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MARION COUNTY CONSERVATION DISTRICT

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Occurrence of Dissolved Solids, Nutrients, Pesticides, and Fecal Coliform Bacteria During Low Flow in the Marion Lake Watershed, Central Kansas, 1998

Water-Resources Investigations Report 99-4158



Cover photograph: Canadian geese at Marion Cove Public Use Area on east side of Marion Lake near dam (photograph by L.M. Pope, U.S. Geological Survey, Lawrence, Kansas).

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By **DAVID P. MAU** and **LARRY M. POPE**

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Lawrence, Kansas
1999

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CONVERSION FACTORS AND ABBREVIATIONS

	Multiply	By	To obtain
acre		4,047	square meter
acre-foot		1,233	cubic meter
cubic foot per second		0.02832	cubic meter per second
foot		0.3048	meter
microgram per liter ($\mu\text{g/L}$)		1.0	part per billion
mile		1.609	kilometer
milligram per liter (mg/L)		1.0	part per million
square mile		2.590	square kilometer
ton		0.9072	megagram

Temperature can be converted to degree Celsius ($^{\circ}\text{C}$) or degrees Fahrenheit ($^{\circ}\text{F}$) by the equations:

$$^{\circ}\text{C} = 5/9 (^{\circ}\text{F} - 32)$$

$$^{\circ}\text{F} = 9/5 (^{\circ}\text{C}) + 32.$$

Occurrence of Dissolved Solids, Nutrients, Pesticides, and Fecal Coliform Bacteria During Low Flow in the Marion Lake Watershed, Central Kansas, 1998

By David P. Mau and Larry M. Pope

Abstract

Water-quality sampling was done at 25 stream sites in the Marion Lake watershed during a low-flow period in December 1998. The one-time (synoptic) sampling was done to evaluate spatial variability in concentrations of dissolved solids, major ions, nutrients, selected pesticides, and fecal coliform bacteria. The watershed encompasses approximately 200 square miles in central Kansas. Land use in the watershed is primarily agricultural, which includes cropland and grassland.

The median concentrations in water from all the sampling sites were 640 mg/L (milligram per liter) for dissolved solids, 0.01 mg/L dissolved ammonia as nitrogen, 0.33 mg/L dissolved nitrite plus nitrate as nitrogen, 0.08 mg/L total phosphorus, 0.05 µg/L (microgram per liter) for dissolved atrazine determined by immunoassay analysis, and 200 colonies per 100 milliliters of water for fecal coliform bacteria. None of these constituents exceeded water-quality criteria except for dissolved solids. The nonenforceable U.S. Environmental Protection Agency Secondary Maximum Contaminant Level in drinking water is 500 mg/L dissolved solids (U.S. Environmental Protection Agency, 1995). All of these constituents were commonly of nonpoint-source origin and probably are related to agricultural activities in the watershed. Larger concentrations of dissolved nitrite plus nitrate as nitrogen, total phosphorus, and fecal coliform bacteria probably are

associated with point-source discharges from nearby municipal wastewater-treatment facilities.

INTRODUCTION

Reservoirs in Kansas have been constructed for a variety of purposes. At the time of construction, flood control was the primary purpose of most reservoirs in the State. However, during the past several decades, the use of reservoir water for domestic and municipal drinking-water supply, recreation, and wildlife habitat has become increasingly important. Inherent in these secondary purposes are water-quality issues related to human health, aesthetic appeal, and viability of the reservoir ecosystem. Contamination of these multiple-use resources is, therefore, extremely undesirable. As a result, many State and Federal agencies are working in cooperation with local conservation and watershed management groups to identify and mitigate potential contamination sources.

In Kansas, watershed-based approaches are now being used to help identify and reduce sources of contamination to reservoirs. In an effort to maintain acceptable long-term water quality and extend the useful life of one reservoir in central Kansas, the Marion County Conservation District (MCCD) currently (1999) is implementing a conservation plan for the Marion Lake watershed (fig. 1). The plan is designed, in part, to mitigate the potential for contamination of Marion Lake through implementation of best-management practices and educational activities to reduce contributions of constituents such as nutrients and pesticides to the reservoir.

