyl cyclo-penta benzopyran (HHCB)	0.5	μg/L	Household	Musk fragrance
Indole	0.5	μg/L	Household	Pesticide inert ingredient, fragrance in coffee
Isoborneol	0.5	μg/L	Household	Fragrance in perfumery, in disinfectants
Isophorone	0.5	μg/L	Industrial	Solvent for lacquer, plastic, oil, silicon, resin
Isopropylbenzene	0.5	μg/L	Industrial	Manufacture phenol/acetone, fuels and paint thinner
Isoquinoline	0.5	μg/L	Household	Flavors and fragrances
Menthol	0.5	μg/L	Household	Cigarettes, cough drops, liniment, mouthwash
Metalaxyl	0.5	μg/L	Pesticide	Fungicide, mildew, blight, pathogens, golf/turf
Methyl salicylate	0.5	μg/L	Household	Liniment, food, beverage, UV-absorbing lotion
Metolachlor	0.5	μg/L	Pesticide	Herbicide
N,N-diethyl-meta-toluamide (DEET)	0.5	μg/L	Pesticide	Insecticide, mosquito repellent, urban usage
Naphthalene	0.5	μg/L	Hydrocarbon	Fumigant, major component (about 10%) of gasoline
Nonylphenol, diethoxy (total)	5	μg/L	Detergent	Nonionic detergent metabolite
Octylphenol, diethoxy	1	μg/L	Detergent	Nonionic detergent metabolite
Octylphenol, monoethoxy	1	μg/L	Detergent	Nonionic detergent metabolite

Table 5. Wastewater compounds and minimum reporting levels as of 2003, U.S. Geological Survey National Water Quality Laboratory custom lab code 8033—Continued

[method reference: Steven Zaugg, U.S. Geological Survey, written commun., 2003; μg/L, micrograms per liter; %, percent; >, greater than; UV, ultraviolet]

Wastewater compounds	Minimum reporting level	Unit	Effluent categories	Use
para-Nonylphenol (total)	5	μg/L	Detergent	Nonionic detergent metabolite
p-Cresol	1	μg/L	Industrial	Wood preservative
Pentachlorophenol	2	μg/L	Pesticide	Herbicide, fungicide, wood preservative, termite control
Phenanthrene	0.5	μg/L	Hydrocarbon	Manufacture explosives, component of tar, diesel fuel, or crude oil
Phenol	0.5	μg/L	Household	Disinfectant, manufacture several products, leachate
Prometon	0.5	μg/L	Pesticide	Herbicide, noncrop usage, applied prior to blacktop
Pyrene	0.5	μg/L	Hydrocarbon	Component of coal tar and asphalt
Skatole (3-Methyl-1(H)-indole)	1	μg/L	Animal	Fragrance, stench in feces and coal tar
Tetrachloroethylene	0.5	μg/L	Industrial	Solvent, degreaser, veterinary anthelmintic
Tonalide	0.5	μg/L	Household	Musk Fragance
Tri(2-butoxyethyl)phosphate	0.5	μg/L	Household	Flame retardant
Tri(2-chloroethyl)phosphate	0.5	μg/L	Household	Plasticizer, flame retardant
Tributylphosphate	0.5	μg/L	Detergent	Antifoaming agent, flame retardant
Triclosan	1	μg/L	Household	Disinfectant, antimicrobial
Triethyl citrate (ethyl citrate)	0.5	μg/L	Household	Cosmetics, pharmaceuticals
Triphenyl phosphate	0.5	μg/L	Industrial	Plasticizer, resin, wax, finish, roofing paper, flame retardant
Tris(dichlorisopropyl)-phosphate	0.5	μg/L	Household	Flame retardant

Statistical Analysis

Several tabular, graphical, and other statistical approaches were used to summarize and analyze water-quality data collected for this study. Water-quality data were analyzed as a single data set and data were analyzed by comparing data grouped by two primary land-use categories, agricultural areas and grassland areas. Summary statistics such as number of detections, minimum and maximum values, selected percentiles, and median values are listed in tables and are referenced throughout the report.

Cross-tabulations were constructed to form contingency tables in order to measure the association between two nominal categorical variables. The rows of the contingency table represent one variable, while the columns represent the second variable. Each variable has two possible responses which are listed as counts in the contingency table. The null hypothesis is that the two variables are independent and is tested using classical Chi-Square techniques for independence (Helsel and Hirsch, 1992).

Graphical approaches including bar charts, box plots, bubble plots, frequency histograms, line plots, and pie charts were used in this report to emphasis key results of this study. For a complete description of the graphical approaches used in this report, refer to Helsel and Hirsch (1992).

Spearmen's rho and Pearson's r correlation were used to measure association between water-quality constituents. Correlation coefficients measure the strength of association between two continuous variables. Correlation coefficients (designated as cor.) are dimensionless and range from -1 to +1 (Helsel and

Hirsch, 1992). When there is no correlation between variables, cor. = 0; when both variable increase, cor. is positive; and when variables vary in opposite directions, cor. is negative (Helsel and Hirsch, 1992). Spearmen's rho is a rank-based correlation coefficient. Spearmen's rho is a non-linear measure of correlation and is less sensitive to outliers. Spearmen's rho was used if data were not normally distributed as determined through graphical techniques. Pearson's r is a measure of linear correlation between two variables and is sensitive to outliers and was used if data followed a normal distribution.

The Wilcoxon rank-sum test was used to determine if differences existed between water-quality concentrations sampled from two independent groups. The Wilcoxon rank-sum test is a non-parametric test that measures the probability that two independent sample groups are similar in median or central value. The null hypothesis is that there is no difference between median values. The alternate hypothesis is that there is a difference between median values. The null hypothesis is rejected in favor of the alternate hypothesis if the attained p-value from the test is less than or equal to the α-level (significance level). An α-value of 0.05 was used in this study. The $\alpha = 0.05$ significance level is the probability (5 percent) that the null hypothesis would incorrectly be rejected in favor of the alternate hypothesis. A p-value is the significance level attained by the data (Helsel and Hirsch, 1992).

Water Quality in the Cimarron Terrace Aquifer

This section describes the water quality of samples collected during July and August 2003, from 45 wells in the Cimarron terrace aquifer. Water properties, nutrients, nitrogen isotopes, pesticides, and wastewater compounds are described independently in separate headings as listed in the "Ground-water sampling and analysis methods," tables 3, 4, and 5. Water-quality samples from agricultural areas were compared with water-quality samples from grassland areas. Associations between nitrate, pesticides, wastewater compounds, and other factors such as water properties, site characteristics, and other water-quality constituents also were evaluated and are described if statistically significant.

Water Properties

Water properties such as specific conductance, pH, water temperature, and dissolved oxygen are important supplemental information which are measured in the field at the time of sampling. Certain water properties such as pH and dissolved oxygen can change rapidly with changes in temperature, atmospheric pressure, and exposure to sunlight. Field measurements of pH and dissolved oxygen also can be useful in the preparation for laboratory analysis.

Specific conductance can be used as an indirect measurement of total dissolved solids in water (Hem, 1992). Specific conductance measurements ranged from 289 to 2,118 microsiemens per centimeter at 25 degrees Celsius (μS/cm), with a median value of 759 μS/cm (table 6). Ninety-one percent of the specific conductance measurements ranged from 289 to 1,232 μS/cm (fig. 4). The four largest specific conductance measurements were from water samples collected in the northern part of the Cimarron terrace aquifer from wells W42, W43, W44, and W45 (fig. 3, Appendix 2).

Table 6. Statistical summary of water properties in samples from 45 wells in the Cimarron terrace aquifer, July and August 2003

[μS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; ˚C, degrees Celsius; --, pH mean not calculated]

Water properties	Minimum	Mean	Concentration at indicated percentile			Maximum
			25	50 (median)	75	
Specific conductance (μS/cm)	289	819	607	759	938	2,118
pH (standard units)	6.1	--	6.7	7.0	7.3	7.5
Water temperature (˚C)	16.0	17.2	17.0	17.2	17.6	18.9
Dissolved oxygen (mg/L)	0.2	3.9	2.0	3.2	5.7	9.4
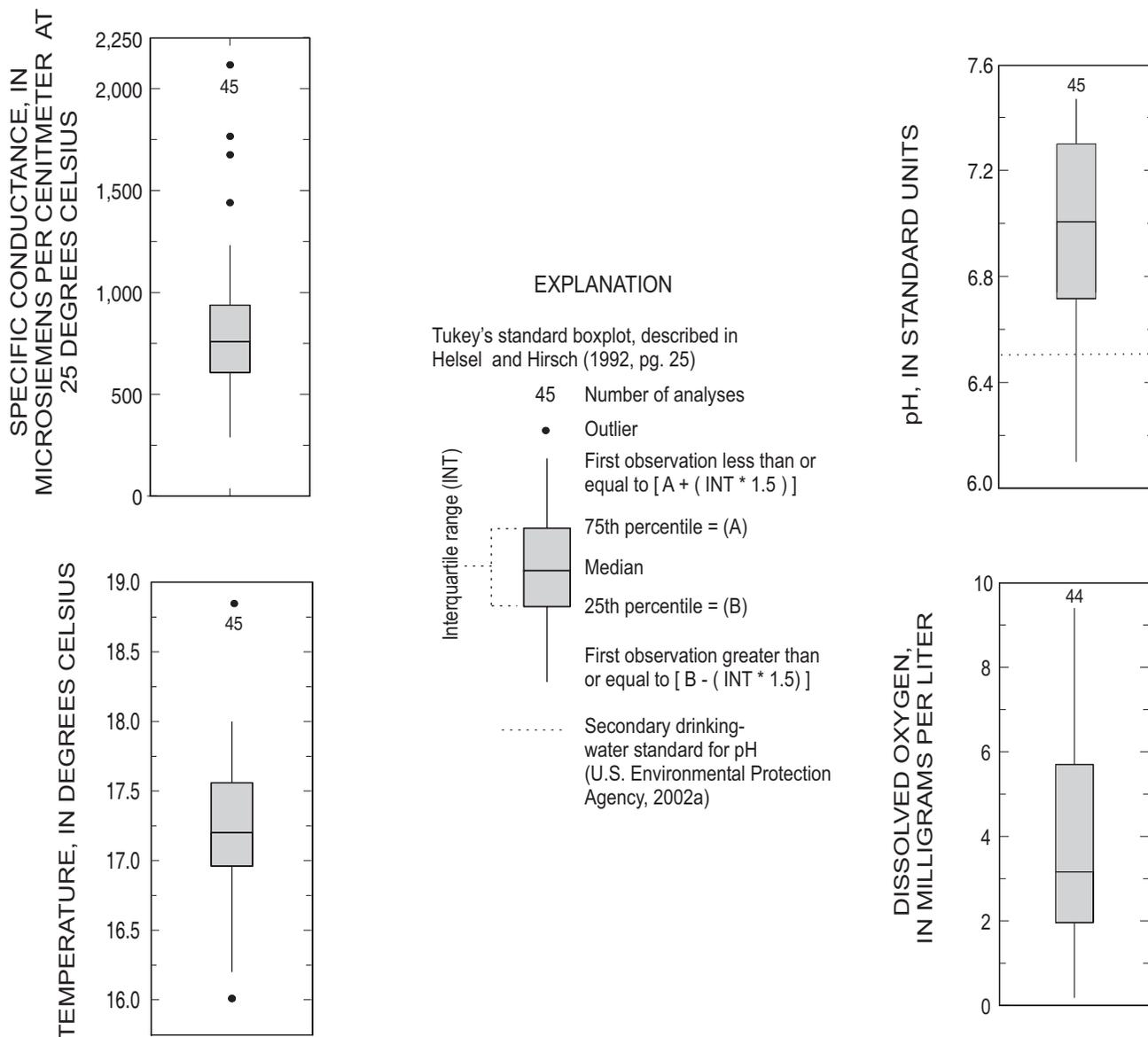
Figure 4. Distribution of water properties measured in samples from 45 wells in the Cimarron terrace aquifer, July and August 2003.

The pH measurements ranged from 6.1 to 7.5 standard units, with a median value of 7.0 standard units (table 6, fig. 4). The USEPA has established secondary drinking water standards for pH ranging from 6.5 to 8.5 standard units (U.S. Environmental Protection Agency, 2002a). The pH measurements at wells W23, W33, W36, and W39 were less than 6.5 standard units (Appendix 2).

Water temperature measurements ranged from 16.0 to 18.9 degrees Celsius, with a median value of 17.2 degrees Celsius (fig. 4, Appendix 2). Dissolved oxygen (DO) concentrations ranged from 0.2 to 9.4 mg/L, with a median concentration of 3.2 mg/L. Eighty-two percent of DO concentrations were greater than 1.5 mg/L. All wells in the study area were generally shal-

low. Results from Spearman's rho correlation test (Helsel and Hirsch, 1992) indicated no significant correlation between DO and well depths. DO is a controlling factor during the oxidation of ammonia to nitrate and lack of DO may facilitate denitrification.

A Wilcoxon Rank-Sum test, comparing specific conductance measured in samples from wells located in agricultural areas to specific conductance measured in samples from wells located in grassland areas, indicated that specific conductance was significantly greater in agricultural areas ($z = 1.92$, p-value $= 0.027$) (fig. 5). The median specific conductance value mea-
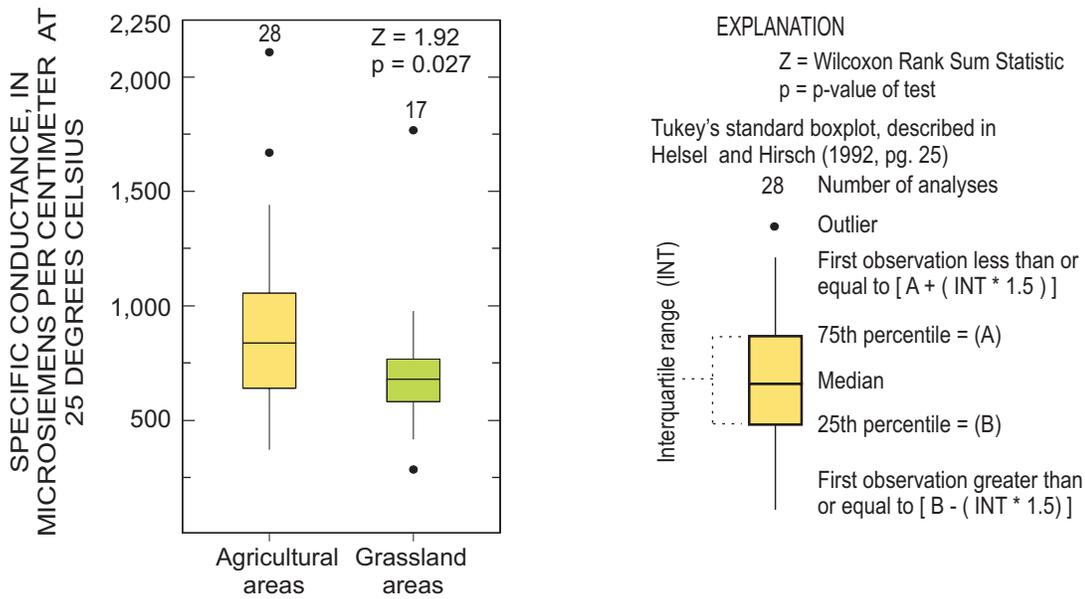
Figure 5. Distribution of specific conductance measured in water samples from 28 wells located in agricultural areas and 17 wells located in grassland areas in the Cimarron terrace aquifer, July and August 2003.

sured in water from wells in agricultural areas was 833 μS/cm (table 7), whereas, the median specific conductance value measured in water from wells in grassland areas was 675 μS/cm (table 8). Comparisons of pH, water temperature, and DO measurements in grassland and agricultural areas did not indicate significant differences in measured values.

Nutrients

Nutrients described in this report are species of nitrogen and phosphorous. Nitrogen and phosphorous are chemical elements that are essential to plant and animal growth, but in large concentrations are considered contaminants. Ground-water samples collected were analyzed for nitrite, nitrate, ammonia, ammonia plus organic nitrogen, phosphorus, and orthophosphate.

Nitrite is an unstable intermediate by-product of nitrification and denitrification. Nitrite concentrations in ground-water samples were generally small. Nitrite concentrations were less than the reporting level of 0.008 mg/L in 42 of the 45 ground-water samples. Nitrite concentrations ranged from E 0.005 to 0.046 mg/L (table 9, Appendix 3).

Nitrate concentrations in ground-water samples commonly are greater in agricultural areas than in areas of other land uses (Mueller and Helsel, 1996). Nitrate is a very soluble compound and is readily transported in the environment. Nitrate

concentrations greater than 3.0 mg/L in ground water are often considered to result from human influence, such as fertilizer applications on row crops or animal waste (Mueller and Helsel, 1996). An investigation using data from over 87,000 wells, collected over a 25-year period, indicated that nitrate concentrations less than 0.2 mg/L were representative of natural background concentrations (Madison and Brunett, 1984). Concentrations of nitrate in ground water between 0.2 to 3.0 mg/L are considered transitional zones between background and possible human influence (Madison and Brunett, 1984). Nitrate concentrations in samples collected from background wells were consistent with background concentrations reported by Madison and Brunett, (1984), having no detectable nitrate in W9 and 0.13 mg/L in W31 (Appendix 3).