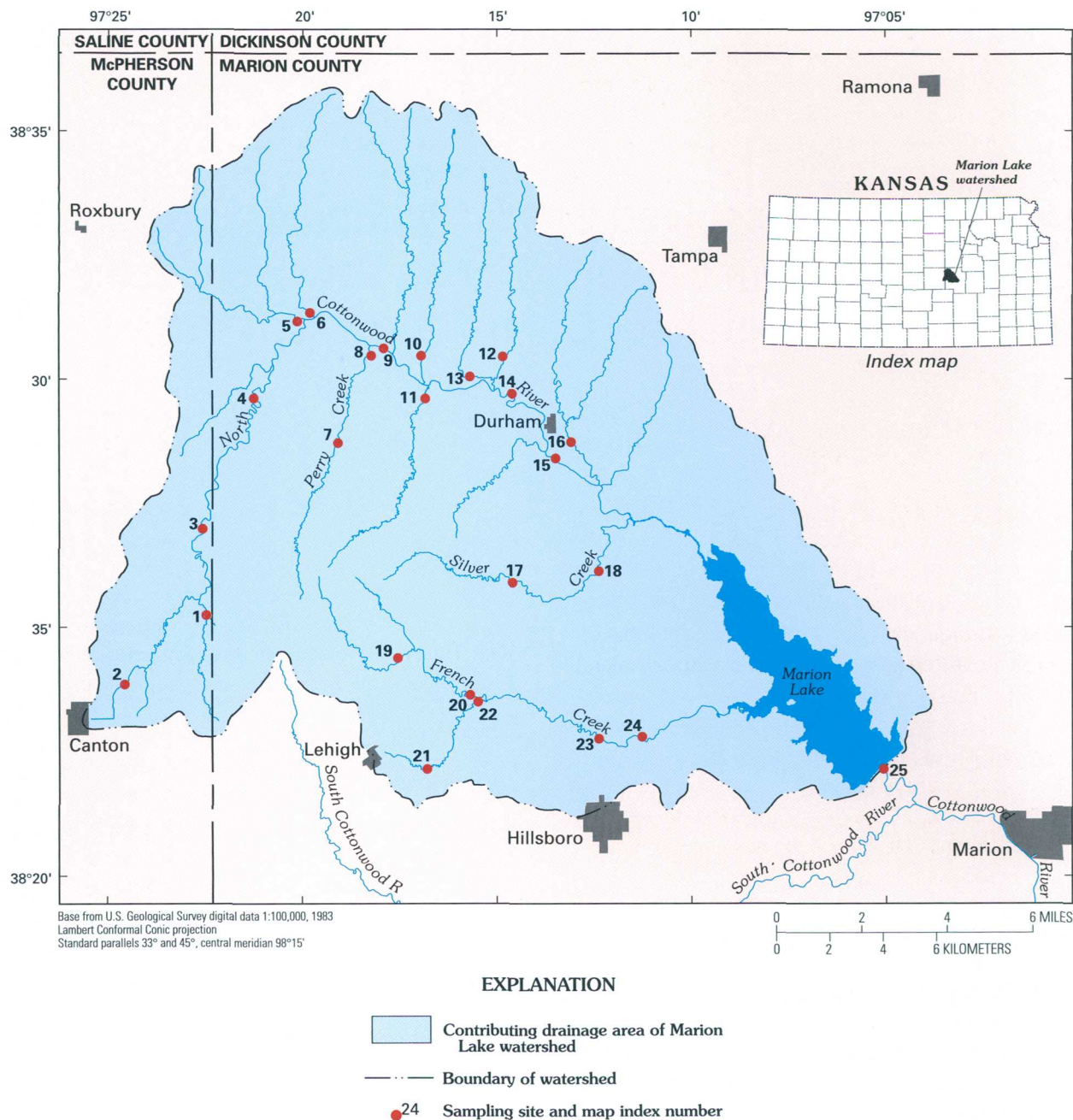


Figure 1. Location of Marion Lake watershed and sampling sites, central Kansas, 1998.

Marion Lake was constructed by the U.S. Army Corps of Engineers between 1964 and 1968. The reservoir encompasses 6,200 acres of water and is surrounded by another 6,000 acres of public lands (U.S. Army Corps of Engineers, 1999). The reservoir has a conservation-pool storage of 79,995 acre-feet, with an additional flood-control pool capacity of 61,210 acre-feet. Little historical water-quality information exists for this watershed; therefore, information concerning

variability and relative occurrence of selected water-quality constituents is needed.

In 1998, the U.S. Geological Survey began a cooperative study with the MCCD to characterize the water quality of the Marion Lake watershed during low flow. This study is in support of U.S. Environmental Protection Agency (USEPA) Section 319 Nonpoint Source Pollution Control Grant No. C9007405-98 through an agreement with the Kansas Department of Health and Environment (KDHE).

Specific surface-water sites were sampled during low flow over a short period of time (2 days in December 1998) to minimize variation in water-quality conditions from natural (rainfall) or human-related (point-source discharges or irrigation return flow) causes. Synoptic (one-time) sampling provides an observation of water-quality conditions as they exist simultaneously over a broad geographical area. Results from a similar low-flow sampling in the Cheney Lake watershed in Kansas were used to help identify areas that pose potential water-quality concerns and to allow site-to-site comparisons for a selected set of water-quality constituents (Christensen and Pope, 1997). However, total annual loads of water-quality constituents or information on suspended sediment cannot be determined solely from low-flow sampling. Sediment is not transported in any meaningful quantities during low flow, which would affect sediment-load calculations.

This report (1) describes the spatial variability of selected water-quality constituent concentrations during stable, low-flow conditions in the Marion Lake watershed and (2) discusses the possible causal factors related to the observed water-quality conditions. Results of this study will improve understanding of land-use characteristics that contribute to observed water quality in the Marion Lake watershed and may relate to similar watersheds on a national scale.

Description of Study Area

The drainage area of the Marion Lake watershed is about 200 square miles (128,000 acres), of which 90 percent is in Marion County and the remaining 10 percent in McPherson County. The study area consists of the entire contributing drainage area of the Marion Lake watershed, including the North Cottonwood River, Perry Creek, Silver Creek, French Creek, and associated smaller tributary streams (fig. 1). Outflow from Marion Lake to the Cottonwood River also was included in the study area.

Marion County lies in the Flint Hills Upland, which consists, for the most part, of a broad undulating plain (Schoewe, 1949). The primary geologic materials of the county consist of sandstone, limestone, and shale. Approximately 50 percent of the arable soils in the county are of the Idana group, which are derived from calcareous shale and limestone and provide good surface drainage. Internal drainage

through the clay subsoil ranges from fair to good (Knobel and Lewis, 1935).

Land use in the Marion Lake watershed is primarily agricultural, with about 52 percent of the land being used for crop production (fig. 2). In 1997 (latest data available), there were about 38,000 acres of wheat, 18,000 acres of grain sorghum, 3,400 acres of soybeans, and 2,500 acres of corn harvested in the watershed. Livestock production also is important to the economy of the watershed. In 1997, there were an estimated 17,500 cattle, 4,000 hogs and pigs, and 16,000 chickens in the watershed. Crop-acreage data and livestock numbers were estimated from county information compiled by the Kansas Department of Agriculture and U.S. Department of Agriculture (1997).

Oil fields are scattered throughout the Marion Lake watershed. Saltwater brine commonly is associated with oil production in central Kansas. Early methods of brine disposal included direct discharge to nearby streams or to infiltration ponds. Although the KDHE has long-established regulations governing the disposal of brine through reinjection into disposal wells, it is possible that past practices of shallow-depth disposal methods (now illegal) could contribute saltwater brine to shallow ground water and subsequent surface-water contamination (Walters, 1978, p. 32).

The largest towns in the watershed include Canton, Lehigh, and Durham (fig. 1). A small percentage of north Hillsboro (population: 3,000) is also in the basin, but the majority of the drainage from the town is south of the watershed. Populations in these towns range from less than 200 people (Lehigh and Durham) to almost 800 people in Canton (Kansas State Library, 1999).

Study Methods

Twenty-five stream sampling sites within the Marion Lake watershed (fig. 1, table 1) were selected to: (1) provide spatial coverage of the watershed by segmenting the North Cottonwood River into stream intervals and documenting water-quality characteristics of major tributary streams, (2) identify significant point-source discharges to differentiate from potential nonpoint-source contributions, (3) identify areas of the watershed that may pose particular water-quality concerns such as oil fields and municipal wastewater discharges, and (4) determine concentrations of selected water-quality constituents in outflow from Marion

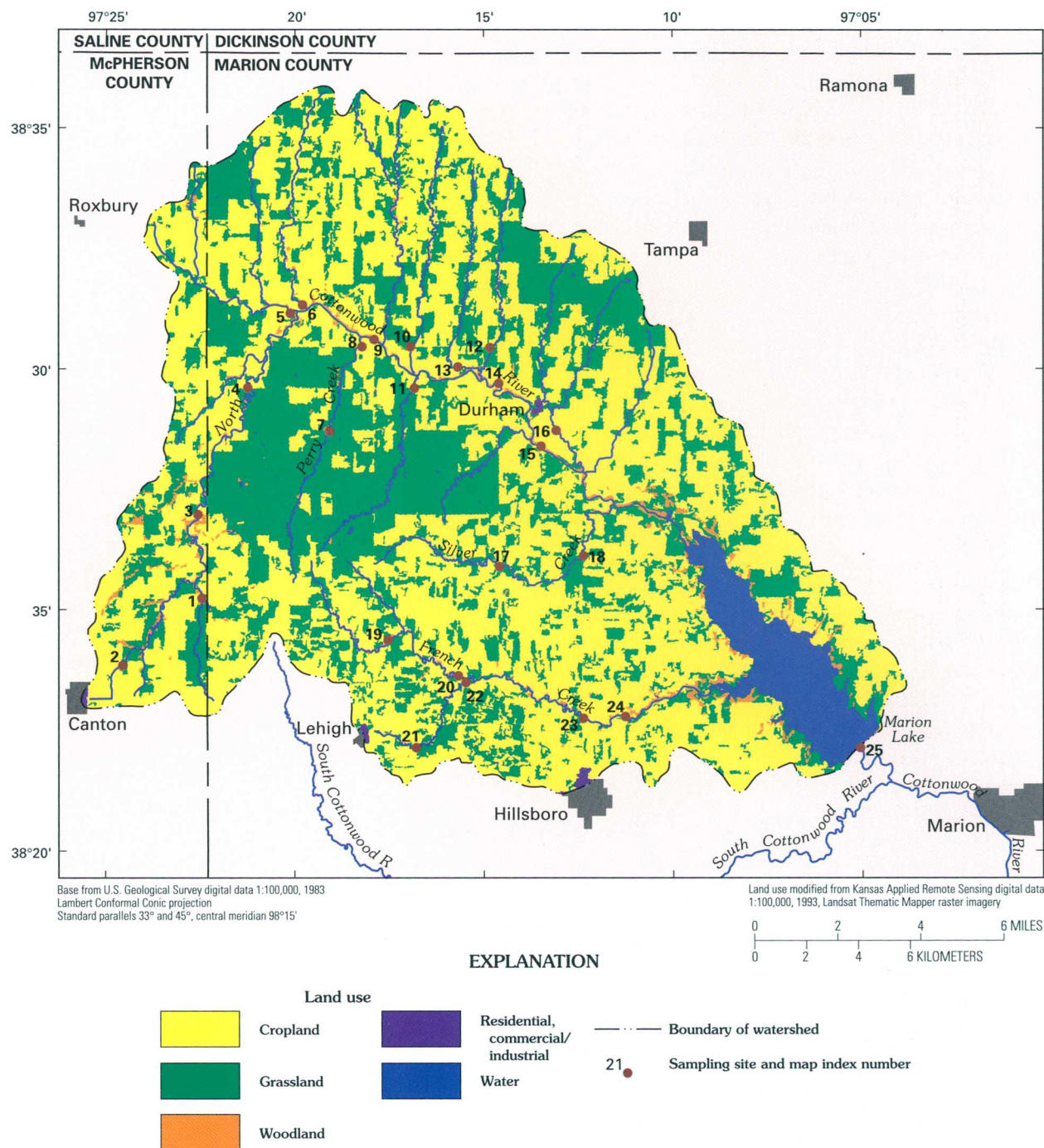


Figure 2. Land use in the Marion Lake watershed, 1993.

Table 1. Location and contributing drainage area of sampling sites in the Marion Lake watershed, central Kansas, December 1–2, 1998

Map index number (fig. 1)	Site name	Contributing drainage area (square miles)	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)
1	North Cottonwood River 3.5 miles northeast of Canton, Kansas	3.1	38°25'14"	97°22'25"
2	North Cottonwood River tributary 1.1 miles northeast of Canton, Kansas	.8	38°23'50"	97°23'50"
3	North Cottonwood River 4.8 miles northeast of Canton, Kansas	16.9	38°26'58"	97°22'32"
4	North Cottonwood River 8.3 miles northeast of Canton, Kansas	24.3	38°29'35"	97°21'13"
5	North Cottonwood River tributary 10 miles northeast of Canton, Kansas	13.1	38°31'08"	97°20'05"
6	North Cottonwood River tributary 10.3 miles northeast of Canton, Kansas	5.5	38°31'19"	97°19'43"
7	Perry Creek 5.0 miles southwest of Durham, Kansas	4.5	38°28'42"	97°19'03"
8	Perry Creek 4.5 miles northwest of Durham, Kansas	8.1	38°30'27"	97°18'10"
9	North Cottonwood River 4.3 miles northwest of Durham, Kansas	63.3	38°30'34"	97°17'52"
10	North Cottonwood River tributary 3.4 miles northwest of Durham, Kansas	5.1	38°30'27"	97°16'53"
11	North Cottonwood River tributary 3.0 miles west of Durham, Kansas	6.1	38°29'35"	97°16'48"
12	North Cottonwood River tributary 1.9 miles northwest of Durham, Kansas	2.9	38°30'27"	97°14'49"
13	North Cottonwood River tributary 2.2 miles northwest of Durham, Kansas	3.6	38°30'02"	97°15'40"
14	North Cottonwood River 1.2 miles northwest of Durham, Kansas	93.8	38°29'42"	97°14'35"
15	North Cottonwood River at Highway 15 south of Durham, Kansas	103	38°28'21"	97°13'28"