Nitrate was detected in 44 of the 45 ground-water samples and had the highest median concentration (8.03 mg/L) of any nutrient analyzed (table 9). Nitrate concentrations ranged from <0.06 to 31.8 mg/L (table 9, Appendix 3). Two samples had nitrate concentrations less than 0.20 mg/L; 9 samples had nitrate concentrations between 0.21 and 3.0 mg/L; and 17 samples had nitrate concentrations between 3.0 and 9.9 mg/L (fig. 6). Seventeen samples (38 percent) had nitrate concentrations that exceeded the MCL of 10 mg/L of nitrate (fig. 6, fig. 7). The 10 highest nitrate concentrations occurred in samples from agricultural areas. Results from a Spearman's Rank Correlation test indicated that nitrate concentrations were not statistically corre-

Table 7. Statistical summary of water properties in samples from 28 wells located in agricultural areas in the Cimarron terrace aquifer, July and August 2003

[μS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; ˚C, degrees Celsius; --, pH mean not calculated]

Water properties	Minimum	Mean	Concentration at indicated percentile			Maximum
			25	50 (median)	75	
Specific conductance (μS/cm)	365	885	642	833	1,028	2,118
pH (standard units)	6.3	--	6.7	6.9	7.2	7.5
Water temperature (˚C)	16.0	17.3	17	17.3	17.6	18.8
Dissolved oxygen (mg/L)	0.2	3.9	1.9	3.1	5.4	8.6

Table 8. Statistical summary of water properties in samples from 17 wells located in grassland areas in the Cimarron terrace aquifer, July and August 2003

[μS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; ˚C, degrees Celsius; --, pH mean not calculated]

Water properties	Minimum	Mean	Concentration at indicated percentile			Maximum
			25	50 (median)	75	
Specific conductance (μS/cm)	289	709	576	675	763	1,770
pH (standard units)	6.1	--	7.0	7.3	7.4	7.4
Water temperature (˚C)	16.0	16.9	16.5	17.0	17.3	18.0
Dissolved oxygen (mg/L)	0.2	3.9	2.8	3.3	5.7	9.4

Table 9. Statistical summary of nutrient data for 45 ground-water samples collected in the Cimarron terrace aquifer, July and August 2003, (all units are in milligrams per liter)

[<, Less than; E, estimate]

Nutrient constituent	Total number of detections	Minimum	Concentration at indicated percentiles					Maximum
			10	25	50 (median)	75	90	
Nitrite	3	E 0.005	<0.008	<0.008	<0.008	<0.008	<0.008	0.046
Nitrite plus nitrate as nitrogen	44	<0.06	1.16	3.30	8.03	14.8	17.5	31.8
Ammonia	3	E 0.03	<0.04	<0.04	<0.04	<0.04	<0.04	0.70
Ammonia plus organic nitrogen	33	E0.05	E 0.06	E 0.09	<0.10	0.10	0.20	0.88
Phosphorus	45	0.006	0.019	0.039	0.053	0.077	0.126	0.160
Orthophosphate	39	<0.02	0.02	0.03	0.04	0.07	0.12	0.15
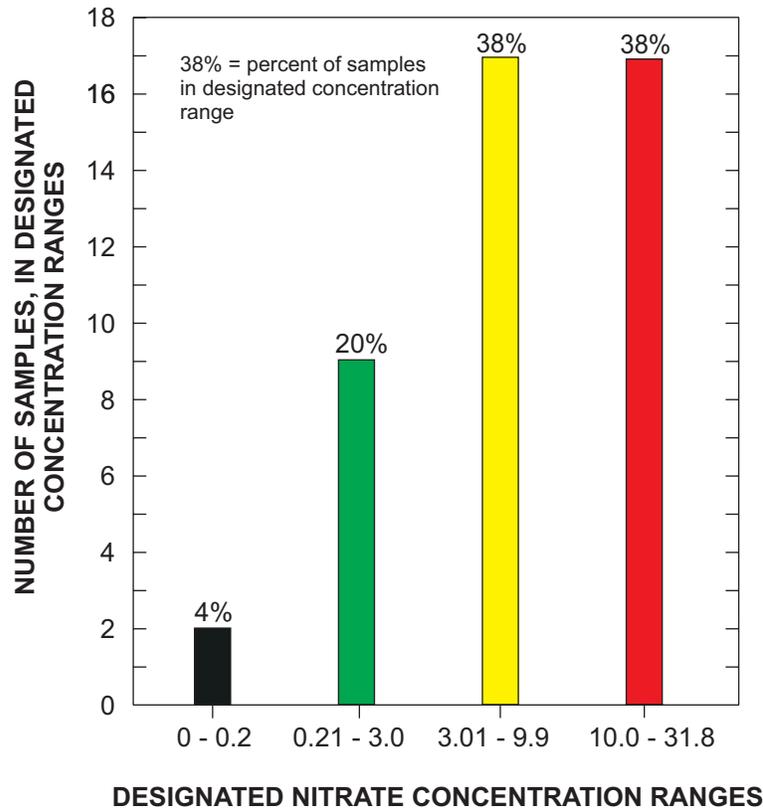
Figure 6. Number of samples in selected nitrate concentrations ranges.

lated with site characteristics such as well depth, depth to water, distance from the Cimarron River, water properties, and other water-quality variables.

Ammonia is a precursor to nitrate in oxidizing systems and is readily used by crops and other plants. Commercial nitrogen fertilizers are commonly applied as ammonia and animal manure, which is converted to ammonia and ultimately converted to nitrate in the soil (Mueller and Helsel, 1996). Ammonia concentrations in most ground-water samples were low (table 9, Appendix 3). Ammonia concentrations were less than the reporting level of 0.04 mg/L in 42 of the 45 ground-water samples. Ammonia concentrations ranged from E 0.03 to 0.70 mg/L. The maximum ammonia concentration occurred in a sample from W38, which also had an elevated nitrate concentration (20.4 mg/L) (Appendix 3).

Ammonia plus organic nitrogen was detected in 33 of the 45 samples and ranged in concentration from E 0.05 to 0.88 mg/L. Thirty of the 33 samples (91 percent) with detectable ammonia plus organic nitrogen consisted mostly of organic nitrogen (Appendix 3). Organic forms of nitrogen may be considered indicators of contamination through disposal of sewage or organic waste (Hem, 1992).

Phosphorus was detected in all 45 samples, with concentrations ranging from 0.006 to 0.160 mg/L (table 9). The median phosphorus concentration was 0.053 mg/L. Phosphorus concentrations can be expected to be low in most ground-water samples because of low solubility in water and tendency to sorb to soil particles. Orthophosphate was detected in 39 of 45 ground-water samples and ranged in concentration from <0.02 to 0.15 mg/L, with a median concentration of 0.04 mg/L.

A Wilcoxon Rank-Sum test, comparing nitrate concentrations in agricultural areas to nitrate concentrations in grassland areas, indicated that nitrate concentrations are significantly greater in agricultural areas than in the grassland areas ($z = 3.557$, p-value = <0.001) (fig. 8). Nitrate concentrations in the agricultural areas ranged from 0.95 to 31.8 mg/L (table 10), whereas, nitrate concentrations in the grassland areas ranged from <0.06 to 14.9 mg/L (table 11). The median nitrate concentration in agricultural areas was 11.6 mg/L, whereas, the median nitrate concentration in grassland areas was 3.63 mg/L. Nitrate was the only nutrient with significant difference in concentration between samples from the agricultural and grassland areas.
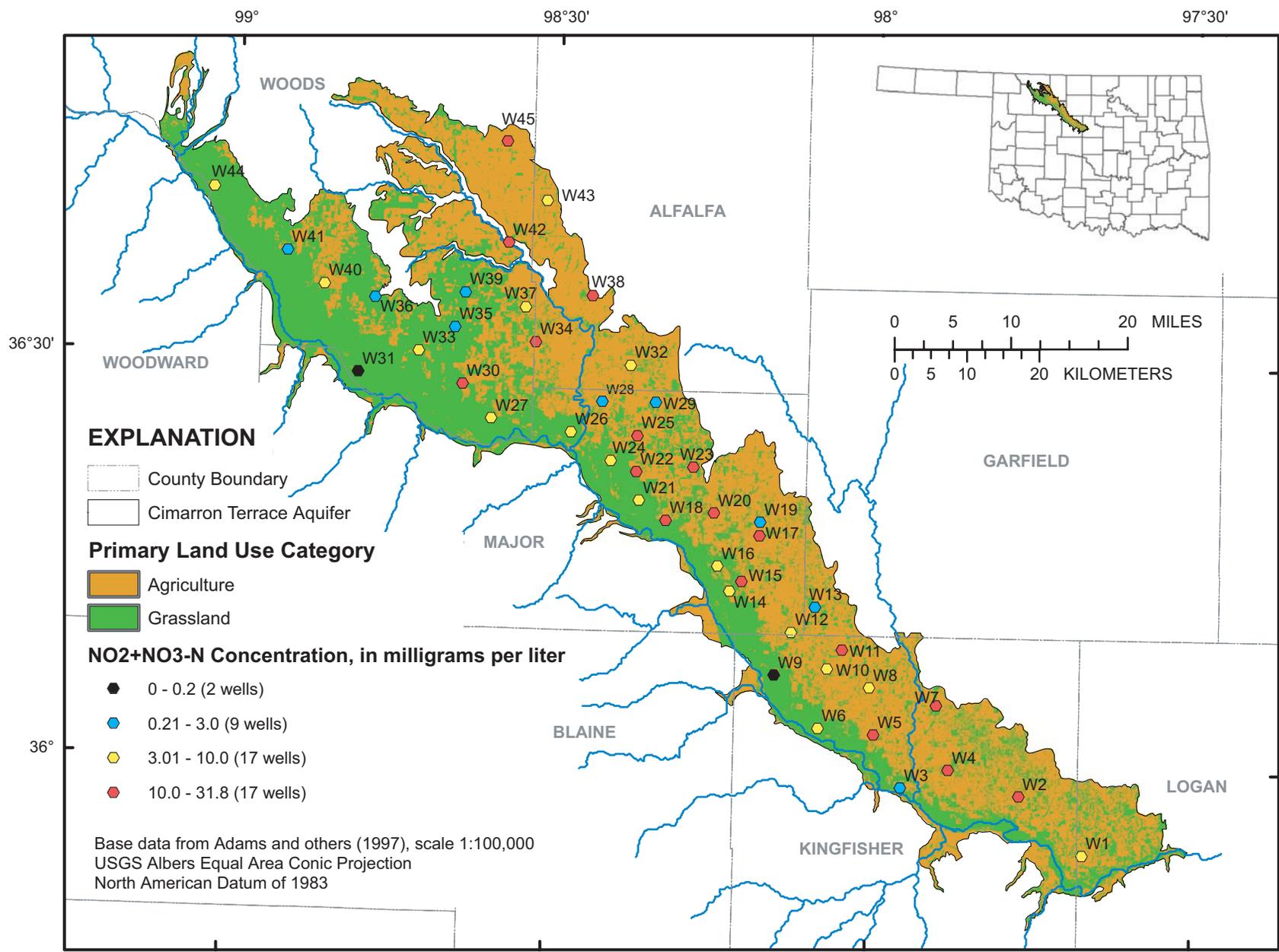
Figure 7. Location of wells and selected nitrate concentration ranges in samples from the Cimarron terrace aquifer, July and August 2003 (U.S. Geological Survey, 2002).
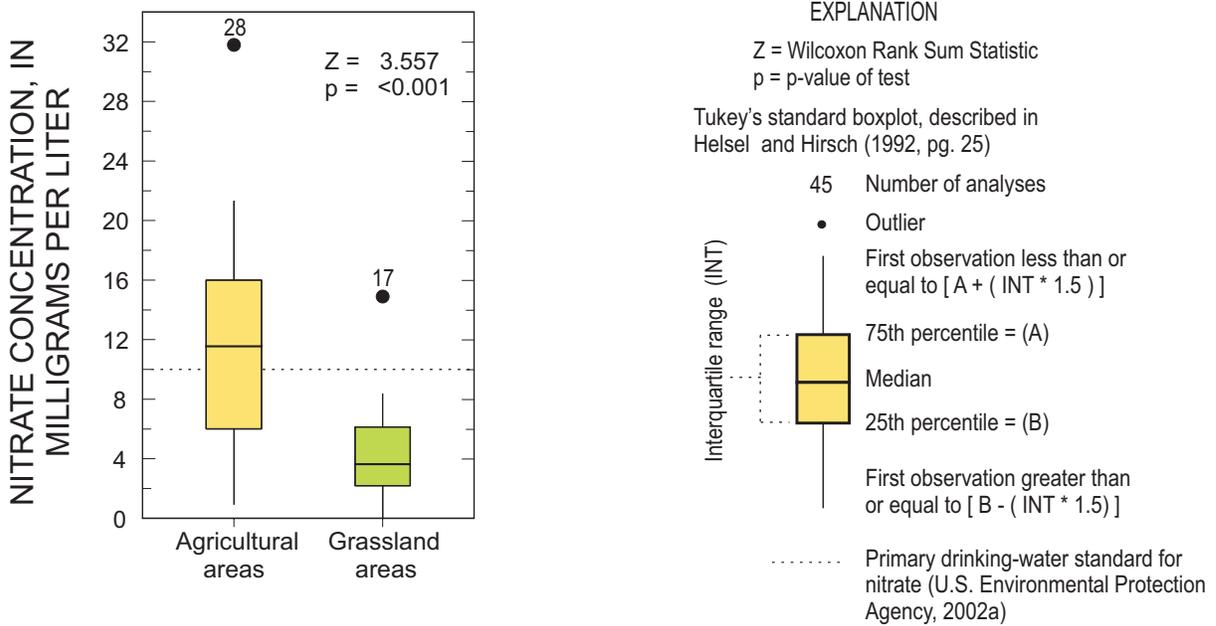
Figure 8. Distribution of nitrate concentrations in samples from 28 wells located in agricultural areas and 17 wells located in grassland areas in the Cimarron terrace aquifer, July and August 2003.

Table 10. Statistical summary of nutrient data collected in samples from 28 wells located in agricultural areas in the Cimarron terrace aquifer, July and August 2003, (all units are in milligrams per liter)

[E, estimate; <, less than]

Nutrient constituent	Number of detections	Minimum	Concentration at indicated percentiles					Maximum
			10	25	50 (median)	75	90	
Nitrite	2	E 0.005	<0.008	<0.008	<0.008	<0.008	<0.008	0.046
Nitrite plus nitrate as nitrogen	28	0.95	2.42	6.02	11.6	15.8	20.4	31.8
Ammonia	1	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.70
Ammonia plus organic nitrogen	21	E 0.06	E 0.08	E 0.10	<0.10	0.10	0.20	0.88
Phosphorus	28	0.006	0.010	0.038	0.054	0.110	0.140	0.160
Orthophosphate	23	<0.02	<0.02	0.03	0.04	0.09	0.12	0.15

Table 11. Statistical summary of nutrient data collected in samples from 17 wells located in grassland areas in the Cimarron terrace aquifer, July and August 2003, (all units are in milligrams per liter)

[E, estimate; <, less than]

Nutrient constituent	Number of detections	Minimum	Concentration at indicated percentiles					Maximum
			10	25	50 (median)	75	90	
Nitrite	3	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	0.020
Nitrite plus nitrate as nitrogen	16	<0.06	0.27	2.19	3.63	6.14	8.35	14.9
Ammonia	2	E 0.03	<0.04	<0.04	<0.04	<0.04	<0.04	0.05
Ammonia plus organic nitrogen	11	E 0.50	E 0.06	E 0.07	E 0.10	0.10	0.14	0.18
Phosphorus	17	0.014	0.030	0.040	0.048	0.062	0.070	0.099
Orthophosphate	16	<0.02	0.03	0.03	0.04	0.06	0.06	0.09

Nitrogen Isotopes

Nitrogen isotopes are commonly used as tracers to indicate sources of nitrate (Kreitler, 1975 and 1979, Kreitler and Browning, 1983; and Wassenaar, 1995). There are many nitrogen isotopes, but only two are stable (non-radioactive), ^{14}N and ^{15}N. The ^{14}N isotope is the lighter of the two stable isotopes and comprises 99.632 percent (plus or minus 0.002 percent) nitrogen in the atmosphere (Junk and Svec, 1958). The ^{15}N isotope is much less abundant than ^{14}N and comprises 0.367 percent nitrogen in the atmosphere (Neyens and others, 1999).

The ratios of ^{14}N to ^{15}N in a sample are compared to ratios of ^{14}N to ^{15}N in atmospheric nitrogen, known as the reference standard. Nitrogen isotope ratios are expressed as the isotopic ratio delta value (δ) in parts per thousand, denoted as permil (‰). The formula used to calculate nitrogen isotopic ratio deltas is expressed in equation 1 (Kendall and Aravena, 1999):

$$\delta^{15}N = \left[\frac{\frac{^{15}N}{^{14}N} sample}{\frac{^{15}N}{^{14}N} standard} - 1 \right] \times 1,000 \qquad (1)$$

where
$^{15}N/^{14}N$ = the ratio of the heavier, less abundant isotope to the lighter, more abundant isotope;
$^{15}N/^{14}N$ sample = the collected sample; and
$^{15}N/^{14}N$ standard = the internationally accepted standard gas, atmospheric N_2

(3.677×10^{-3}, Clark and Fritz, 1997)

Nitrogen-isotope ratios in nitrate are controlled by biological, chemical, and physical processes that may cause preferential enrichment or depletion of one isotope relative to the other, a process known as fractionation (Clark and Fritz, 1997). Samples enriched in ^{15}N relative to atmospheric nitrogen have positive $\delta^{15}N$ values, whereas, samples depleted in ^{15}N relative to atmospheric nitrogen will have negative $\delta^{15}N$ values. Sufficient fractionation may result in distinct isotopic compositions that allow identification of nitrate sources in the environment (Clark and Fritz, 1997).

Nitrogen in nitrate leached from animal waste, including humans, is relatively enriched in ^{15}N, with $\delta^{15}N$ values ranging from +10 to +20‰ (table 12). Increases in $\delta^{15}N$ values from animal waste are due to the excretion of the lighter ^{14}N isotope, volatilization of ^{15}N-depleted ammonia, and oxidation of residual waste (Wolterink and others, 1979). Nitrate leached from synthetic fertilizers have $\delta^{15}N$ values ranging from –4 to +4‰ due to fixation of atmospheric N_2 (table 12). Nitrate from synthetic fertilizers and precipitation have similar $\delta^{15}N$ ranges due to common exposure to atmospheric N_2. Nitrate leached from soils generally has $\delta^{15}N$ values ranging from +2 to +10‰, while nitrate leached from plants generally has $\delta^{15}N$ values ranging from –10 to + 10‰ (table 12). $\delta^{15}N$ values in soils are controlled by a wide range of soil factors, such as soil depth, vegetation, soil use, and climate (Kendall, 1998). Plants can have a wide range $\delta^{15}N$ values due to the ability to utilize a variety of inorganic compounds (NH_4, NO_3, N_2, and NO_2) and amino acids (Kendall, 1998).