Table 1. Location and contributing drainage area of sampling sites in the Marion Lake watershed, central Kansas, December 1–2, 1998—Continued

Map index number (fig. 1)	Site name	Contributing drainage area (square miles)	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)
16	North Cottonwood River tributary 0.6 mile southeast of Durham, Kansas	9.1	38°28'43"	97°13'03"
17	Silver Creek 3.8 miles southwest of Durham, Kansas	5.1	38°25'54"	97°14'33"
18	Silver Creek 3.6 miles southeast of Durham, Kansas	11.9	38°26'07"	97°12'20"
19	French Creek 2.0 miles north of Lehigh, Kansas	5.2	38°24'22"	97°17'30"
20	French Creek 2.3 miles northeast of Lehigh, Kansas	10.8	38°23'37"	97°15'40"
21	French Creek tributary 1.1 miles east of Lehigh, Kansas	1.2	38°22'10"	97°16'47"
22	French Creek tributary 2.4 miles northeast of Lehigh, Kansas	3.4	38°23'29"	97°15'27"
23	French Creek 1.2 miles north of Hillsboro, Kansas	22.5	38°22'43"	97°12'22"
24	French Creek 1.3 miles northeast of Hillsboro, Kansas	26.8	38°22'46"	97°11'15"
25	North Cottonwood River downstream from Marion Lake, Kansas	200	38°22'00"	97°05'00"

Lake. Sampling during a low-flow period was important to eliminate the surface-runoff component that could introduce water-quality variability associated with fluctuations in streamflow and thus complicate site-to-site comparison. Low flow is defined as streamflow originating primarily as springs or groundwater seepage (including irrigation return flow) or from point-source discharges such as water-treatment plants (Christensen and Pope, 1997). Streamflow was measured using methods presented in Buchanan and Somers (1969).

Each of the 25 stream sites was sampled once during December 1–2, 1998. Physical properties determined onsite (in stream) included streamflow, specific conductance, pH, air and water temperatures, turbidity, barometric pressure, and dissolved-oxygen concentration. Laboratory analyses were performed for dissolved solids and major ions, nutrients (nitrogen and phosphorus species), selected pesticides, fecal coliform bacteria, and suspended sediment. All samples were collected according to methods presented in Horowitz and others (1994).

Laboratory analyses of water samples collected during this study were sent to several laboratories. Major ions and nutrients were analyzed at the U.S. Geological Survey National Water-Quality Laboratory (NWQL) in Denver, Colorado, according to methods presented in Fishman (1993). Samples for analysis of fecal coliform bacteria were processed at a centrally located site (Durham, Kansas) during the 2-day sampling. All bacteria samples were processed within 6 hours of collection using the membrane filtration method presented in Wilde and others (1998). Suspended-sediment samples were analyzed at the U.S. Geological Survey sediment laboratory in Iowa City, Iowa, according to methods presented in Guy (1969).

A selected group of pesticides were analyzed at the U.S. Geological Survey Organic Geochemistry Research Laboratory in Lawrence, Kansas, using traditional gas chromatography/mass spectrometry (GC/MS) procedures according to methods presented in Zimmerman and Thurman (1999). Atrazine was analyzed using both GC/MS and a relatively new enzyme-linked immunosorbent assay (ELISA) method as described in Thurman and others (1990) and used previously in a surface-water study of atrazine in northeast Kansas (Pope and others, 1997). During this study, 25 samples were analyzed for atrazine using the ELISA method, and three split-replicate samples were analyzed for atrazine using GC/MS. The average dif-

ference between ELISA- and GC/MS-determined concentrations was 0.10 µg/L (microgram per liter) after assuming all concentrations less than the analytical detection limit to be one-half the detection limits for the methods (0.05 µg/L and 0.025 µg/L, respectively). Results indicate that the atrazine values determined by the ELISA method (table 2) are a reasonable estimate of GC/MS-determined concentrations.

DISSOLVED SOLIDS AND MAJOR IONS

Dissolved solids are an important indicator of water quality, and in uncontaminated surface water, are the result of natural dissolution of rocks and minerals. Aquatic biota are affected by changes to habitat, which can be altered by dissolved-solids concentrations that are too high or too low (Maidment, 1993, p. 11.37). Dissolved solids are also an important indicator of the suitability of water for drinking, irrigation, and industrial use. The major constituents of dissolved solids are the ions calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulfate, and chloride. The USEPA has not established enforceable water-quality regulations for dissolved solids, but the nonenforceable Secondary Maximum Contaminant Level (SMCL) in drinking water is 500 mg/L (milligrams per liter) dissolved solids (U.S. Environmental Protection Agency, 1995).

Dissolved solids occur naturally in surface water, and concentrations vary widely. Rainwater has dissolved-solids concentrations of less than 10 mg/L, slightly saline water ranges from 1,000 to 3,000 mg/L dissolved-solids concentrations, whereas seawater has dissolved-solids concentrations exceeding 35,000 mg/L (Maidment, 1993, p. 11.37). Human activities also can increase dissolved-solids concentrations. Point-source discharges from wastewater-treatment facilities (Pope and Putnam, 1997) or leaching from oil-field wastewater ponds (Buddemeier and others, 1995) adjacent to streams can alter dissolved-solids concentrations in surface water.