The $\delta^{15}N$ values were measured in water samples from 42 of 45 wells sampled in the Cimarron terrace aquifer (fig. 9,

Table 12. Range of nitrogen isotope delta values ($\delta^{15}N$) in nitrate in water for selected sources of nitrate

Nitrogen isotope ratios	$\delta^{15}N$ ranges	References
Animal (manure) and septic waste (human)	+10 to +20‰	Kendall and Aravena (1999), Kreitler (1975)
Synthetic fertilizers	–4 to +4‰	Kendall and Aravena (1999)
Soils	+2 to +10‰	Kendall and Aravena (1999)
Plants	–10 to +10‰	Clark and Fritz (1997)
Precipitation	-8 to +4‰	Clark and Fritz (1997)

Appendix 4). $\delta^{15}N$ values were not analyzed in water samples from wells W9, W31, and W36, because nitrate concentrations were less than the needed concentration (0.5 mg/L) to determine $\delta^{15}N$ values. Measured $\delta^{15}N$ values ranged from –0.83 to 10.1‰, with a median value of 4.28‰ and a mean of 4.59‰.

A complicating factor in using $\delta^{15}N$ values alone to determine possible sources of nitrate is mixing of nitrogen from several sources such as manure or septic waste, the atmosphere, fertilizers, plants, and soils. Mixing of several nitrogen sources can cause isotopic ratios in water to resemble those of plants and natural soils (fig. 9). $\delta^{15}N$ values can be used with nitrate concentrations, and detection of pesticides and wastewater compounds to indicate possible sources of nitrate and are described in the "Possible sources of nitrate" section.

Results from a Wilcoxon Rank-Sum test indicated that $\delta^{15}N$ values were significantly greater in samples from agricultural areas than in samples from grassland areas (z = 2.98, p-value = 0.002) (fig. 10). The median $\delta^{15}N$ value in the agricultural areas was 5.15‰, whereas the median $\delta^{15}N$ value in the grassland areas was 2.36‰ (table 13). This difference was unexpected because low $\delta^{15}N$ values and greater nitrate concentrations are commonly associated with agricultural areas where fertilizers are applied to soils. An investigation in the Central High Plains aquifer showed that anthropogenic compounds including pesticides tend to be detected twice as often in public-water supply wells than in domestic wells due to altered flow paths and recharge rates (Bruce and Oelsner, 2001). A Wilcoxon Rank-Sum test was done to see if $\delta^{15}N$ values were significantly greater in samples from public-water supply wells than in samples from domestic wells and results indicated no significant difference (z = 1.03, p-value = 0.154). The reason for $\delta^{15}N$ values being greater in agricultural areas than in grassland areas is not understood.

Pesticides

Synthetic pesticides are organic compounds that are not naturally present in water and are used to control unwanted plants or animals (Ware, 1989). Two common characteristics associated with the mobility and ultimately the presence of pesticides in ground water are the aqueous solubility and partition coefficient between a contaminant and natural organic matter (K_{oc}) (Bedient and others, 1997). Aqueous solubility quantifies the amount of a particular compound that will dissolve in a known volume of water. Compounds with greater aqueous solubility have a greater likelihood of moving in the environment. The K_{oc} is a measure of the tendency for a compound to adsorb to soil particles or partition into soil organic matter. The smaller the K_{oc}, the weaker the potential for a compound to adsorb to soil particles or partition into soil organic matter, resulting in greater mobility in the environment.

Each of the samples collected from 45 ground-water wells sampled in the Cimarron terrace aquifer was analyzed for 52 commonly applied pesticide compounds (table 4). Pesticides were detected in samples from 15 of 45 (33 percent) wells (fig. 11, Appendix 5).

Five pesticides and 1 metabolite of the 52 pesticides that were analyzed in each sample were detected, (table 14, Appendix 5). Atrazine and deethylatrazine, a metabolite of atrazine, were the most frequently detected. Deethylatrazine was detected in water samples from 9 of the 15 wells with pesticide detections (table 14). Atrazine was detected in water samples from 8 of 15 wells. Atrazine is a triazine herbicide that disrupts photosynthesis in selected plants, and is commonly applied to kill weeds in corn, sorghum, wheat, hay, sod, and turf grasses (Thelin and Gianessi, 2000). Atrazine was the second most frequently detected pesticide in USEPA National Survey of Pesticides in Drinking Water Wells (U.S. Environmental Protection Agency, 2002b). Based on an aqueous solubility of 30 mg/L at 20 degrees Celsius and a K_{oc} of 122, atrazine is considered to have a moderate mobility rating (U.S. Environmental Protection Agency, 2002b). Atrazine may potentially cause a variety of health effects from exposures at concentrations above the MCL of 3 micrograms per liter (µg/L) (U.S. Environmental Protection Agency, 2002a). Although atrazine was detected in water samples from 8 of the 15 wells, concentrations were less
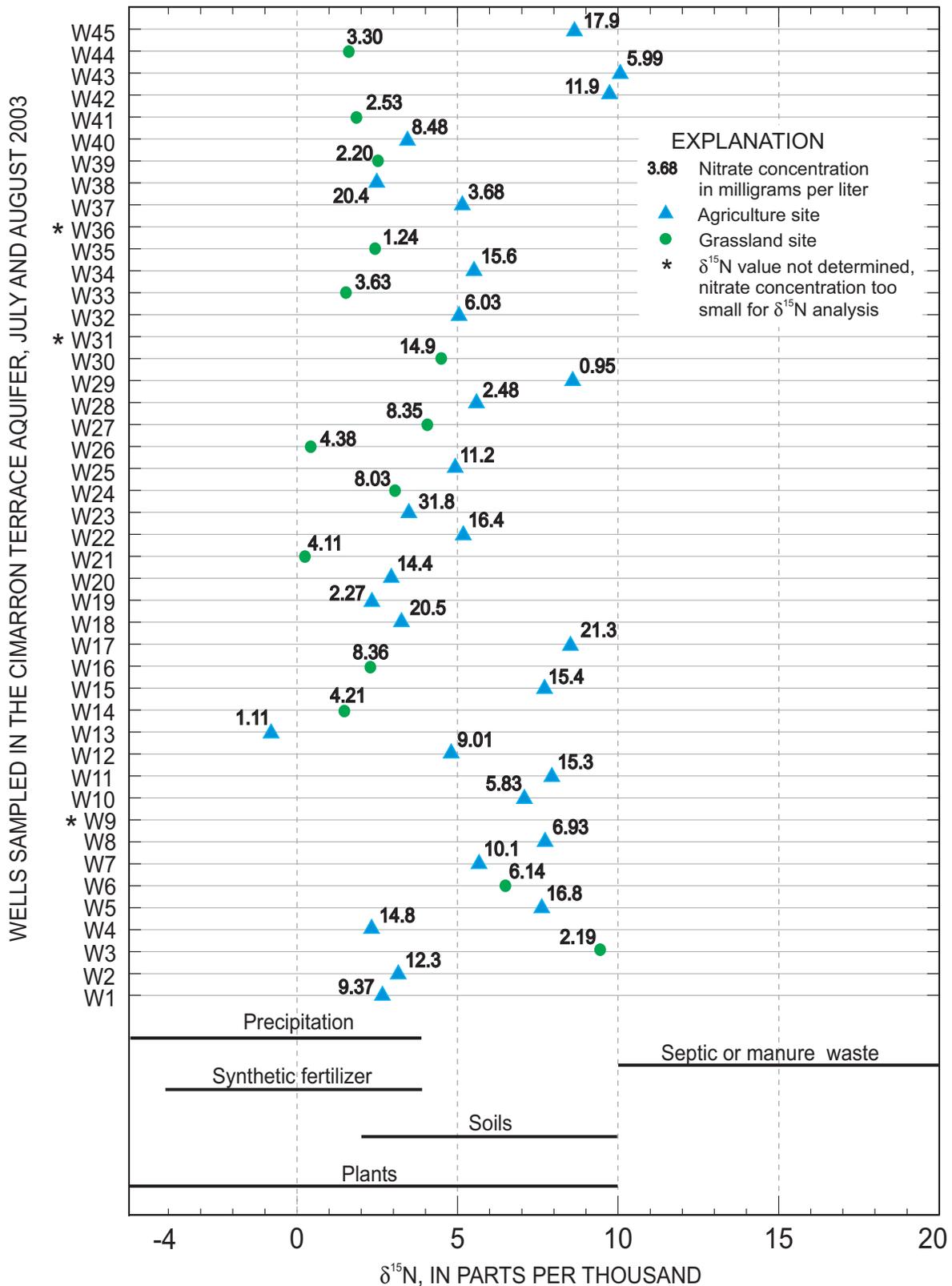
Figure 9. Nitrogen isotope delta values ($\delta^{15}N$) in nitrate measured in samples from 42 of 45 wells in the Cimarron terrace aquifer, July and August 2003. Shown with nitrate concentrations and $\delta^{15}N$ ranges for major sources of nitrate in the hydrosphere (based on Kreitler, 1975; Clark and Fritz, 1997; and Kendall and Aravena, 1999).
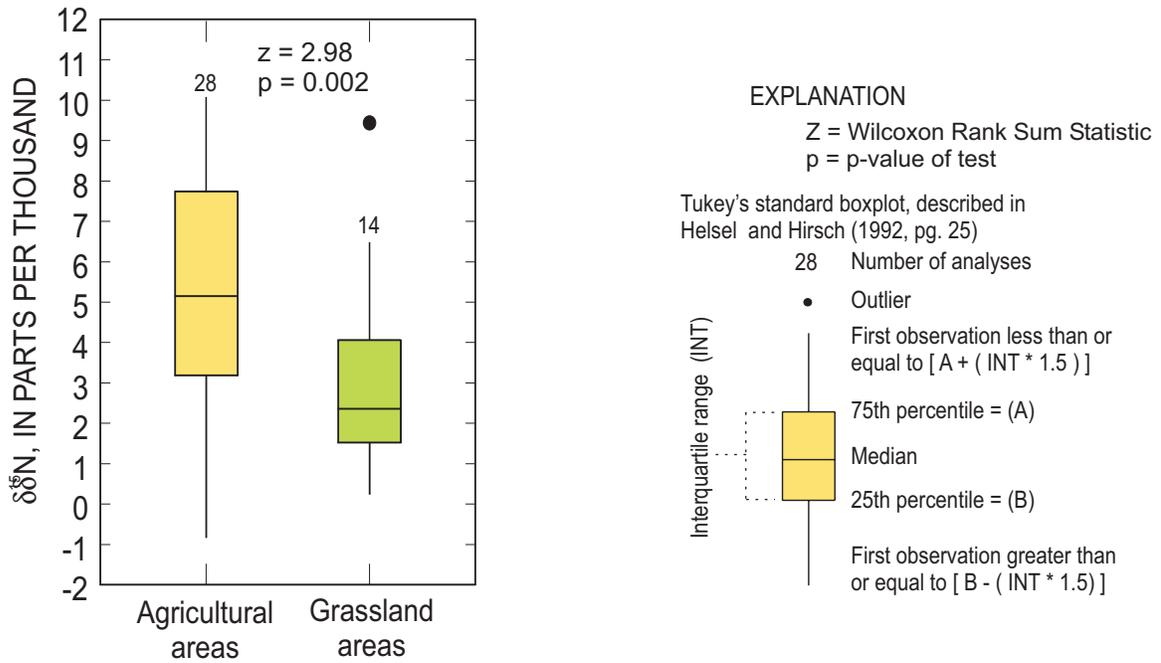
Figure 10. Nitrogen isotope delta values (δ^{15}N) in nitrate measured in samples from 28 wells in agricultural areas and δ^{15}N values from 14 of 17 wells in grassland areas in the Cimarron terrace aquifer, July and August 2003.

Table 13. Statistical summary of nitrogen delta values (δ^{15}N) in nitrate measured in samples from 28 wells in agricultural areas and 14 of 17 wells in grassland areas in the Cimarron terrace aquifer, July and August 2003

Land use	Minimum	Mean	25th	50th (median)	75th	Maximum
Agriculture	-0.83	5.38	3.19	5.15	7.72	10.1
Grassland	0.25	2.99	1.55	2.36	3.81	9.44
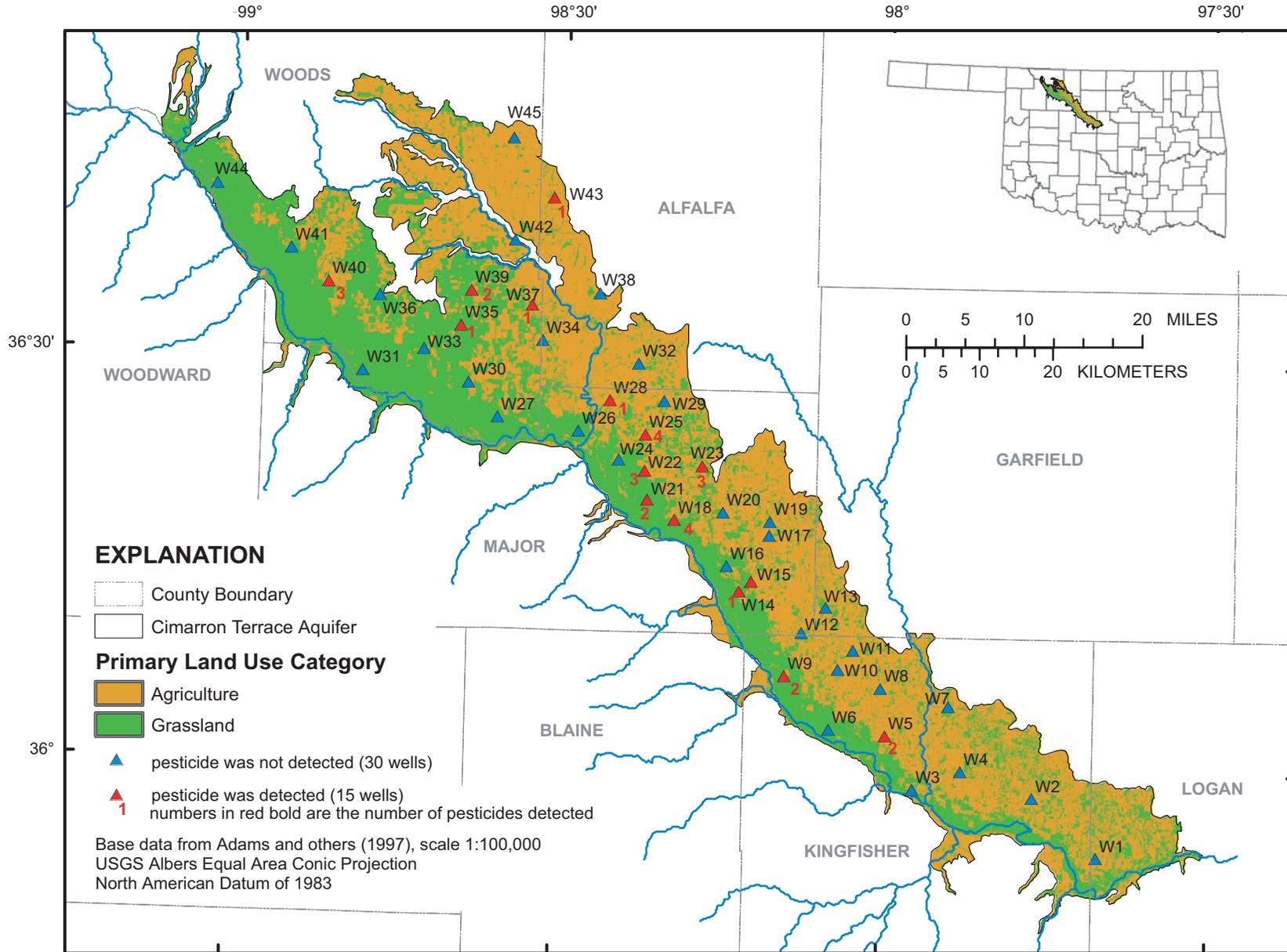
Figure 11. Locations of wells with samples having detectable concentrations of pesticide compounds in the Cimarron terrace aquifer, July and August 2003.

Table 14. Detected pesticide and metabolite compounds and range of concentrations in samples from 15 of 45 wells in the Cimarron terrace aquifer, July and August 2003

[E, estimate; μg/L, micrograms per liter]

Pesticides detected	Number of pesticides detected			Range of concentrations (μg/L)	Use
	Agricultural areas	Grassland areas	Total		
Alachlor	1	0	1	0.009	Herbicide
Atrazine	6	2	8	E 0.004 - 0.111	Herbicide
Deethylatrazine	6	3	9	E 0.007 - E 0.580	None (metabolite)
Metolachlor	4	0	4	E 0.011 - 0.092	Herbicide
Prometon	4	0	4	0.025 - 0.127	Herbicide
Tebuthiuron	2	3	5	E 0.010 - 0.159	Herbicide

than the MCL of 3 μg/L (fig. 12, Appendix 5).

Tebuthiuron was detected in water samples from 5 wells (fig. 12, Appendix 5). Tebuthiuron is a herbicide used to control weeds in non-cropland areas, rangelands, rights-of-way, and industrial sites by disrupting the photosynthetic process (Ventures, Inc., 2003). Due to a large aqueous solubility of 2,500 mg/L at 25 degrees Celsius and low K_{oc} of 80, tebuthiuron can be very prevalent in the environment and is classified as very mobile (U.S. Department of Agriculture, 1996). The USEPA has not set a MCL for tebuthiuron, but has established a health advisory for a lifetime consumption of 500 μg/L (U.S. Environmental Protection Agency, 2002a). The lifetime health advisory is based on the concentration of a chemical in drinking water that is not expected to cause any adverse non-carcinogenic or carcinogenic effects for a lifetime exposure (based on 70 kilogram adult consuming 2 liters of water per day) (U.S. Environmental Protection Agency, 2002a). None of the detected tebuthiuron concentrations exceeded the USEPA lifetime health advisory (fig. 12).