The median dissolved-solids concentration for samples collected in December 1998 in the Marion Lake watershed was 640 mg/L. Water samples collected from the North Cottonwood River and tributary streams (sampling sites 1–16) had a median dissolved-solids concentration of 520 mg/L. The median dissolved-solids concentration in water from various sampling sites in the French Creek drainage (sampling sites 19–24) was 960 mg/L, and in water from Silver

Table 2. Results of chemical analyses of surface-water samples collected from the Marion Lake watershed, central Kansas, December 1–2, 1998

[ft³/s, cubic feet per second; mm of Hg, millimeters of mercury; μ S/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; μ m, micrometer; μ g/L, micrograms per liter; GC/MS, gas chromatography/mass spectrometry analysis; col/100 mL, colonies per 100 milliliters of water; μ m-mf, micrometers on nutrient medium; --, no data; <, less than]

Map index number (fig. 1)	Date (month/day/year)	Physical properties									
		Streamflow, instantaneous (ft ³ /s)	Barometric pressure (mm of Hg)	Specific conductance (μ S/cm)	Onsite pH (standard units)	Laboratory pH (standard units)	Temperature, air (°C)	Temperature, water (°C)	Laboratory turbidity (NTU)	Oxygen, dissolved (mg/L)	Alkalinity, total as CaCO ₃ (mg/L)
1	12/1/98	0.42	720	950	7.5	7.7	18.0	12.7	11	7.3	255
2	12/1/98	.11	733	2,680	7.4	7.6	--	12.1	7.5	6.8	239
3	12/1/98	2.37	720	1,060	7.5	7.7	22.5	11.8	16	7.8	259
4	12/1/98	6.19	722	720	7.7	7.8	20.0	12.6	27	9.5	193
5	12/1/98	2.46	733	710	7.6	7.8	14.0	11.1	9.1	7.1	294
6	12/1/98	1.11	733	700	7.6	7.8	15.5	11.6	4.0	7.4	266
7	12/1/98	1.74	722	500	7.7	7.9	19.0	11.8	18	11	113
8	12/1/98	3.34	733	630	7.7	7.8	16.0	11.8	17	9.6	193
9	12/1/98	15.2	733	770	7.9	7.9	15.0	12.1	10	9.8	243
10	12/2/98	.93	727	750	7.7	7.9	15.5	11.5	20	9.2	292
11	12/2/98	1.69	727	790	7.9	8.0	14.3	11.9	11	10	300
12	12/1/98	.28	--	1,290	8.0	8.1	19.0	11.2	24	15	405
13	12/2/98	.53	727	1,000	8.1	8.1	16.2	12.6	9.2	13	411
14	12/1/98	25.4	733	800	7.8	7.9	17.0	10.5	37	9.1	271
15	12/1/98	27.0	--	900	7.7	7.9	18.0	11.7	47	7.8	288
16	12/1/98	2.18	--	1,720	7.8	7.9	18.0	11.6	28	10	342
17	12/2/98	.61	719	1,360	8.0	8.0	--	12.9	47	11	330
18	12/2/98	2.84	719	2,050	7.8	7.9	19.3	12.9	32	12	363
19	12/2/98	.38	716	1,270	7.7	7.8	15.5	11.0	7.5	8.1	296
20	12/2/98	1.56	718	1,300	7.8	8.0	15.5	12.0	17	7.5	440
21	12/2/98	.05	716	840	7.6	7.9	14.0	10.4	66	7.5	261
22	12/2/98	.78	718	1,360	7.8	7.9	14.5	11.8	2.5	9.5	439
23	12/2/98	7.53	719	1,780	7.6	7.7	16.5	12.1	31	7.7	405
24	12/2/98	8.0	719	1,830	7.6	7.8	16.5	11.9	52	7.5	415
25	12/2/98	2.9	716	386	7.9	8.0	13.0	11.3	140	9.6	89

Table 2. Results of chemical analyses of surface-water samples collected from the Marion Lake watershed, central Kansas, December 1-2, 1998—Continued

Map index number (fig. 1)	Date (month/day/ year)	Dissolved solids		Major ions							
		Solids, residue at 105 °C dissolved (mg/L)	Calcium, total recoverable (mg/L as Ca)	Magne- sium, total recover- able (mg/L as Mg)	Sodium, total recover- able (mg/L as Na)	Potas- sium, total recover- able (mg/L as K)	Sulfate, filtered 0.45 µm (mg/L as SO ₄)	Chloride, filtered 0.45 µm (mg/L as Cl)	Fluoride, filtered 0.45 µm (mg/L as F)	Silica, total recover- able (mg/L as Si)	
1	12/1/98	640	107	22	54	4.8	176	48	0.36	14	
2	12/1/98	1,680	205	20	260	11	42	650	.16	23	
3	12/1/98	680	107	23	72	5.3	135	103	.34	16	
4	12/1/98	470	70	18	42	4.0	98	53	.31	16	
5	12/1/98	470	86	18	28	3.5	82	11	.38	13	
6	12/1/98	460	84	19	26	6.2	93	14	.33	10	
7	12/1/98	340	45	18	26	2.9	121	13	.22	12	
8	12/1/98	420	64	27	26	2.8	124	14	.31	13	
9	12/1/98	510	81	23	36	4.0	115	34	.34	15	
10	12/2/98	480	75	30	41	4.2	87	24	.39	12	
11	12/2/98	520	70	45	29	3.0	122	17	.45	11	
12	12/1/98	910	145	63	35	8.9	265	51	.35	7.2	
13	12/2/98	640	104	49	42	4.6	116	33	.38	10	
14	12/1/98	520	84	30	37	4.1	118	28	.39	15	
15	12/1/98	620	102	35	36	3.9	173	26	.35	15	
16	12/1/98	1,440	266	65	29	2.9	682	14	.36	12	
17	12/2/98	1,020	160	67	32	5.8	427	32	.32	8.0	
18	12/2/98	1,740	320	88	40	6.4	864	34	.42	10	
19	12/2/98	930	139	63	46	6.6	381	30	.34	12	
20	12/2/98	930	140	83	34	4.4	308	21	.43	13	
21	12/2/98	560	74	46	36	5.5	153	32	.42	9.4	
22	12/2/98	990	169	83	19	3.4	349	17	.45	12	
23	12/2/98	1,420	265	83	30	4.0	630	33	.44	13	
24	12/2/98	1,460	272	85	35	4.3	636	41	.43	13	
25	12/2/98	240	40	13	10	5.2	82	10	.27	5.6	

Table 2. Results of chemical analyses of surface-water samples collected from the Marion Lake watershed, central Kansas, December 1-2, 1998—Continued

Map index number (fig. 1)	Date (month/day/year)	Nutrients										Metals		
		Nitrogen, ammonia plus organic material, filtered 0.45 µm (mg/L as N)					Nitrogen, ammonia plus organic material, filtered 0.45 µm (mg/L as N)					Phosphorus, filtered 0.45 µm (mg/L as P)		
		Nitrogen, nitrite, filtered 0.45 µm (mg/L as N)	Nitrite plus nitrate, filtered 0.45 µm (mg/L as N)	Nitrogen, ammonia, filtered 0.45 µm (mg/L as N)	Nitrogen, ammonia plus organic material, filtered 0.45 µm (mg/L as N)	Nitrogen, ammonia plus organic material, filtered 0.45 µm (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, filtered 0.45 µm (mg/L as P)	Orthophosphate, filtered 0.45 µm (mg/L as P)	Iron, total recoverable (µg/L as Fe)	Manganese, total recoverable (µg/L as Mn)			
1	12/1/98	<.01	<.05	<.02	0.33	0.41	0.05	0.01	0.03	38	580			
2	12/1/98	.62	10	.49	1.6	1.6	2.5	2.1	2.1	43	230			
3	12/1/98	.01	.25	.11	.81	.40	.02	--	.04	24	750			
4	12/1/98	<.01	.21	<.02	.30	.75	.09	.02	.03	13	280			
5	12/1/98	<.01	.10	<.02	.31	.52	.06	.06	.06	24	250			
6	12/1/98	<.01	.08	.03	.51	.61	.09	.06	.05	37	210			
7	12/1/98	<.01	.17	<.02	.32	.35	.02	.01	.01	10	300			
8	12/1/98	<.01	.21	<.02	.26	.38	.03	<.05	.02	8.9	190			
9	12/1/98	<.01	.44	<.02	.39	.49	.08	.05	.04	13	170			
10	12/2/98	.02	1.5	<.02	.44	.58	.08	.04	.03	9.7	270			
11	12/2/98	<.01	.05	<.02	.27	.37	.06	.05	.04	12	94			
12	12/1/98	.03	.70	<.02	.64	.69	.09	.07	.06	27	160			
13	12/2/98	.02	.86	<.02	.39	.62	.05	.02	.03	13	110			
14	12/1/98	.01	.74	<.02	<.10	.53	.09	--	.05	13	140			
15	12/1/98	<.01	.73	<.02	.38	1.3	.09	.05	.05	11	200			
16	12/1/98	<.01	.27	<.02	.17	.28	.03	.02	.02	5.9	180			
17	12/2/98	.01	.33	<.02	.46	.94	.10	.01	.02	9.4	760			
18	12/2/98	.03	2.6	.03	.46	.59	.08	.04	.04	30	290			
19	12/2/98	<.01	.16	<.02	.48	.60	.05	<.05	.02	22	200			
20	12/2/98	<.01	.13	<.02	.40	.61	.08	.02	.03	19	210			
21	12/2/98	<.01	.36	.03	.22	.84	.30	--	.18	13	150			
22	12/2/98	<.01	.16	<.02	.28	.36	.03	.03	.03	23	150			
23	12/2/98	.01	1.0	.03	.27	.39	.05	.04	.04	11	160			
24	12/2/98	.01	1.0	.04	.28	.48	.09	.04	.05	13	210			
25	12/2/98	.03	.96	.06	.39	.58	.19	.10	.10	<10	--			

Table 2. Results of chemical analyses of surface-water samples collected from the Marion Lake watershed, central Kansas, December 1–2, 1998—Continued

Map index number (fig. 1)	Date (month/day/ year)	Pesticides				Bacteria	Sediment
		Atrazine, immuno- assay (µg/L)	Atrazine, GC/MS (µg/L)	Deethyl- atrazine, GC/MS (µg/L)	Metol- achlor, GC/MS (µg/L)	Coliform, fecal, 0.7 µm-mf (col/ 100 mL)	
1	12/1/98	<0.10	--	--	--	200	11.5
2	12/1/98	.20	--	--	--	3,300	12.8
3	12/1/98	<.10	--	--	--	1,000	9.4
4	12/1/98	<.10	--	--	--	340	23.5
5	12/1/98	<.10	--	--	--	160	3.8
6	12/1/98	<.10	--	--	--	37	15.5
7	12/1/98	<.10	--	--	--	150	13.8
8	12/1/98	<.10	--	--	--	88	8.5
9	12/1/98	<.10	--	--	--	140	10.5
10	12/2/98	<.10	--	--	--	2,000	9.2
11	12/2/98	<.10	--	--	--	180	6.2
12	12/1/98	.10	--	--	--	84	7.3
13	12/2/98	.20	--	--	--	80	40.2
14	12/1/98	<.10	<.05	<.05	<.05	970	14.7
15	12/1/98	<.10	--	--	--	130	20.2
16	12/1/98	<.10	--	--	--	230	60.8
17	12/2/98	.20	--	--	--	410	50.7
18	12/2/98	<.10	--	--	--	530	114
19	12/2/98	.10	--	--	--	190	15.9
20	12/2/98	<.10	--	--	--	220	113
21	12/2/98	.52	--	--	--	210	51.2
22	12/2/98	<.10	--	--	--	120	43.0
23	12/2/98	<.10	--	--	--	420	61.6
24	12/2/98	<.10	<.05	<.05	<.05	490	73.3
25	12/2/98	.80	.50	.12	.07	54	68.2

Creek (sampling sites 17–18) was 1,380 mg/L. Overall, water from 18 of the 25 sampling sites exceeded the SMCL for dissolved-solids concentrations (fig. 3).