Metolachlor was detected in water samples from 4 wells (fig. 12, Appendix 5). Metolachlor is a chloroacetanilide herbicide that acts as a growth inhibitor in selected plants, and is primarily used to kill weeds in corn, soybeans, peanuts, sorghum, potatoes, and cotton (Thelin and Gianessi, 2000). Metolachlor has an aqueous solubility of 530 mg/L at 20 degrees Celsius and a K_{oc} of 200, indicating that metolachlor has moderate to high mobility and can potentially contaminate ground water (Rivard, 2003). The USEPA has not set a MCL for metolachlor, but has established a health advisory concentration for a lifetime exposure greater than 100 μg/L (U.S. Environmental Protection

Agency, 2002a). None of the detected metolachlor concentrations exceeded the USEPA lifetime health advisory level (fig. 12).

Prometon was detected in water samples from 4 wells (fig. 12, Appendix 5). Like tebuthiuron, prometon is a herbicide that is used to control broadleaf weeds in non-cropland areas, rangelands, rights-of-way, industrial sites, and recreational areas by disrupting the photosynthetic process (Ventures, Inc., 2003). Prometon can be very persistent in the environment due to a half-life in soil of 500 days. Prometon has an aqueous solubility of 700 mg/L at 22 degrees Celsius (AERVOE, 2003) and a K_{oc} of 150. It is rated as having very high mobility (Kerle and others, 1996). The USEPA has not set a MCL for prometon, but has established a health advisory level of 500 μg/L (U.S. Environmental Protection Agency, 2002a). None of the detected prometon concentrations exceeded the USEPA lifetime health advisory level (fig. 12).

Alachlor was only detected in a water sample from 1 well (fig. 12, Appendix 5). Alachlor is a pre-emergent herbicide used to control grasses and weeds in cropland areas such as corn, sorghum, soybeans, peanuts, and cotton. Like the other pesticides detected, alachlor has a moderate to high mobility rating due to an aqueous solubility of 140 mg/L and an average K_{oc} value of 155 (U.S. Environmental Protection Agency, 2002c). Alachlor may cause a variety of health effects from long-term exposure at concentrations exceeding the MCL of 2 μg/L for alachlor (U.S. Environmental Protection Agency, 2002a). The concentration of alachlor detected in water from the single well was less than the MCL of 2 μg/L (fig. 12).
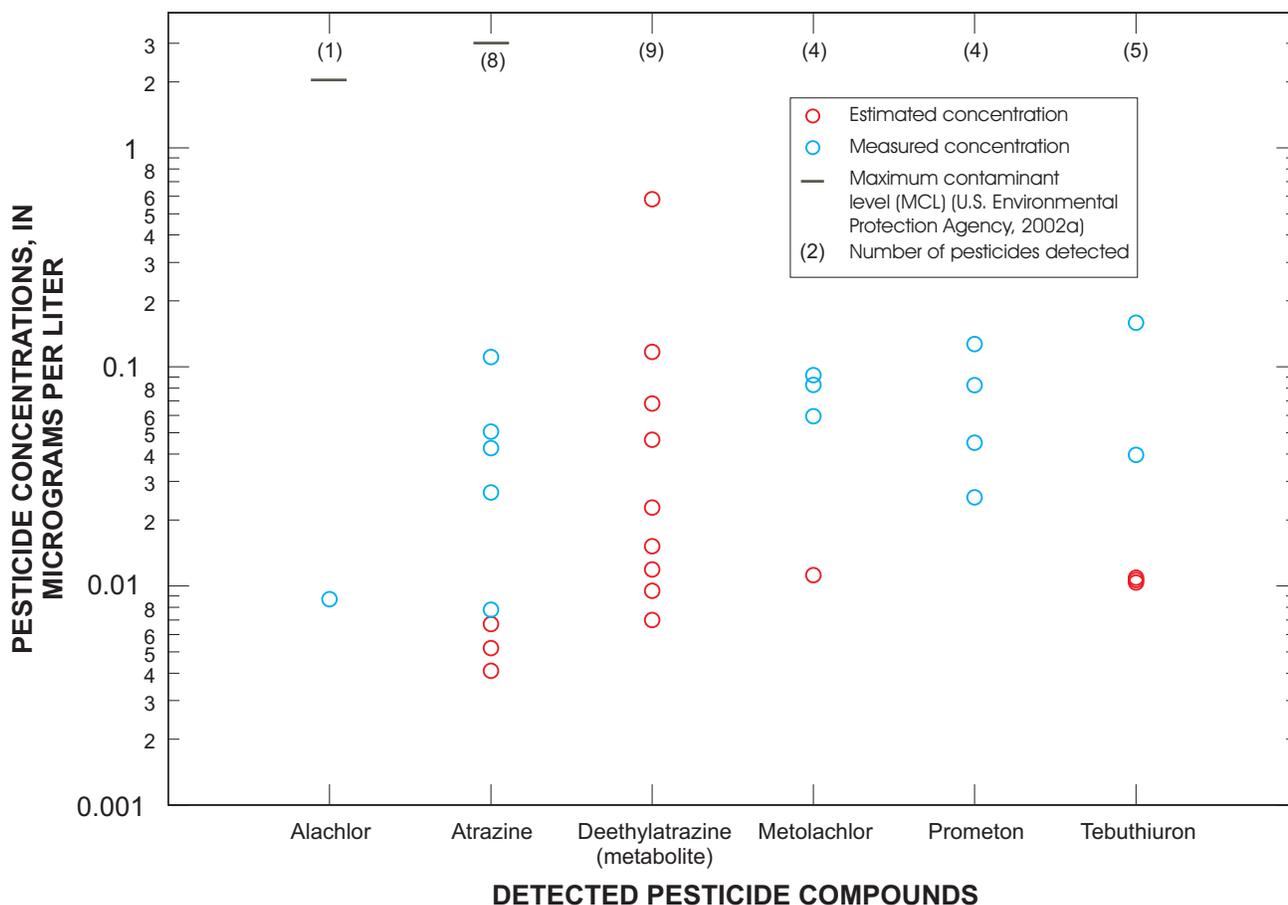
Figure 12. Distribution of pesticide and metabolite compounds detected in samples from 15 of 45 wells in the Cimarron terrace aquifer, July and August 2003.

Results from contingency tables indicated that the number of pesticide detections were not statistically different between wells sampled in agricultural areas and wells sampled in grassland areas (Chi squared = 0.189, p-value = 0.664) (Helsel and Hirsch, 1992). Pesticide concentrations were not significantly correlated to nitrate and phosphorus concentrations, nor were pesticide concentrations significantly correlated to well depth or any other site characteristics.

Wastewater Compounds

Wastewater compounds in this report refer to a wide range of organic chemicals that are commonly associated with domestic and industrial wastewater effluent. The wastewater compounds can be grouped into six categories: (1) animal, (2) detergent, (3) household, (4) hydrocarbon, (5) industrial, and (6) pesticide (table 5).

Each of the samples from the 45 ground-water wells in the Cimarron terrace aquifer was analyzed for 72 wastewater compounds (table 5). Wastewater compounds were detected in water samples from 28 of 45 wells (62 percent) (fig. 13, Appendix 6). Twenty of the 72 wastewater compounds were detected. Of the 20 wastewater compounds detected, 11 compounds (55 percent) were in the household category, 3 compounds (15 percent) were in the hydrocarbon category, 2 compounds (10 percent) were in the industrial category, 2 compounds (10 percent) were in the pesticides category, 1 compound (5 percent) was in the animal category, and 1 compound (5 percent) was in the detergent category (fig. 14, table 15).

Wastewater compounds in the household category (fig. 15) are commonly used in products such as perfumes, coffee, soaps, dyes, flame retardant products, lubricants, and disinfectants (table 5). Fluoranthene, phenanthrene, and pyrene were in the hydrocarbon category and are commonly used in asphalt, diesel fuel, crude oil, and tar products. P-cresol and triphenyl
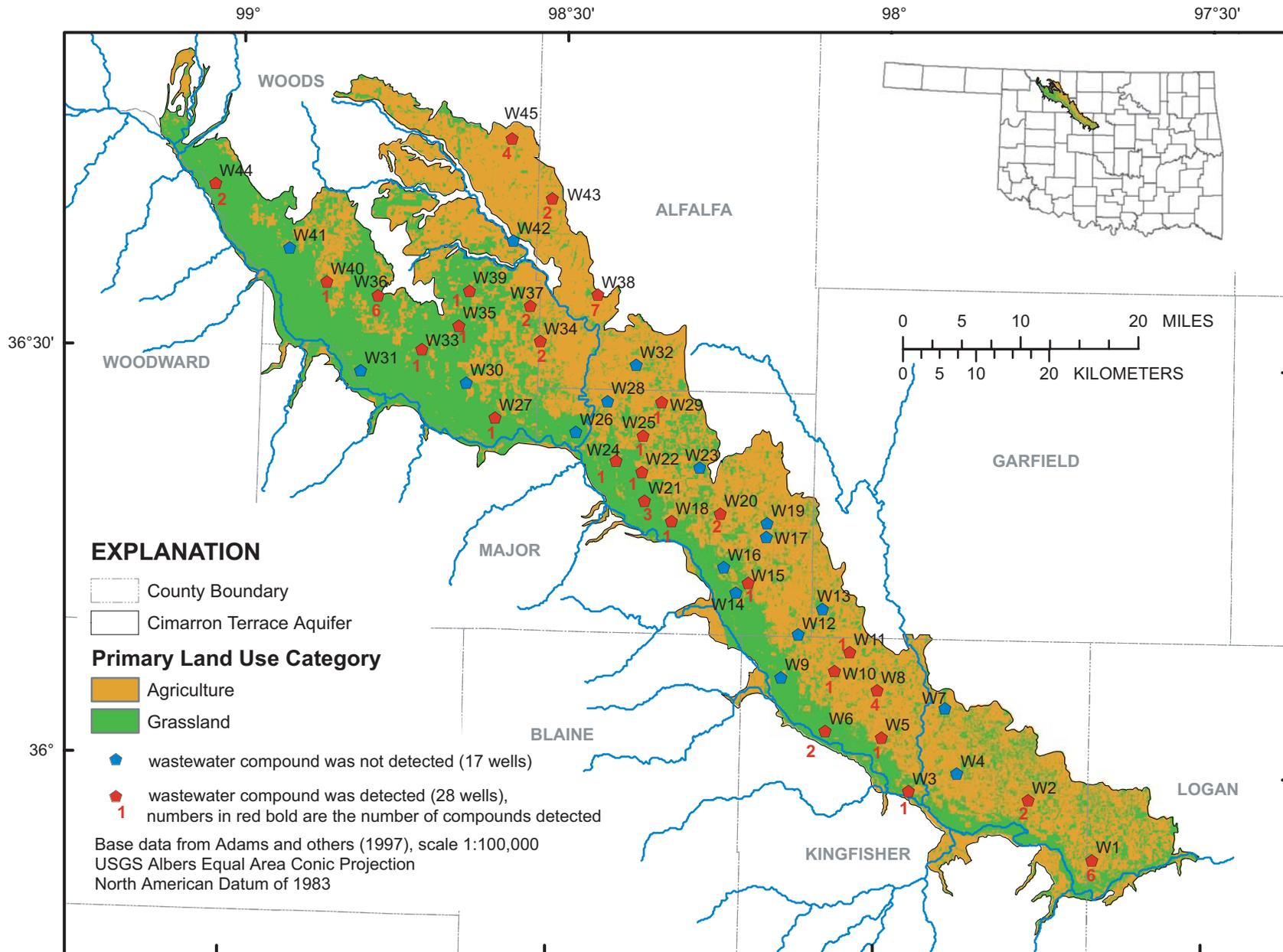
Figure 13. Location of wells with samples having detectable concentrations of wastewater compounds in the Cimarron terrace aquifer, July and August 2003.
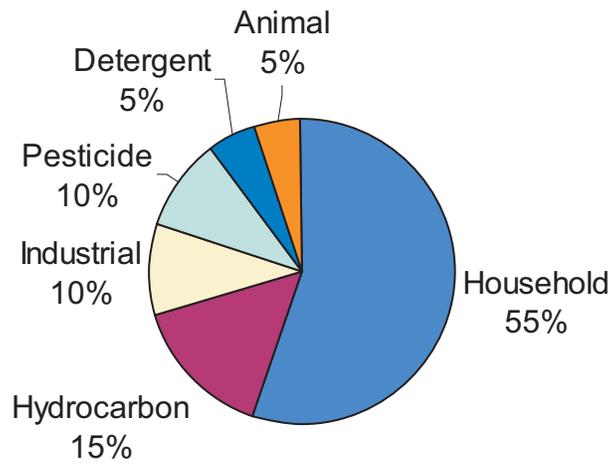
Figure 14. Proportion of wastewater compounds detected in water samples for six selected wastewater-effluent categories.

Table 15. Detected wastewater compounds and range of concentrations in samples from 28 of 45 wells sampled in the Cimarron terrace aquifer, July and August 2003

[µg/L, micrograms per liter; E, estimate]

Wastewater compounds detected	Number of wastewater compounds detected			Range of concentrations (µg/L)	Effluent categories
	Agricultural areas	Grassland areas	Total		
Skatole (3-methyl-1h-indole)	1	0	1	E 0.83	Animal
Tributylphosphate	3	0	3	E 0.02 – E 0.03	Detergent
Anthraquinone	1	0	1	E 0.23	Household
Benzophenone	2	1	3	E 0.01 – E 0.02	Household
Benzo[a]pyrene	0	1	1	E 0.01	Household
Caffeine	1	0	1	E 0.02	Household
Carbazole	1	1	2	E 0.01 – E 0.11	Household
Diethylhexyl phthalate	2	0	2	1.10 – 1.5	Household
Ethanol-2-butoxy-phosphate	1	2	3	E 0.19 – E 0.82	Household
Indole	1	0	1	E 0.12	Household
Isoquinoline	1	0	1	0.04	Household
Methyl salicylate	0	1	1	E 0.02	Household
Phenol	15	8	23	E 0.20 – 5.0	Household
Fluoranthene	1	1	2	E 0.01	Hydrocarbon
Phenanthrene	1	1	2	E 0.01 – E 0.02	Hydrocarbon
Pyrene	1	1	2	E 0.01	Hydrocarbon
P-cresol	2	0	2	E 0.03 - 35.0	Industrial
Triphenyl phosphate	1	0	1	E 0.02	Industrial
Bromacil	1	1	2	E 0.10 - 1.7	Pesticide
N,N-diethyltoluamide (DEET)	4	1	5	E 0.03 – E 0.04	Pesticide
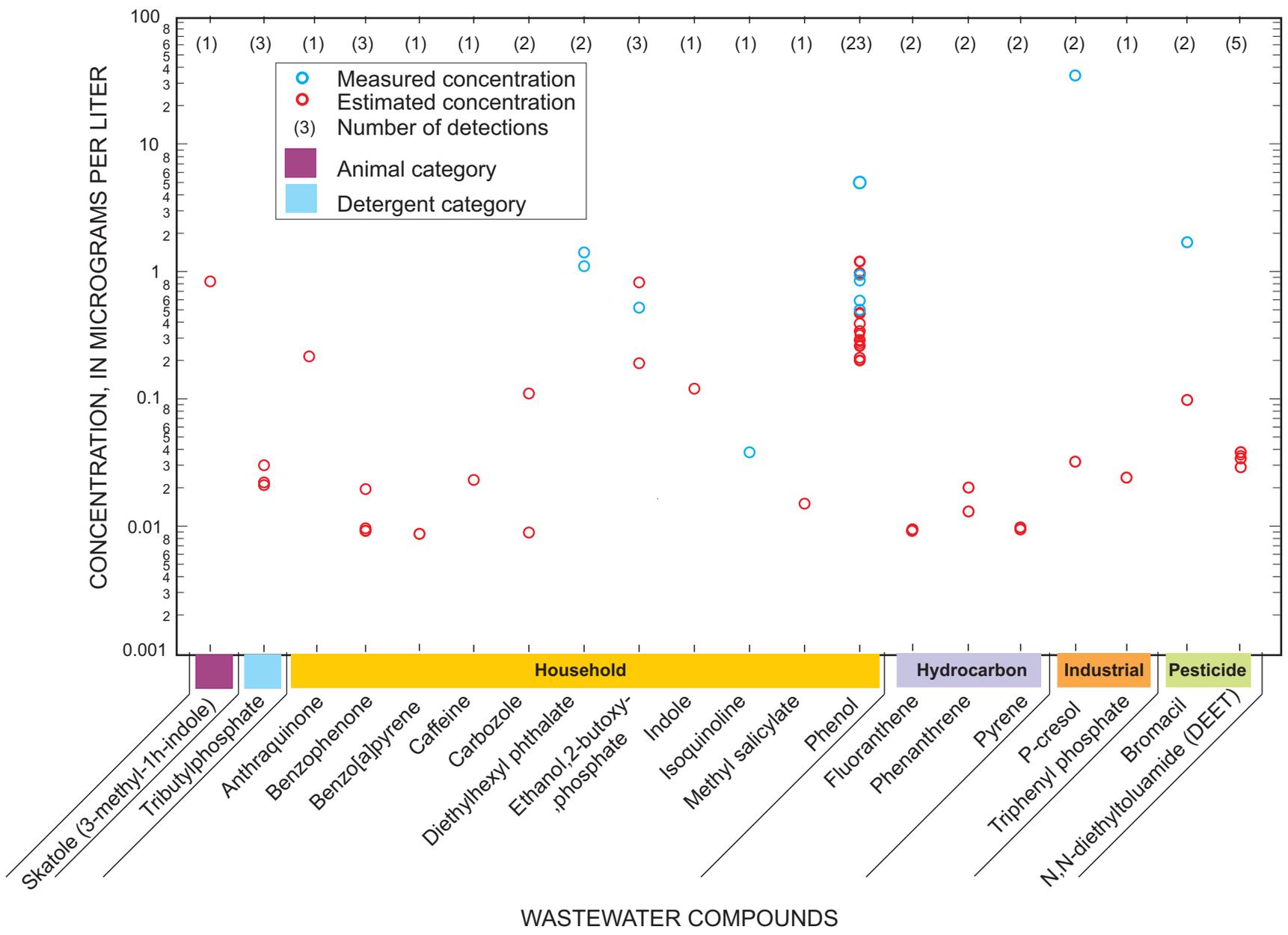
Figure 15. Wastewater compounds detected in samples from 28 of 45 wells in the Cimarron terrace aquifer, July and August 2003.

phosphate were the compounds detected from the industrial category and are commonly used in wood preservation and flame retardant products. Bromacil and N,N-diethyl-meta-toluamide (DEET) were the compounds detected in the pesticides category. Bromacil is a herbicide that is used for brush and weed control in non-cropland areas. DEET is a common insecticide used to control ticks, chiggers, and mosquitoes. Skatole (3-methyl-1h-indole) was the compound detected from the animal category and is commonly found in feces. Tributylphosphate was the compound detected from the detergent category and is a common anti-foaming agent and flame retardant.

The most frequently detected wastewater compound was phenol. It was detected in water samples from 23 wells and ranged from E0.20 to 5.0 µg/L (fig. 15, table 15, Appendix 6). DEET was the second most frequently detected wastewater compound. DEET was detected in 5 wells and ranged from E0.03 to E0.04 µg/L. Benzophenone, ethanol-2-butoxy-phosphate, and tributylphosphate each were detected in 3 wells, ranging from E0.01 to E0.02, E0.19 to E0.82, and E0.02 to E0.03 µg/L, respectively. A sample from W38 had the greatest p-cresol and phenol concentrations, with 35.0 µg/L and 5.0 µg/L.

The greatest number of wastewater compounds detected in a single sample was from well W38, with 7 detections (Appendix 6). Six wastewater compounds were detected in water samples from wells W1 and W36. Water samples from wells W8 and W45 each had 4 wastewater compounds detected. Water samples from the remaining 23 wells had 3 or fewer wastewater compounds detected.

Results from contingency tables indicate that the number of wastewater compounds detected were not statistically different between wells sampled in agricultural areas and wells sampled in grassland areas (Chi squared = 0.134, p-value = 0.714) (Helsel and Hirsch, 1992). Concentrations of wastewater compounds were not significantly correlated with nitrate and phosphorus concentrations, nor were they significantly correlated to well depth or any other site characteristics.

Possible Sources of Nitrate

Nitrogen isotope ratios in nitrate are a common tool for determining the sources of nitrate in water (Kreitler, 1975 and 1989; Kreitler and Browning, 1983; and Wassenaar, 1995). Denitrification is a complicating factor that can limit the use of nitrogen isotopes to determine sources of nitrate. Denitrification causes $\delta^{15}N$ values to increase substantially as nitrate concentrations decrease (Kendall, 1998). Denitrification is a process in which bacteria or inorganic substrates can convert nitrate to nitrous oxide or nitrogen gas (Madison and Brunett, 1984). A second complicating factor can occur when mixing of nitrogen occurs from several sources such as manure or septic waste, the atmosphere, fertilizers, plants, and soils. Denitrification and mixing of several nitrogen sources can cause isotopic ratios to resemble those of plants and natural soils. Nitrate from

synthetic fertilizers and precipitation have similar $\delta^{15}N$ ranges because of common exposure to atmospheric nitrogen (table 12), but nitrate concentrations in precipitation were much less than nitrate concentrations in ground-water samples collected for this study. The annual precipitated-weighted mean nitrate concentration in northwest Oklahoma for 2002 was 1.34 mg/L (National Atmospheric Deposition Program, 2002).

Using multiple lines of evidence from chemical analysis in conjunction with nitrogen isotopes may assist in determining possible nitrate sources. The methods used to determine the possible nitrate sources are based on nitrate source criteria developed using nitrate concentrations, nitrogen-isotope ratios, detection of pesticides, and detection of wastewater compounds. Pesticides and wastewater compounds were used as indicators of fertilizer application or septic or manure waste. Using these diagnostic tools, individual wells were grouped into four possible nitrate source (PNS) categories: (PNS -1) synthetic fertilizer source; (PNS -2) mixed sources (combination of synthetic fertilizer, septic or manure waste, or natural sources); (PNS -3) septic or manure source; and (PNS -4) natural source (plant, soil, or precipitation) (table 16).

There are four main components of how the nitrate source criteria were determined: (1) a nitrate concentration of 3.0 mg/L is used to help determine if nitrate could be from natural sources or the result of human or animal influence; (2) the use of published nitrogen isotopic delta values; (3) indication that synthetic fertilizer could be or is contributing to nitrate concentrations by the detection of one or more pesticides; and (4) the indication that septic or manure waste could be or is contributing to nitrate concentrations by the detection of two or more wastewater compounds detected. Due to very low concentrations and the likelihood of a few of the compounds included in the wastewater schedule (table 5) to occur naturally in the environment, at least two wastewater compounds had to be detected before septic or manure could be considered a possible source of nitrate. The pesticides used as indicators of fertilizer application do not occur naturally and, therefore, only one pesticide had to be detected before synthetic fertilizer could be considered a possible source of nitrate.

Two sets of criteria, Criteria 1 and Criteria 2, were developed by combining nitrate concentrations, nitrogen isotopic delta values, detection of pesticides, or detection of wastewater compounds (table 16). Criteria 1 overrides Criteria 2. If conditions in Criteria 1 were not met, then the determination of the possible source of nitrate was based on Criteria 2. If $\delta^{15}N$ values could not be determined because of nitrate concentrations being too low, the possible nitrate source was considered to be from natural sources.

Synthetic fertilizer was the possible source of nitrate for 13 of 45 wells sampled in the Cimarron terrace aquifer (fig. 16 and 17, table 17). $\delta^{15}N$ values in the synthetic fertilizer category ranged from 0.43 to 3.46‰ (table 18). The nitrate source category with the greatest number of wells (22 wells) was in the mixed sources category. $\delta^{15}N$ values in the mixed sources category ranged from 0.25 to 9.83‰. Two wells (W36 and W43)

Table 16. Description of nitrate source categories used to determine possible sources of nitrate, based on nitrate concentrations, nitrogen isotope delta values ($\delta^{15}N$) in nitrate, and detection of pesticides and wastewater compounds

[<, less than; , $\geq$ greater than or equal to; $\leq$, less than or equal to; PNS, possible nitrate sources; ID, identification number; mg/L, milligrams per liter; $\delta^{15}N$, nitrogen isotope delta value; ‰, permil]

PNS ID	Nitrate source categories	[1]Criteria 1 for nitrate source categories	[2]Criteria 2 for nitrate source categories
PNS-1	Synthetic fertilizer source	One or more pesticides detected and < 2 wastewater compounds detected and -4‰ < $\delta^{15}N$ < +4‰	Nitrate $\geq$ 3.0 mg/L, and -4‰ < $\delta^{15}N$ < +4‰
PNS-2	Mixed, combination of synthetic fertilizer, septic or manure waste, or natural sources	One or more pesticides detected and 2 or more household wastewater compounds detected; or Two or more wastewater compounds detected and 0‰ $\leq \delta^{15}N$ < +10‰	Nitrate $\geq$ 3.0 mg/L and, +4‰ $\leq$ $\delta^{15}N$ < +10‰
PNS-3	Septic or manure sources	Nitrate < 3.0 mg/L and 2 or more wastewater compounds detected	Nitrate $\geq$ 3.0 mg/L and, +10‰ $\leq \delta15N \leq$ +20‰
PNS-4	Natural sources (plant, soil, or precipitation)	Nitrate < 3.0 mg/L, and -10‰ < $\delta^{15}N$ < +10‰	Nitrate < 3.0 mg/L

[1]Criteria 1 overrides Criteria 2.

[2]Nitrate concentration based on Mueller and Helsel (1996) and Madison and Brunett (1984), $\delta^{15}N$ values based on table 12.

had possible septic or manure source as the possible source of nitrate. A $\delta^{15}N$ value was not analyzed in water samples from well W36, because the nitrate concentration was less than the needed concentration (0.5 mg/L) for $\delta^{15}N$ analysis. Natural sources were the possible source of nitrate for 7 wells. The natural sources category had the greatest range of $\delta^{15}N$ values (table 17), ranging from -0.83 to 9.44‰.

Of the 28 wells in the agricultural areas, 5 wells (18 percent) were in the synthetic fertilizer category, 18 wells (64 percent) were in the mixed sources category, 1 well (4 percent) was in the septic or manure source category, and 4 wells (14 percent) were in the natural sources category (fig. 18). Of the 17 wells in the grassland areas, the possible sources of nitrate were determined for 16 wells. Eight wells (50 percent) were in the synthetic fertilizer category, 4 wells (25 percent) were in the mixed sources category, 1 well (6 percent) was in septic or manure sources category, and 3 wells (19 percent) were in the natural sources category (fig. 18).

Summary

Water in the Cimarron terrace aquifer in northwestern Oklahoma commonly has nitrate concentrations that exceed the maximum contaminant level (MCL) of 10 milligrams per liter (mg/L) of nitrite plus nitrate as nitrogen (referred to as nitrate) set by the U.S. Environmental Protection Agency for public drinking water.

Starting in July 2003, the U.S. Geological Survey, in cooperation with the Oklahoma Department of Environmental Quality, conducted a study in the Cimarron terrace aquifer to assess the occurrence and distribution of nitrate, pesticides, and wastewater compounds from land-use activities and to determine possible sources of nitrate. A quantitative and qualitative approach based on multiple lines of evidence from chemical analysis of nitrate, nitrogen isotopes in nitrate, commonly applied pesticides (indicative of fertilizer application), and
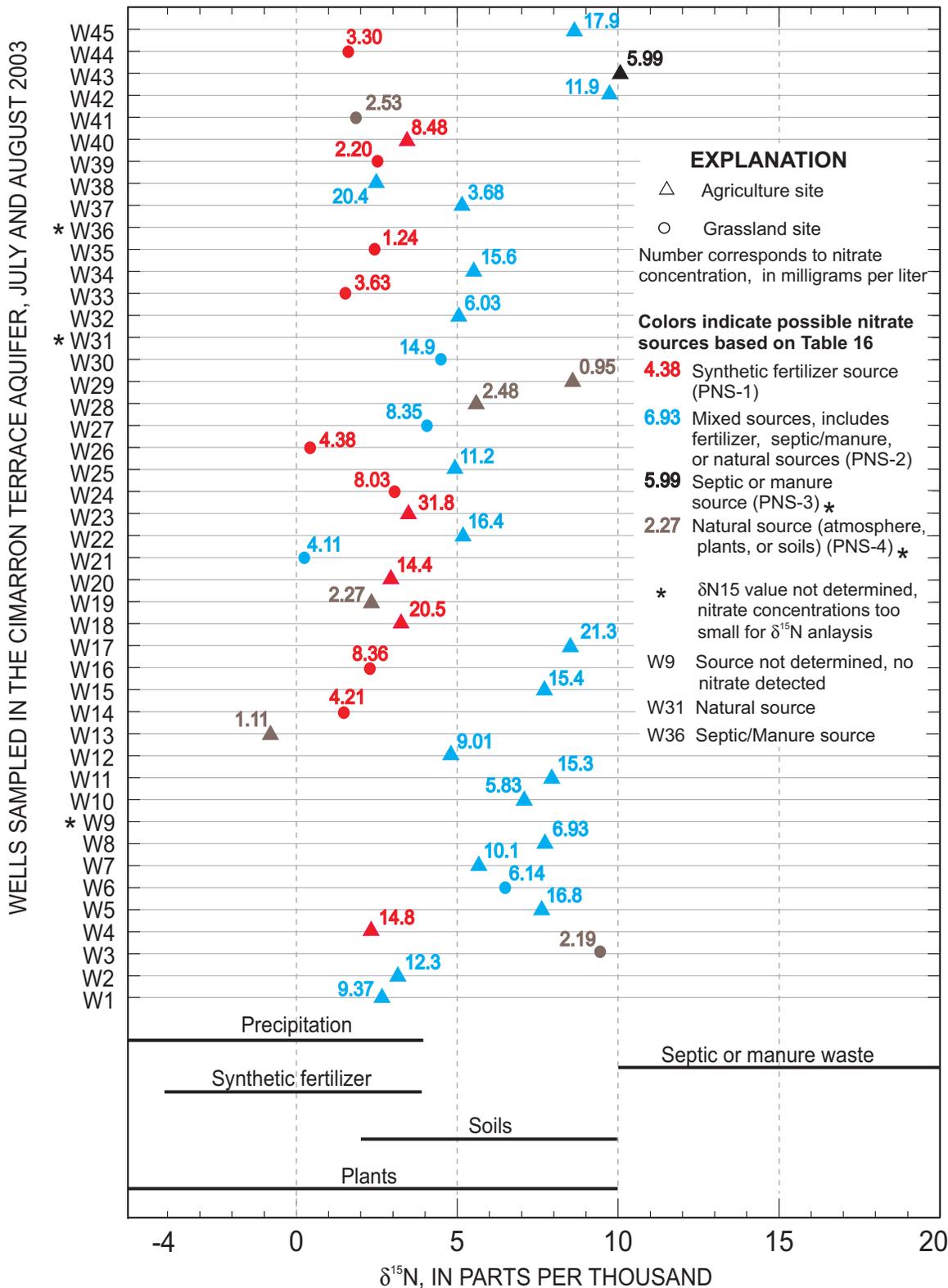
Figure 16. Distribution of nitrogen isotope delta values ($\delta^{15}N$) in nitrate measured in samples, grouped by possible sources of nitrate, from 42 of 45 wells in the Cimarron terrace aquifer, July and August 2003. Shown with nitrate concentrations and $\delta^{15}N$ ranges for major sources of nitrate in the hydrosphere (based on Kreitler, 1975 and Kendall and Aravena, 1999).
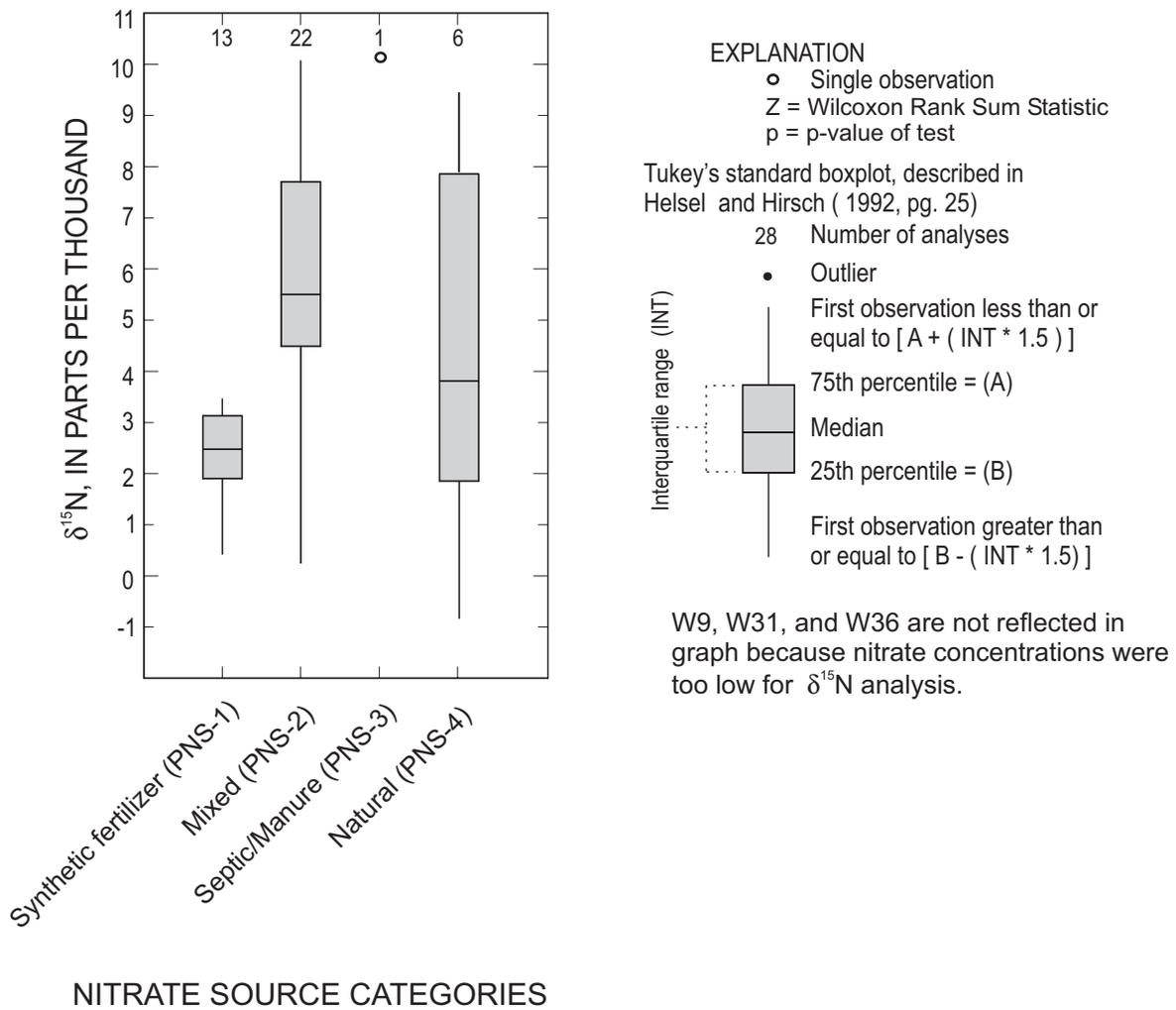
Figure 17. Distribution of nitrogen isotope delta values ($\delta^{15}N$) in nitrate for selected nitrate source categories.