Variation in dissolved-solids concentrations within the Marion Lake watershed is the result of several sources of dissolved solids. Water from sampling site 2 (downstream from the municipal wastewater discharge from Canton) had the second highest dissolved-solids concentration (1,680 mg/L) in water from sites

sampled in the watershed (table 2). The relatively high dissolved-solids concentration in water from sampling site 2 was due to relatively high concentrations of dissolved sodium and chloride, presumably a component of municipal wastewater (table 2). Increases in sodium and chloride concentrations as a result of municipal wastewater discharges were documented in a previous study of point-source discharges in Topeka, Kansas (Pope and Putnam, 1997).

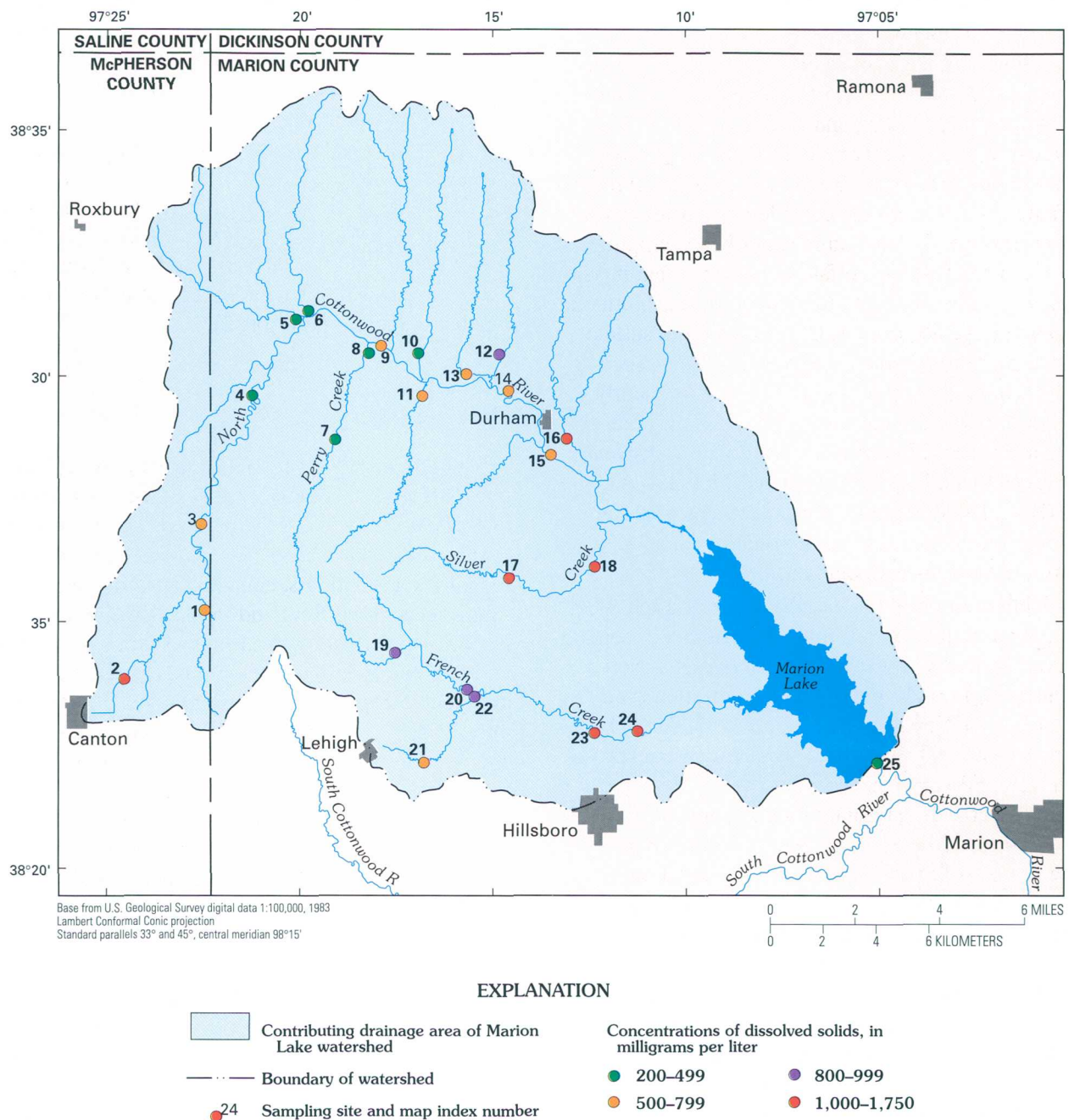


Figure 3. Distribution of dissolved-solids concentrations in December 1998 samples.

Concentrations in water from sampling site 2 were 7 and 21 times (respectively) greater than the average sodium and chloride concentrations in water from the other 24 sampling sites. The dissolved-solids concentrations in water from the North Cottonwood River downstream from sampling site 2 decreased rapidly as ground and surface water with lower dissolved-solids concentrations entered the stream and diluted the dissolved-solids concentration determined at sampling site 2. This dilution effect was evident in water from sampling site 4 where the dissolved-solids concentration was less than the SMCL (fig. 3).

High concentrations of dissolved solids in water from sites 23 and 24 coincide with high concentrations of calcium, magnesium, and sulfate (table 2). The source of these constituents appears to be an area between sampling sites 20 and 23 because calcium and sulfate concentrations are considerably lower in water from sampling site 20 than in water from sampling site 23. The source of sulfate is unknown, but it typically originates naturally from either the dissolution of evaporite deposits, such as hydrous calcium sulfate (gypsum), or the oxidation of metal sulfides, such as pyrite (Hem, 1985, p. 112). Gypsum is frequently interstratified with limestone, shale, and clay that are common to the Clime silty clay and Crete silty loam soil types found in both Marion and McPherson Counties (Rott, 1983). Human-related sources of sulfate include brines from oil-well production and discharge from wastewater-treatment facilities.