Table 17. Number of detected pesticides and wastewater compounds, land-use categories, nitrate concentrations, nitrogen isotope delta values (δ^{15}N) in nitrate, and possible sources of nitrate in water samples from the Cimarron terrace aquifer, July and August 2003

[ID, identification number; δ, isotope delta value; ‰, permil; mg/L, milligrams per liter; Syn., synthetic; n/a, nitrogen isotope delta value not measured because nitrate concentration was less than the concentration needed for nitrogen isotope analysis; <, less than; -, non-detect]

| Well number | Site ID | Detections | | | | | | | Land use | Nitrate (mg/L) | δ^{15}N (‰) | Possible sources of nitrate |
| | | | Wastewater compounds | | | | | | | | | |
		Total	Pesti-cides	Animal	Deter-gent	House-hold	Hydro-carbon	Indus-trial				
W1	355351097400301	6	1	-	-	4	1	-	Agriculture	9.37	2.66	Mixed
W2	355812097460001	2	-	-	-	2	-	-	Agriculture	12.3	3.16	Mixed
W3	355842097570001	1	-	-	-	1	-	-	Grassland	2.19	9.44	Natural
W4	360004097523601	-	-	-	-	-	-	-	Agriculture	14.8	2.31	Syn. fertilizer
W5	360236097593501	3	2	-	-	1	-	-	Agriculture	16.8	7.61	Mixed
W6	360300098044601	2	1	-	-	1	-	-	Grassland	6.14	6.47	Mixed
W7	360451097534801	-	-	-	-	-	-	-	Agriculture	10.1	5.70	Mixed
W8	360605098000401	4	1	-	-	3	-	-	Agriculture	6.93	7.70	Mixed
W9	360653098085601	2	2	-	-	-	-	-	Grassland	<0.06	n/a	n/a
W10	360726098040101	1	-	-	-	1	-	-	Agriculture	5.83	7.11	Mixed
W11	360851098023901	1	-	-	-	1	-	-	Agriculture	15.3	7.96	Mixed
W12	361005098072601	-	-	-	-	-	-	-	Agriculture	9.01	4.88	Mixed
W13	361159098051501	-	-	-	-	-	-	-	Agriculture	1.11	-0.83	Natural
W14	361303098131501	1	1	-	-	-	-	-	Grassland	4.21	1.47	Syn. fertilizer
W15	361347098120901	2	1	-	-	1	-	-	Agriculture	15.4	7.77	Mixed
W16	361454098142601	-	-	-	-	-	-	-	Grassland	8.36	2.28	Syn. fertilizer
W17	361712098103401	-	-	-	-	-	-	-	Agriculture	21.3	8.53	Mixed
W18	361812098192101	4	3	-	-	1	-	-	Agriculture	20.5	3.20	Syn. fertilizer

Table 17. Number of detected pesticides and wastewater compounds, land-use categories, nitrate concentrations, nitrogen isotope delta values (δ^{15}N) in nitrate, and possible sources of nitrate in water samples from the Cimarron terrace aquifer, July and August 2003—Continued

[ID, identification number; δ, isotope delta value; ‰, permil; mg/L, milligrams per liter; Syn., synthetic; n/a, nitrogen isotope delta value not measured because nitrate concentration was less than the concentration needed for nitrogen isotope analysis; <, less than; -, non-detect]

Well number	Site ID	Detections							Land use	Nitrate (mg/L)	δ^{15}N (‰)	Possible sources of nitrate
			Wastewater compounds									
		Total	Pesti-cides	Animal	Deter-gent	House-hold	Hydro-carbon	Indus-trial				
W19	361813098103201	-	-	-	-	-	-	-	Agriculture	2.27	2.34	Natural
W20	361850098145201	2	-	-	-	1	-	1	Agriculture	14.4	2.85	Syn. fertilizer
W21	361939098215301	5	2	-	-	3	-	-	Grassland	4.11	0.25	Mixed
W22	362146098215401	4	3	-	-	1	-	-	Agriculture	16.4	5.15	Mixed
W23	362212098165201	3	3	-	-	-	-	-	Agriculture	31.8	3.46	Syn. fertilizer
W24	362233098243601	1	-	-	-	1	-	-	Grassland	8.03	3.05	Syn. fertilizer
W25	362426098221001	5	4	-	-	1	-	-	Agriculture	11.2	4.95	Mixed
W26	362435098282201	-	-	-	-	-	-	-	Grassland	4.38	0.43	Syn. fertilizer
W27	362530098355201	1	-	-	-	1	-	-	Grassland	8.35	4.06	Mixed
W28	362655098253101	1	1	-	-	-	-	-	Agriculture	2.48	5.50	Natural
W29	362657098203101	1	-	-	-	1	-	-	Agriculture	0.95	8.60	Natural
W30	362800098383701	-	-	-	-	-	-	-	Grassland	14.9	4.49	Mixed
W31	362842098482401	-	-	-	-	-	-	-	Grassland	0.13	n/a	Natural
W32	362939098225701	-	-	-	-	-	-	-	Agriculture	6.03	4.98	Mixed
W33	363023098424801	1	-	-	-	1	-	-	Grassland	3.63	1.52	Syn. fertilizer
W34	363113098315201	2	-	-	-	2	-	-	Agriculture	15.6	5.50	Mixed
W35	363211098392401	2	1	-	-	1	-	-	Grassland	1.24	2.43	Syn. fertilizer
W36	363330098470001	6	-	-	-	2	4	-	Grassland	0.37	n/a	Septic or Manure
W37	363348098325401	4	2	-	-	2	-	-	Agriculture	3.68	5.14	Mixed
W38	363445098264001	7	-	1	1	4	-	1	Agriculture	20.4	2.48	Mixed

Table 17. Number of detected pesticides and wastewater compounds, land-use categories, nitrate concentrations, nitrogen isotope delta values (δ^{15}N) in nitrate, and possible sources of nitrate in water samples from the Cimarron terrace aquifer, July and August 2003—Continued

[ID, identification number; δ, isotope delta value; ‰, permil; mg/L, milligrams per liter; Syn., synthetic; n/a, nitrogen isotope delta value not measured because nitrate concentration was less than the concentration needed for nitrogen isotope analysis; <, less than; -, non-detect]

| Well number | Site ID | Detections | | | | | | | Land use | Nitrate (mg/L) | δ^{15}N (‰) | Possible sources of nitrate |
| | | | Wastewater compounds | | | | | | | | | |
		Total	Pesti-cides	Animal	Deter-gent	House-hold	Hydro-carbon	Indus-trial				
W39	363452098384301	3	2	-	-	1	-	-	Grassland	2.20	2.52	Syn. fertilizer
W40	363510098514601	4	3	-	-	1	-	-	Agriculture	8.48	3.42	Syn. fertilizer
W41	363735098551801	-	-	-	-	-	-	-	Grassland	2.53	1.85	Natural
W42	363834098343801	-	-	-	-	-	-	-	Agriculture	11.9	9.83	Mixed
W43	364519098311701	3	1	-	-	-	2	-	Agriculture	5.99	10.1	Septic or Manure
W44	364258099000801	2	-	-	-	2	-	-	Grassland	3.30	1.61	Syn. fertilizer
W45	364605098350001	4	1	-	1	2	-	-	Agriculture	17.9	8.69	Mixed

Table 18. Statistical summary of nitrogen isotope delta values (δ^{15}N) in nitrate, for selected nitrate source categories, from samples of 42 of 45 wells in the Cimarron terrace aquifer, July and August 2003.

[PNS, possible nitrate sources; ID, identification number]

PNS ID	Nitrate source categories	[1]Number of wells in category	δ^{15}N summary statistics, in permil					Maximum
			Minimum	Mean	25th	50th (median)	75th	
PNS-1	Synthetic fertil-izer source	13	0.43	2.35	1.61	2.43	3.05	3.46
PNS-2	Mixed source	22	0.25	5.69	4.59	5.30	7.68	9.83
PNS-3	Septic/Manure source	[2](1)	10.1					
PNS-4	Natural source	[3](6)	-0.83	4.48	1.97	3.92	7.83	9.44

[1]δ^{15}N value not determined for well (W9) because nitrate was not detected.

[2]δ^{15}N value not determined for well (W36) because the nitrate concentration was too low for δ^{15}N analysis. Nitrate source was determined using criteria 1.

[3]δ^{15}N value not determined for well (W31) because the nitrate concentration was too low for δ^{15}N analysis. Nitrate source was determined using only nitrate concentrations as described in criteria 2.
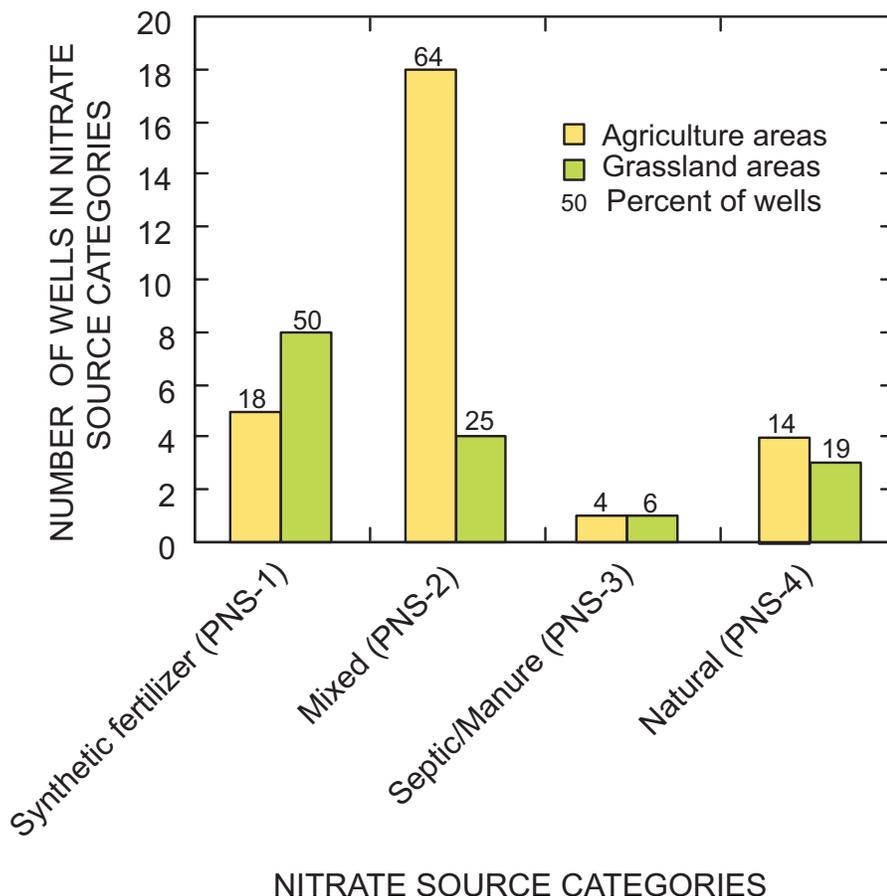
Figure 18. Number of wells located in agricultural and grassland areas for selected nitrate source categories.

wastewater compounds (indicative of animal and human waste-water) was used to assess sources of nitrate contamination in the Cimarron terrace aquifer.

Forty-five ground-water sampling locations were selected randomly using a computerized stratified random selection algorithm. Land-use information from the National Land Cover Dataset (NLCD) was used to categorize the land use in the Cimarron terrace aquifer into two general land-use categories, agricultural areas and grassland areas.

Specific conductance measurements ranged from 289 to 2,118 microsiemens per centimeter at 25 degrees Celsius (μS/cm), with a median concentration of 759 μS/cm. The pH measurements ranged from 6.1 to 7.5, with a median value of 7.0. The USEPA has established secondary drinking water standards for pH ranging from 6.5 to 8.5. The pH measurements at wells W23, W33, W36, and W39 were less than 6.5. Temperature measurements ranged from 16.0 to 18.9 degrees Celsius, with a median value of 17.2 degrees Celsius. Dissolved oxygen measurements ranged from 0.2 to 9.4 mg/L, with a median value of 3.2 mg/L. Specific conductance measurements from wells in agricultural areas were significantly greater than specific conductance measurements from wells in grassland areas ($z = 1.92$, p-value = 0.027).

Nitrate was detected in 44 of 45 ground-water samples and had the greatest median concentration (8.03 mg/L) of any nutrient. Nitrate concentrations ranged from <0.06 to 31.8 mg/L. Seventeen samples (38 percent) had nitrate concentrations that exceeded the MCL of 10 mg/L. Nitrate concentrations in wells in agricultural areas were significantly greater than nitrate concentrations in grassland areas ($z = 3.55$, p-value = <0.001).

The δ^{15}N values were measured in water samples from 42 of 45 wells sampled in the Cimarron terrace aquifer. δ^{15}N values for the 42 wells ranged from –0.83 to 10.1‰, with a median value of 4.28‰ and a mean of 4.59‰. Results from a Wilcoxon Rank-Sum test comparing δ^{15}N values measured in samples from agricultural areas to δ^{15}N values measured in samples from grassland areas indicated that δ^{15}N values were significantly greater in the agricultural areas than in the grassland areas ($z = 2.98$, p-value = 0.002). The median δ^{15}N value in the agricultural areas was 5.15‰, whereas the median δ^{15}N value in the grassland areas was 2.36‰.

Pesticides were detected in water samples from 15 of 45 (33 percent) wells. Atrazine and deethylatrazine, a metabolite of atrazine, were the most frequently detected. Deethylatrazine was detected in water samples from 9 wells and atrazine was detected in water samples from 8 wells. Atrazine concentrations were less than the MCL of 3 micrograms per liter (μg/L). Tebuthiuron was detected in water samples from 5 of the 45 wells, but none of the tebuthiuron concentrations exceeded the USEPA health advisory of 500 μg/L. Metolachlor was detected in water samples from 4 wells, but none of the metolachlor concentrations exceeded the USEPA health advisory of 100 μg/L. Prometon was detected in water samples from 4 wells, but none of the prometon concentrations exceeded the USEPA health advisory of 500 μg/L. Alachlor was only detected in 1 well and the concentration was less than the MCL of 2 μg/L.

Wastewater compounds were detected in water samples from 28 of 45 wells (62 percent). Of the 20 wastewater compounds detected, 11 compounds (55 percent) were in the household category, 3 compounds (15 percent) were in the hydrocarbon category, 2 compounds (10 percent) were in the industrial category, 2 compounds (10 percent) were in the pesticides category, 1 compound (5 percent) was in the animal category, and 1 compound (5 percent) was in the detergent category.

Wastewater compounds in the household category are commonly used in products such as perfumes, coffee, soaps, dyes, flame retardant products, lubricants, and disinfectants. Fluoranthene, phenanthrene, and pyrene were the compounds in the hydrocarbon category. P-cresol and triphenyl phosphate were the compounds detected in the industrial category and are commonly used in wood preservation and flame retardant products. Bromacil and N,N-diethyl-meta-toluamide (DEET) were the compounds detected in the pesticides category. Skatole (3-methyl-1h-indole) was the compound detected from the animal category and is found in feces. Tributylphosphate was the compound detected from the detergent category and is a common anti-foaming agent and flame retardant.

Phenol was the most frequently detected wastewater compound and was detected in 23 wells. DEET was the second most frequently detected wastewater compound and was detected in 5 wells. Benzophenone, ethanol,2-butoxy phosphate, and tributylphosphate each were detected in 3 wells. The greatest number of wastewater compounds detected in a single well occurred in W38 with 7 detections. Six wastewater compounds were detected in W1 and W36. Wells W8 and W45 each had 4 wastewater compounds detected. The remaining 23 wells had 3 or fewer wastewater compounds detected.

A qualitative and quantitative approach based on multiple lines of evidence from chemical analysis of nitrate, nitrogen isotopes in nitrate, commonly applied pesticides (indicative of fertilizer application), and wastewater compounds (indicative of human animal waste) was used to indicate possible sources of nitrate. Individual wells were grouped into four possible nitrate source categories: (1) synthetic fertilizer source; (2) mixed sources (combination of synthetic fertilizer, septic or manure sources, or natural sources); (3) septic or manure sources; and (4) natural sources (plant, soil, or precipitation). Synthetic fertilizer was the possible source of nitrate for 13 wells sampled in the Cimarron terrace aquifer. The nitrate source category with the greatest number of wells (22 wells) was the mixed sources category. There were 2 wells (W36 and W43) where the possible source of nitrate was from septic or manure sources. Seven wells had natural sources as the possible nitrate source. The natural sources category had the greatest range of δ^{15}N values, with δ^{15}N values ranging from –0.83 to 9.44‰.

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Appendixes

Appendix 1. Quality Control

All equipment used to collect water samples was cleaned between sites using a non-phosphate detergent and was thoroughly rinsed with tap water followed by deionized water. After rinsing of equipment with tap and deionized water, pesticide equipment was rinsed with pesticide-grade methanol solvent then allowed to air dry. Stainless steel compression fittings and aluminum equipment were wrapped in aluminum foil and placed inside new quality-assured plastic bags, as was the Teflon tubing.

Quality-control samples were collected and analyzed to evaluate the degree of accuracy, precision, and bias of environmental samples. Quality-control samples for this investigation consisted of two field blank samples from W3 and W32, three replicate environmental samples from wells W2, W19, and W39, and two environmental-matrix spike samples from wells W19 and W28.

Field blank samples are used to determine if environmental samples were contaminated during the sampling process. Field blanks were prepared in the field by processing quality-assured high purity organic blank water through the sampling equipment in exactly the same manner that environmental samples were collected. Field blank samples were analyzed for concentrations of nutrients, pesticides, and wastewater compounds. For nutrients, a concentration of 0.2 mg/L of ammonia plus organic nitrogen and a concentration of 0.002 mg/L of phospho-

rus were detected in a field blank collected at W3 (Appendix 3). No nutrient concentrations were detected in the field blank sample collected from W32. Pesticide and wastewater compounds were not detected in any of the field blanks collected from W3 and W32 (Appendix 5 and 6). Field blank samples indicated that contamination from equipment and field procedures were minimal.

Replicate environmental samples were analyzed for concentrations of nutrients, nitrogen isotopes, pesticides, and wastewater compounds. Precision is calculated from one environmental sample and one replicate environmental sample, expressed as the relative percent difference (RPD) using equation 2:

$$RPD = |C_1 - C_2| / ((C_1 + C_2) / 2) * 100 \qquad (2)$$

where
C_1 = largest of the two values;
C_2 = smaller of the two values.

If either of a constituent concentration was less than the analytical reporting level, then the RPD was not calculated. RPD values for nutrient replicate samples ranged from 0 to 40 percent (table 19). RPD values for nitrogen isotope replicate samples ranged from 3.9 to 41.8 percent (table 20). Pesticides were not detected in environmental and replicate samples col-

Table 19. Nutrient concentrations for environmental and replicate samples, shown with relative percent difference (RPD) values

[mg/L, milligrams per liter; RPD, relative percent difference; <, less than]

Well number	Nitrite (mg/L)	Nitrite plus nitrate as Nitrogen (mg/L)	Ammonia (mg/L)	Ammonia plus organic nitrogen (mg/L)	Phosphorus (mg/L)	Orthophosphate (mg/L)
W39 (sample)	<0.008	2.2	<0.04	0.06	0.047	0.04
W39 (replicate)	<0.008	2.21	<0.04	0.05	0.048	0.04
RPD (percent)		0.45		18.2	1.4	0
W2 (sample)	<0.008	12.3	<0.04	0.06	0.16	0.15
W2 (replicate)	<0.008	12.5	<0.04	0.09	0.16	0.14
RPD (percent)		1.6		40.0	0	6.9
W19 (sample)	<0.008	2.27	<0.04	<0.1	0.009	0.02
W19 (replicate)	<0.008	2.18	<0.04	0.08	0.008	<0.02
RPD (percent)		4.0			11.7	

Table 20. Nitrogen isotope delta values ($\delta^{15}N$) in nitrate for environmental and replicate samples, shown with relative percent difference (RPD) values

[RPD, relative percent difference; $\delta^{15}N$ nitrogen isotope delta value]

Well number	δ^{15}N (permil)
W2 (sample)	3.16
W2 (replicate)	3.04
RPD (percent)	3.9
W19 (sample)	2.34
W19 (replicate)	2.75
RPD (percent)	16.1
W39 (sample)	2.52
W39 (replicate)	3.85
RPD (percent)	41.8

lected from wells W2 and W19 (Appendix 5). Out of the three replicate samples collected, pesticides were only detected in well W39. RPD values were less than 6 percent (table 21). Concentrations in environmental and replicate samples for wastewater compounds were very similar (Appendix 6). RPD values were not calculated because concentrations were listed as estimates or as non-detects. Small differences in low constituent concentrations led to the greater RPD values. Replicate samples generally indicated an acceptable degree of reproducibility of results.

Two samples (W19 and W28) were spiked in the field with known concentrations of pesticide compounds. Analytical recoveries (AR) of the spiked pesticide compounds are expressed in percentages in relation to a theoretical or calculated (expected) concentration using equation 3:

$$AR = ((Cspike - Csample) / Cexpect) * 100 \qquad (3)$$

where
Cspike = is the concentration of the spiked environmental sample;
Csample = is the concentration of the environmental sample;
Cexpect = is the theoretical or calculated concentration, based on spiked concentrations, known volume of individ-

ual spiked compounds, and volume of spiked environmental sample.

Analytical recoveries for samples from W19 ranged from 44.9 to 126.1 percent, with a mean recovery of 93.8 percent (table 22). Analytical recoveries for the spiked sample from well W28 ranged from 35.1 to 314.6 percent, with a mean recovery of 102.7 percent. Five pesticides in the spiked sample from well W19 (azinphos-methyl, carbaryl, cis-permethrin, deethylatrazine, and Disulfoton) had analytical recoveries less than 70 percent, and eight pesticides (acetochlor, alachlor, alpha-HCH, diazinon, 2-6 diethylaniline, fonofos, lindane, and Linuron) had analytical recoveries greater than 115 percent (table 23). Six pesticides in the spiked sample from well W28 (cis-permethrin, deethylatrazine, disulfoton, p,p'-DDE, phorate, and Terbufos) had analytical recoveries less than 70 percent, and five pesticides (azinphos-methyl, carbaryl, carbofuran, Linuron, and propargite) had analytical recoveries greater than 115 percent (table 23). Pesticides concentrations that are underestimated in spike samples indicate that they could be underestimated in the environmental samples. Pesticides concentrations that are overestimated in spike samples indicate that they could be overestimated in the environmental samples.

Table 21. Pesticide concentrations for the single environmental and replicate sample in which pesticides were detected, shown with relative percent differences (RPD) values

[µg/L, micrograms per liter; RPD, relative percent difference; E, estimate]

Well ID	Deethylatrazine (µg/L)	Atrazine (µg/L)
W39 (sample)	E 0.117	0.043
W39 (replicate)	E 0.124	0.043
RPD (percent)	5.8	0

Table 22. Summary of pesticide environmental-matrix spike recoveries for selected pesticides in U.S. Geological Survey schedule 2001.

[all units are in percent]

Well ID	Percentiles				Maximum	Mean
	Minimum	25th	50th (Median)	75th		
W19	44.9	72.2	92.8	109.0	126.1	93.8
W28	35.1	68.0	95.7	105.8	314.6	102.7

Table 23. Individual pesticide environmental-matrix spike recoveries for selected pesticides in U.S. Geological Survey schedule 2001

[Env., environmental sample; conc., concentration; μg/L, micrograms per liter; %, percent]

Pesticide	W19			W28		
	[1]Env. Sample conc. (μg/L)	Spiked conc. (μg/L)	Recovery (%)	Env. Sample conc. (μg/L)	Spiked conc. (μg/L)	Recovery (%)
Acetochlor	0	0.128	115.3	0	0.114	104.9
Alachlor	0	0.128	115.3	0	0.116	106.7
Alpha-HCH	0	0.134	120.7	0	0.101	92.9
Atrazine	0	0.112	100.9	0	0.121	111.3
Azinphos-methyl	0	0.052	46.9	0	0.221	203.3
Benfluralin	0	0.083	75.1	0	0.083	76.6
Butylate	0	0.127	114.4	0	0.096	88.5
Carbaryl	0	0.075	67.8	0	0.342	314.6
Carbofuran	0	0.11	99.1	0	0.26	239.5
Chlorpyrifos	0	0.111	100	0	0.107	98.4
cis-permethrin	0	0.067	60.5	0	0.067	62
Cyanazine	0	0.122	109.9	0	0.11	101.2
Dacthal (dcpa)	0	0.12	108.1	0	0.112	103
Deethylatrazine	0	0.05	44.9	0	0.041	37.8
Diazinon	0	0.14	126.1	0	0.106	97.5
Dieldrin	0	0.096	86	0	0.1	91.9
2-6 diethylaniline	0	0.131	118	0	0.112	103
Disulfoton	0	0.055	49.9	0	0.038	35.1
EPTC	0	0.102	91.9	0	0.095	87
Ethalfluralin	0	0.095	85.7	0	0.094	86.6
Ethoprophos	0	0.097	86.9	0	0.098	89.7
Fonofos	0	0.131	118	0	0.099	90.6
Lindane (Gamma-HCH)	0	0.137	123.4	0	0.104	95.7
Linuron	0	0.135	121.6	0	0.147	135.2
Malathion	0	0.102	91.9	0	0.137	126
Metolachlor	0	0.108	97.3	0	0.117	107.6
Metribuzin	0	0.091	81.8	0	0.094	86
Molinate	0	0.098	88.5	0	0.099	90.9

Table 23. Individual pesticide environmental-matrix spike recoveries for selected pesticides in U.S. Geological Survey schedule 2001—Continued

Pesticide	W19			W28		
	[1]Env. Sample conc. (μg/L)	Spiked conc. (μg/L)	Recovery (%)	Env. Sample conc. (μg/L)	Spiked conc. (μg/L)	Recovery (%)
Napropamide	0	0.102	91.9	0	0.087	80.4
p,p'-DDE	0	0.089	80.4	0	0.072	66.2
Parathion	0	0.094	84.8	0	0.113	104
Parathion-methyl	0	0.09	80.7	0	0.123	113.2
Pebulate	0	0.1	89.8	0	0.097	89
Pendimethalin	0	0.084	75.9	0	0.084	77.5
Phorate	0	0.106	95.5	0	0.075	68.9
Prometon	0	0.125	112.6	0	0.117	107.6
Pronamide	0	0.115	103.6	0	0.096	88.7
Propachlor	0	0.114	102.7	0	0.115	105.8
Propanil	0	0.103	92.8	0	0.111	102.1
Propargite	0	0.113	101.8	0	0.131	120.5
Simazine	0	0.093	84	0	0.115	105.8
Tebuthiuron	0	0.111	100	0.0397	0.154	105.2
Terbacil	0	0.1	90.1	0	0.097	88.8
Terbufos	0	0.084	75.5	0	0.072	66.6
Thiobencarb	0	0.117	105.4	0	0.111	102.1
Triallate	0	0.126	113.5	0	0.095	86.9
Trifluralin	0	0.088	79.1	0	0.09	83.1

[1]If a pesticide compound was not detected, a "0" was substituted as a value in order to calculate the recoveries.

Appendix 2. Water properties measured in samples from 45 wells in the Cimarron terrace aquifer, July and August 2003

[ID, identification number; μS/cm; microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter: -, no data]

Well number (fig. 3)	Site ID	Date measured	Time	Specific conductance (μS/cm)	pH (standard units)	Water temperature (degrees Celsius)	Dissolved oxygen (mg/L)
W1	355351097400301	08/07/03	0900	365	6.9	17.6	7.2
W2	355812097460001	07/18/03	0900	482	7.0	17.8	3.0
W3	355842097570001	07/16/03	1600	763	7.4	17.1	0.2
W4	360004097523601	07/15/03	0900	460	6.7	17.4	4.9
W5	360236097593501	07/15/03	1500	873	7.3	18.9	5.2
W6	360300098044601	07/15/03	1700	675	7.3	16.6	1.9
W7	360451097534801	07/11/03	1100	759	7.0	17.4	3.0
W8	360605098000401	07/15/03	1200	1,005	6.9	17.4	0.9
W9	360653098085601	07/16/03	1400	735	7.3	17.2	3.9
W10	360726098040101	07/11/03	0900	830	7.1	17.2	1.3
W11	360851098023901	07/08/03	1600	804	6.8	16.9	3.1
W12	361005098072601	07/16/03	1100	423	7.3	17.6	5.1
W13	361159098051501	07/08/03	1400	622	7.5	17.5	0.4
W14	361303098131501	07/10/03	1000	630	7.3	17.2	1.1
W15	361347098120901	07/10/03	1100	948	7.2	17.2	2.8
W16	361454098142601	07/09/03	1000	806	7.3	17.9	6.8
W17	361712098103401	07/08/03	1030	1,200	7.1	17.2	1.3
W18	361812098192101	07/09/03	1200	1,130	7.2	17.0	3.1
W19	361813098103201	07/08/03	0800	649	7.4	17.2	7.0
W20	361850098145201	07/10/03	1500	674	7.0	17.0	4.5
W21	361939098215301	07/09/03	1400	622	7.4	16.2	6.2
W22	362146098215401	07/16/03	1300	778	6.6	16.5	8.6
W23	362212098165201	07/16/03	0900	862	6.3	17.5	5.7
W24	362233098243601	08/07/03	1500	435	7.1	17.3	3.2
W25	362426098221001	07/16/03	1130	837	7.0	18.0	8.1
W26	362435098282201	07/09/03	1600	809	7.4	16.4	2.8
W27	362530098355201	07/03/03	1530	519	7.4	16.3	3.3
W28	362655098253101	07/17/03	0900	860	6.7	18.0	1.6
W29	362657098203101	08/08/03	1200	1,230	7.5	17.4	1.0
W30	362800098383701	07/02/03	1400	696	7.3	17.6	5.0
W31	362842098482401	07/02/03	1030	411	7.4	16.6	5.7
W32	362939098225701	07/17/03	1130	489	6.9	17.0	6.6
W33	363023098424801	07/16/03	1500	289	6.3	18.0	7.5
W34	363113098315201	07/11/03	1200	532	6.6	18.0	3.0
W35	363211098392401	07/03/03	0900	607	7.4	16.0	2.8
W36	363330098470001	07/08/03	1400	747	6.4	17.0	0.2
W37	363348098325401	07/09/03	1400	938	6.6	17.0	2.0
W38	363445098264001	07/23/03	1000	1,100	6.9	16.0	-
W39	363452098384301	07/08/03	1530	575	6.1	18.0	3.7
W40	363510098514601	07/02/03	1500	715	7.3	17.2	5.2
W41	363735098551801	07/11/03	1500	974	7.0	17.0	9.4
W42	363834098343801	07/09/03	1030	1,440	6.6	17.0	2.0
W43	364519098311701	07/09/03	1200	1,680	6.6	16.0	1.8
W44	364258099000801	07/08/03	1000	1,770	6.8	16.5	3.0
W45	364605098350001	07/11/03	0930	2,118	6.7	18.0	8.5

Appendix 3. Nutrient concentrations in samples from 45 wells in the Cimarron terrace aquifer, July and August 2003

[shading indicates quality-control sample; FB, field blank; R, replicate; E, estimate; mg/L, milligrams per liter; <, less than]

Well number (fig. 3)	Site ID	Date Measured	Time	Nitrite (mg/L)	Nitrite plus nitrate as nitrogen (mg/L)	Ammonia (mg/L)	Ammonia plus organic nitrogen (mg/L)	Phosphorus (mg/L)	Ortho-phosphate (mg/L)
W1	355351097400301	08/07/03	0900	<0.008	9.37	<0.04	<0.10	0.078	0.07
W2	355812097460001	07/18/03	0900	<0.008	12.3	<0.04	E 0.06	0.160	0.15
W2-R	355812097460001	07/18/03	0905	<0.008	12.5	<0.04	E 0.09	0.160	0.14
W3	355842097570001	07/16/03	1600	<0.008	2.19	<0.04	<0.10	0.044	0.04
W3-FB	355842097570001	07/16/03	1615	<0.008	<0.06	<0.04	0.2	0.002	<0.02
W4	360004097523601	07/15/03	0900	<0.008	14.8	<0.04	E 0.06	0.140	0.12
W5	360236097593501	07/15/03	1500	<0.008	16.8	<0.04	E 0.09	0.050	<0.09
W6	360300098044601	07/15/03	1700	<0.008	6.14	<0.04	<0.10	0.064	0.06
W7	360451097534801	07/11/03	1100	<0.008	10.1	<0.04	0.13	0.039	0.03
W8	360605098000401	07/15/03	1200	<0.008	6.93	<0.04	E 0.09	0.132	0.12
W9	360653098085601	07/16/03	1400	<0.008	<0.06	0.05	E 0.09	0.058	0.03
W10	360726098040101	07/11/03	0900	<0.008	5.83	<0.04	E 0.09	0.153	0.15
W11	360851098023901	07/08/03	1600	<0.008	15.3	<0.04	0.14	0.082	0.07
W12	361005098072601	07/16/03	1100	<0.008	9.01	<0.04	<0.10	0.125	0.11
W13	361159098051501	07/08/03	1400	<0.008	1.11	<0.04	<0.10	0.034	0.03
W14	361303098131501	07/10/03	1000	<0.008	4.21	<0.04	0.15	0.077	0.06
W15	361347098120901	07/10/03	1100	<0.008	15.4	<0.04	0.14	0.077	0.07
W16	361454098142601	07/09/03	1000	<0.008	8.36	<0.04	0.13	0.035	0.03
W17	361712098103401	07/08/03	1030	<0.008	21.3	<0.04	0.16	0.049	0.04
W18	361812098192101	07/09/03	1200	<0.008	20.5	<0.04	0.12	0.026	0.02
W19	361813098103201	07/08/03	0800	<0.008	2.27	<0.04	<0.10	0.009	<0.02
W19-R	361813098103201	07/08/03	0805	<0.008	2.18	<0.04	E 0.08	0.008	<0.02
W20	361850098145201	07/10/03	1500	<0.008	14.4	<0.04	0.11	0.107	0.09
W21	361939098215301	07/09/03	1400	<0.008	4.11	<0.04	E 0.1	0.040	0.03
W22	362146098215401	07/16/03	1300	<0.008	16.4	<0.04	<0.10	0.053	0.04
W23	362212098165201	07/16/03	0900	<0.008	31.8	<0.04	E 0.1	0.138	0.12
W24	362233098243601	08/07/03	1500	<0.008	8.03	<0.04	<0.10	0.071	0.06
W25	362426098221001	07/16/03	1130	<0.008	11.2	<0.04	E 0.07	0.059	0.04
W26	362435098282201	07/09/03	1600	<0.008	4.38	<0.04	0.13	0.048	0.04
W27	362530098355201	07/03/03	1530	<0.008	8.35	<0.04	0.18	0.053	0.04
W28	362655098253101	07/17/03	0900	<0.008	2.48	<0.04	0.10	0.050	0.04
W29	362657098203101	08/08/03	1200	E 0.005	0.95	<0.04	<0.10	0.006	<0.02
W30	362800098383701	07/02/03	1400	<0.008	14.9	<0.04	<0.10	0.061	0.06

Appendix 3. Nutrient concentrations for 45 wells sampled in the Cimarron terrace aquifer, July and August 2003 –Continued

[FB, field blank; R, replicate; E, estimate; mg/L, milligrams per liter; <, less than]

Well number	Site ID	Date Measured	Time	Nitrite (mg/L)	Nitrite plus nitrate as nitrogen (mg/L)	Ammonia (mg/L)	Ammonia plus organic nitrogen (mg/L)	Phosphorus (mg/L)	Ortho-phosphate (mg/L)
W31	362842098482401	07/02/03	1030	<0.008	0.13	E 0.03	E 0.05	0.014	<0.02
W32	362939098225701	07/17/03	1130	<0.008	6.03	<0.04	<0.10	0.111	0.10
W32-FB	362939098225701	07/17/03	1133	<0.008	<0.02	<0.04	<0.1	<0.004	<0.02
W33	363023098424801	07/16/03	1500	<0.008	3.63	<0.04	E 0.06	0.099	0.09
W34	363113098315201	07/11/03	1200	<0.008	15.6	<0.04	E 0.09	0.033	0.03
W35	363211098392401	07/03/03	0900	<0.008	1.24	<0.04	<0.10	0.045	0.04
W36	363330098470001	07/08/03	1400	0.020	0.37	<0.04	E 0.06	0.062	0.06
W37	363348098325401	07/09/03	1400	<0.008	3.68	<0.04	0.15	0.009	<0.02
W38	363445098264001	07/23/03	1000	<0.008	20.4	0.70	0.88	0.068	0.06
W39	363452098384301	07/08/03	1530	<0.008	2.20	<0.04	E 0.06	0.047	0.04
W39-R	363452098384301	07/08/03	1531	<0.008	2.21	<0.04	E 0.05	0.048	0.04
W40	363510098514601	07/02/03	1500	<0.008	8.48	<0.04	0.10	0.047	0.03
W41	363735098551801	07/11/03	1500	<0.008	2.53	<0.04	E 0.07	0.037	0.03
W42	363834098343801	07/09/03	1030	0.046	11.9	<0.04	0.15	0.049	0.04
W43	364519098311701	07/09/03	1200	<0.008	5.99	<0.04	0.20	0.010	<0.02
W44	364258099000801	07/08/03	1000	<0.008	3.30	<0.04	0.10	0.028	0.02
W45	364605098350001	07/11/03	0930	<0.008	17.9	<0.04	0.12	0.054	0.03

Appendix 4. Nitrogen isotope delta values (δ^{15}N) in nitrate measured in samples from 45 wells in the Cimarron terrace aquifer, July and August 2003

[shading indicates quality-control samples; ID, identification number; R, replicate; n/a, nitrogen isotopes not measured because nitrate concentration was less than the concentration needed for nitrogen isotope analysis]

Well number (fig. 3)	Site ID	Date measured	Time	δ^{15}N (permil)
W1	355351097400301	08/07/03	900	2.66
W2	355812097460001	07/18/03	900	3.16
W2-R	355812097460001	07/18/03	905	3.04
W3	355842097570001	07/16/03	1,600	9.44
W4	360004097523601	07/15/03	900	2.31
W5	360236097593501	07/15/03	1,500	7.61
W6	360300098044601	07/15/03	1,700	6.47
W7	360451097534801	07/11/03	1,100	5.70
W8	360605098000401	07/15/03	1,200	7.70
W9	360653098085601	07/16/03	1,400	n/a
W10	360726098040101	07/11/03	900	7.11
W11	360851098023901	07/08/03	1,600	7.96
W12	361005098072601	07/16/03	1,100	4.88
W13	361159098051501	07/08/03	1,400	-0.83
W14	361303098131501	07/10/03	1,000	1.47
W15	361347098120901	07/10/03	1,100	7.77
W16	361454098142601	07/09/03	1,000	2.28
W17	361712098103401	07/08/03	1,030	8.53
W18	361812098192101	07/09/03	1,200	3.20
W19	361813098103201	07/08/03	800	2.34
W19-R	361813098103201	07/08/03	805	2.75
W20	361850098145201	07/10/03	1,500	2.85
W21	361939098215301	07/09/03	1,400	0.25
W22	362146098215401	07/16/03	1,300	5.15
W23	362212098165201	07/16/03	900	3.46
W24	362233098243601	08/07/03	1,500	3.05
W25	362426098221001	07/16/03	1,130	4.95
W26	362435098282201	07/09/03	1,600	0.43
W27	362530098355201	07/03/03	1,530	4.06
W28	362655098253101	07/17/03	900	5.50
W29	362657098203101	08/08/03	1,200	8.60
W30	362800098383701	07/02/03	1,400	4.49
W31	362842098482401	07/02/03	1,030	n/a
W32	362939098225701	07/17/03	1,130	4.98
W33	363023098424801	07/16/03	1,500	1.52
W34	363113098315201	07/11/03	1,200	5.50
W35	363211098392401	07/03/03	900	2.43
W36	363330098470001	07/08/03	1,400	n/a
W37	363348098325401	07/09/03	1,400	5.14
W38	363445098264001	07/23/03	1,000	2.48
W39	363452098384301	07/08/03	1,530	2.52
W39-R	363452098384301	07/08/03	1,531	3.85
W40	363510098514601	07/02/03	1,500	3.42
W41	363735098551801	07/11/03	1,500	1.85
W42	363834098343801	07/09/03	1,030	9.83
W43	364519098311701	07/09/03	1,200	10.1
W44	364258099000801	07/08/03	1,000	1.61
W45	364605098350001	07/11/03	930	8.69

Appendix 5. Concentrations of pesticide and metabolite compounds detected in samples from 15 of 45 wells in the Cimarron terrace aquifer, July and August 2003

[shading indicates quality-control sample; ID, site identification number; -, not detected; R, replicate; E, estimate; μg/L micrograms per liter]

Well number (fig. 3)	Site ID	Date measured	Time	Total number of detections	Alachlor (μg/L)	Atrazine (μg/L)	Deethylatrazine (metabolite) (μg/L)	Metolachlor (μg/L)	Prometon (μg/L)	Tebuthiuron (μg/L)
W5	360236097593501	07/15/03	1500	2	-	E 0.004	E 0.012	-	-	-
W9	360653098085601	07/16/03	1400	2	-	-	E 0.007	-	-	0.159
W14	361303098131501	07/10/03	1000	1	-	-	-	-	-	E 0.010
W15	361347098120901	07/10/03	1100	1	-	-	-	-	-	E 0.010
W18	361812098192101	07/09/03	1200	4	-	E 0.051	E 0.580	0.092	0.025	-
W21	361939098215301	07/09/03	1400	2	-	0.111	E 0.056	-	-	-
W22	362146098215401	07/16/03	1300	3	-	0.027	E 0.063	E 0.011	-	-
W23	362212098165201	07/16/03	0900	3	-	E 0.007	E 0.023	0.060	-	-
W25	362426098221001	07/16/03	1130	4	0.009	E 0.005	E 0.009	0.083	-	-
W28	362655098253101	07/17/03	0900	1	-	-	-	-	-	0.040
W32	362939098225701	07/17/03	1130	0	-	-	-	-	-	-
W32-FB	362939098225701	07/17/03	1133	0	-	-	-	-	-	-
W35	363211098392401	07/03/03	0900	1	-	-	-	-	-	E 0.010
W37	363348098325401	07/09/03	1400	1	-	-	-	-	0.045	-
W39	363452098384301	07/08/03	1530	2	-	0.043	E 0.12	-	-	-
W39-R	363452098384301	07/08/03	1531	2	-	E 0.043	E 0.12	-	-	-
W40	363510098514601	07/02/03	1500	3	-	0.008	E 0.02	-	0.127	-
W43	364519098311701	07/09/03	1200	1	-	-	-	-	0.083	-

Appendix 6. Concentrations of wastewater compounds detected in 28 of 45 wells sampled in the Cimarron terrace aquifer, July and August 2003

[ID, identification number; E, estimate; FB, field blank; <, less than; R, replicate; µg/L, micrograms per liter; -, non-detect]

Well number	Station ID	Date measured	Time	Total number of detections	Anthraquinone (µg/L)	Benzophenone (µg/L)	Benzo[a]pyrene (µg/L)	Bromacil (µg/L)	Caffeine (µg/L)
W1	355351097400301	08/07/03	0900	6	E 0.23	-	-	-	-
W2	355812097460001	07/18/03	0900	2	-	E 0.02	-	-	-
W2-R	355812097460001	07/18/03	0905	1	-	<0.5	-	-	-
W3	355842097570001	07/16/03	1600	1	-	-	-	-	-
W5	360236097593501	07/15/03	1500	1	-	-	-	-	-
W6	360300098044601	07/15/03	1700	2	-	-	-	-	-
W8	360605098000401	07/15/03	1200	4	-	-	-	-	E 0.02
W10	360726098040101	07/11/03	0900	1	-	-	-	-	-
W11	360851098023901	07/08/03	1600	1	-	-	-	-	-
W15	361347098120901	07/10/03	1100	1	-	-	-	-	-
W18	361812098192101	07/09/03	1200	1	-	-	-	-	-
W20	361850098145201	07/10/03	1500	2	-	-	-	-	-
W21	361939098215301	07/09/03	1400	3	-	E 0.01	-	-	-
W22	362146098215401	07/16/03	1300	1	-	-	-	-	-
W24	362233098243601	08/07/03	1500	1	-	-	-	-	-
W25	362426098221001	07/16/03	1130	1	-	-	-	-	-
W27	362530098355201	07/03/03	1530	1	-	-	-	-	-
W29	362657098203101	08/08/03	1200	1	-	-	-	-	-
W32	362939098225701	07/17/03	1130	0	-	-	-	-	-
W32-FB	362939098225701	07/17/03	1133	0	-	-	-	-	-
W33	363023098424801	07/16/03	1500	1	-	-	-	-	-
W34	363113098315201	07/11/03	1200	2	-	-	-	-	-
W35	363211098392401	07/03/03	0900	1	-	-	-	-	-
W36	363330098470001	07/08/03	1400	6	-	-	E 0.01	-	-
W37	363348098325401	07/09/03	1400	2	-	-	-	E 0.10	-
W38	363445098264001	07/23/03	1000	7	-	E 0.01	-	-	-
W39	363452098384301	07/08/03	1530	1	-	<0.50	-	-	-
W39-R	363452098384301	07/08/03	1531	4	-	E 0.01	-	-	-
W40	363510098514601	07/02/03	1500	1	-	-	-	-	-
W43	364519098311701	07/09/03	1200	2	-	-	-	-	-
W44	364258099000801	07/28/03	0900	2	-	-	-	1.7	-
W45	364605098350001	07/11/03	0930	4	-	-	-	-	-

Well ID	Station ID	Date measured (mo/dy/yr)	Time	Total number of detections	Carbazole (μg/L)	Diethyhexyl phthalate (μg/L)	Ethanol,2-butoxy-phosphate (μg/L)	Fluoranthene (μg/L)	Indole (μg/L)
W1	355351097400301	08/07/03	0900	6	E 0.11	-	-	-	-
W2	355812097460001	07/18/03	0900	2	-	-	-	-	-
W3	355842097570001	07/16/03	1600	1	-	-	-	-	-
W5	360236097593501	07/15/03	1500	1	-	-	-	-	-
W6	360300098044601	07/15/03	1700	2	-	-	-	-	-
W8	360605098000401	07/15/03	1200	4	-	-	-	-	-
W10	360726098040101	07/11/03	0900	1	-	-	-	-	-
W11	360851098023901	07/08/03	1600	1	-	-	-	-	-
W15	361347098120901	07/10/03	1100	1	-	-	-	-	-
W18	361812098192101	07/09/03	1200	1	-	-	-	-	-
W20	361850098145201	07/10/03	1500	2	-	-	-	-	-
W21	361939098215301	07/09/03	1400	3	-	-	E 0.19	-	-
W22	362146098215401	07/16/03	1300	1	-	-	-	-	-
W24	362233098243601	08/07/03	1500	1	-	-	-	-	-
W25	362426098221001	07/16/03	1130	1	-	-	-	-	-
W27	362530098355201	07/03/03	1530	1	-	-	-	-	-
W29	362657098203101	08/08/03	1200	1	-	-	-	-	-
W32	362939098225701	07/17/03	1130	0	-	-	-	-	-
W32-FB	362939098225701	07/17/03	1133	0	-	-	-	-	-
W33	363023098424801	07/16/03	1500	1	-	-	E 0.82	-	-
W34	363113098315201	07/11/03	1200	2	-	-	0.50	-	-
W35	363211098392401	07/03/03	0900	1	-	-	-	-	-
W36	363330098470001	07/08/03	1400	6	E 0.01	-	-	E 0.01	-
W37	363348098325401	07/09/03	1400	2	-	-	-	-	-
W38	363445098264001	07/23/03	1000	7	-	1.10	-	-	E 0.12
W39	363452098384301	07/08/03	1530	1	-	<1.0	-	-	-
W39-R	363452098384301	07/08/03	1531	4	-	0.16	-	-	-
W40	363510098514601	07/02/03	1500	1	-	-	-	-	-
W43	364519098311701	07/09/03	1200	2	-	-	-	E 0.01	-
W44	364258099000801	07/28/03	0900	2	-	-	-	-	-
W45	364605098350001	07/11/03	0930	4	-	1.50	-	-	-

Appendix 6. Concentrations of wastewater compounds detected in 28 of 45 wells sampled in the Cimarron terrace aquifer, July and August 2003—Continued

Well number	Station ID	Date measured	Time	Total number of detections	Isoquinoline (μg/L)	Methyl salicylate (μg/L)	N,N-diethyl-meta-toluamide (DEET) (μg/L)	P-cresol (μg/L)	Phenanthrene (μg/L)
W1	355351097400301	08/07/03	0900	6	0.04	-	E 0.04	-	E 0.020
W2	355812097460001	07/18/03	0900	2	-	-	-	-	-
W3	355842097570001	07/16/03	1600	1	-	-	-	-	-
W5	360236097593501	07/15/03	1500	1	-	-	-	-	-
W6	360300098044601	07/15/03	1700	2	-	-	E 0.03	-	-
W8	360605098000401	07/15/03	1200	4	-	-	E 0.04	-	-
W10	360726098040101	07/11/03	0900	1	-	-	-	-	-
W11	360851098023901	07/08/03	1600	1	-	-	-	-	-
W15	361347098120901	07/10/03	1100	1	-	-	-	-	-
W18	361812098192101	07/09/03	1200	1	-	-	-	-	-
W20	361850098145201	07/10/03	1500	2	-	-	-	-	-
W21	361939098215301	07/09/03	1400	3	-	E 0.02	-	-	-
W22	362146098215401	07/16/03	1300	1	-	-	-	-	-
W24	362233098243601	08/07/03	1500	1	-	-	-	-	-
W25	362426098221001	07/16/03	1130	1	-	-	-	-	-
W27	362530098355201	07/03/03	1530	1	-	-	-	-	-
W29	362657098203101	08/08/03	1200	1	-	-	-	-	-
W32	362939098225701	07/17/03	1130	0	-	-	-	-	-
W32-FB	362939098225701	07/17/03	1133	0	-	-	-	-	-
W33	363023098424801	07/16/03	1500	1	-	-	-	-	-
W34	363113098315201	07/11/03	1200	2	-	-	-	-	-
W35	363211098392401	07/03/03	0900	1	-	-	-	-	-
W36	363330098470001	07/08/03	1400	6	-	-	-	-	E 0.01
W37	363348098325401	07/09/03	1400	2	-	-	E 0.04	-	-
W38	363445098264001	07/23/03	1000	7	-	-	-	35.0	-
W39	363452098384301	07/08/03	1530	1	-	-	<0.5	-	-
W39-R	363452098384301	07/08/03	1531	4	-	-	E 0.04	-	-
W40	363510098514601	07/02/03	1500	1	-	-	-	-	-
W43	364519098311701	07/09/03	1200	2	-	-	-	-	-
W44	364258099000801	07/28/03	0900	2	-	-	-	-	-
W45	364605098350001	07/11/03	0930	4	-	-	E 0.03	E 0.03	-

Well number	Station ID	Date measured	Time	Total number of detections	Phenol (μg/L)	Pyrene (μg/L)	Skatole (3-methyl-1h-indole) (μg/L)	Tributyl-phosphate (μg/L)	Triphenyl phosphate (μg/L)
W1	355351097400301	08/07/03	0900	6	E 0.29	-	-	-	-
W2	355812097460001	07/18/03	0900	2	E 0.33	-	-	-	-
W2-R	355812097460001	07/18/03	0905	1	2.0	-	-	-	-
W3	355842097570001	07/16/03	1600	1	1.20	-	-	-	-
W3-FB	355842097570001	07/16/03	1615	0	<0.5	-	-	-	-
W5	360236097593501	07/15/03	1500	1	E 0.98	-	-	-	-
W6	360300098044601	07/15/03	1700	2	E 0.26	-	-	-	-
W8	360605098000401	07/15/03	1200	4	E 0.48	-	-	E 0.02	-
W10	360726098040101	07/11/03	0900	1	0.85	-	-	-	-
W11	360851098023901	07/08/03	1600	1	E 0.20	-	-	-	-
W15	361347098120901	07/10/03	1100	1	0.59	-	-	-	-
W18	361812098192101	07/09/03	1200	1	E 0.26	-	-	-	-
W20	361850098145201	07/10/03	1500	2	0.94	-	-	-	E 0.02
W21	361939098215301	07/09/03	1400	3	-	-	-	-	-
W22	362146098215401	07/16/03	1300	1	E 0.97	-	-	-	-
W24	362233098243601	08/07/03	1500	1	E 0.47	-	-	-	-
W25	362426098221001	07/16/03	1130	1	1.20	-	-	-	-
W27	362530098355201	07/03/03	1530	1	E 0.32	-	-	-	-
W29	362657098203101	08/08/03	1200	1	E 0.39	-	-	-	-
W32	362939098225701	07/17/03	1130	0	-	-	-	-	-
W32-FB	362939098225701	07/17/03	1133	0	-	-	-	-	-
W33	363023098424801	07/16/03	1500	1	-	-	-	-	-
W34	363113098315201	07/11/03	1200	2	E 0.47	-	-	-	-
W35	363211098392401	07/03/03	0900	1	E 0.28	-	-	-	-
W36	363330098470001	07/08/03	1400	6	E 0.21	E 0.01	-	-	-
W37	363348098325401	07/09/03	1400	2	-	-	-	-	-
W38	363445098264001	07/23/03	1000	7	5.0	-	E 0.83	E 0.02	-
W39	363452098384301	07/08/03	1530	1	E 0.20	-	-	-	-
W39-R	363452098384301	07/08/03	1531	4	E 0.43	-	-	-	-
W40	363510098514601	07/02/03	1500	1	E 0.34	-	-	-	-
W43	364519098311701	07/09/03	1200	2	-	E 0.01	-	-	-
W44	364258099000801	07/28/03	0900	2	E 0.27	-	-	-	-
W45	364605098350001	07/11/03	0930	4	-	-	-	E 0.03	-