Whittemore (1995) describes a method for differentiating among different sources of saltwater contamination (natural versus human related) that uses the sulfate (SO_4)-to-chloride (Cl) concentration ratio. According to Whittemore (1995), the highest SO_4 :Cl ratios for natural mineralized water (saltwater) occur in low chloride water saturated with respect to gypsum (high SO_4 concentrations); ratios can approach 200 in water with less than 10 mg/L chloride and about 1,700 mg/L sulfate. Freshwater has SO_4 :Cl ratios commonly between 0.1 and 20. Conversely, sulfate concentrations are very low in formation brines, commonly associated with oil and gas reservoirs, because of chemical reduction of sulfate to sulfides. SO_4 :Cl mass ratios in these brines can be less than 0.00005, and chloride concentrations can exceed 100,000 mg/L. The SO_4 :Cl ratios in water between sampling sites 20 and 24 ranged from 4.8 to 21 (table 2), which would categorize the sulfate concentrations as being from a natural source, such as gypsum. The source of high

calcium and sulfate concentrations in samples from French Creek (sampling sites 20 and 23) may be attributed to ground-water contributions to the creek that increased streamflow about 383 percent (table 2), and calcium and sulfate concentrations about 100 percent, between these two sites.

Water from sampling sites 16 (tributary to North Cottonwood River) and 17 and 18 (Silver Creek) also had high concentrations of calcium, magnesium, and sulfate (table 2). Oil fields are located near Silver Creek but are downstream from sampling sites 17 and 18. The SO_4 :Cl ratios in samples from all three sites suggest that the high concentrations of these constituents also are derived from a natural geologic source, such as gypsum.

The SMCL for sulfate in drinking water is 250 mg/L (U.S. Environmental Protection Agency, 1995). Many of the streamwater samples collected during low flow from French Creek, Silver Creek, and the tributary to North Cottonwood River (sampling site 16) exceeded this nonenforceable criterion by as much as a factor of 3 (table 2).

NUTRIENTS

Nutrients, including the elements nitrogen and phosphorus, are essential for the growth and reproduction of plants. Nitrogen is important in ecosystems because of its role in protein synthesis and, along with carbohydrates and fats, constitutes the major part of living substances (Reid and Wood, 1976, p. 231). Nitrogen occurs in water in several forms—as elemental nitrogen (N_2), bound to organic compounds, or as inorganic compounds such as ammonia, nitrite, and nitrate (Hem, 1985, p. 125). Phosphorus is used as an energy source in the cells of plants and animals and can have a direct effect on the production of phytoplankton populations, an important component of the food chain. In uncontaminated water, phosphorus occurs in relatively small concentrations and may be a limiting factor in primary productivity (Reid and Wood, 1976, p. 236). At normal lake pH ranges, soluble phosphate is the only form of phosphorus of significance, and most soluble phosphate is present as orthophosphate (Horne and Goldman, 1994, p. 155).

Although nutrients are vital to the health of an aquatic ecosystem, excessive concentrations can have deleterious effects. Accelerated growth of algae and other aquatic plants in rivers, lakes, and reservoirs can clog pipelines, result in fish kills, and restrict recre-

ation (Litke, 1996). Excess nutrients also can affect water quality and may produce taste and odor problems in drinking water. High nutrient concentrations in drinking water may be physiologically damaging to humans and interfere with growth and reproduction of aquatic organisms. Therefore, it is desirable to prevent or reduce the introduction of excessive nutrients into surface-water bodies that serve as public drinking-water supplies or where sensitive aquatic organisms may be present.

Major nonpoint sources of nutrients in Kansas include agricultural usage of synthetic fertilizers and confined feeding of livestock. A partial list of synthetic fertilizers include anhydrous ammonia, ammonium nitrate, urea, and mono- and diammonium phosphates. Synthetic fertilizer usage in Kansas more than doubled from 1965 to 1995, from 640,000 to about 1,800,000 tons (Kansas Department of Agriculture and U.S. Department of Agriculture, 1997), and similar increasing trends are likely in the Marion Lake watershed. Farm livestock also produce large quantities of phosphorus and nitrogen-rich organic wastes (urine and manure) that contribute to nonpoint sources of nitrogen nutrients, especially if large numbers of animals are pastured or confined to feedlots. These organic wastes can be transported through surface runoff or shallow ground-water systems and potentially discharged to nearby receiving streams.

Common point sources of nitrogen and phosphorus are municipal wastewater discharges. Nitrogen in wastewater is from human waste, nitrogen-containing organic compounds, and industrial waste (Hem, 1985). Phosphorus is a component of sewage, is always present in animal metabolic waste (Hem, 1985), and according to Hammer (1986), only 20 to 30 percent of the total phosphorus is removed by conventional wastewater-treatment processes.

The nitrogen species analyzed in this study included nitrite as nitrogen, dissolved nitrite plus nitrate, dissolved ammonia as nitrogen, dissolved ammonia plus organic material as nitrogen (filtered), and ammonia plus organic material as nitrogen (total) (table 2). Water from sampling site 2, North Cottonwood River tributary downstream from a wastewater-treatment facility, was consistently higher than the watershed average in concentrations of all nitrogen species. Phosphorus species analyzed in this study included total phosphorus, dissolved phosphorus (filtered), and orthophosphates.

Nitrite Plus Nitrate

Nitrite and nitrate are inorganic ions produced during various stages of the nitrogen cycle. In most oxygenated surface water, nitrate is by far the most predominant ion because of the rapid oxidation of nitrite (Reid and Wood, 1976, p. 235). Nitrate nitrogen usually occurs in relatively low concentrations in uncontaminated surface water with a worldwide average of 0.30 mg/L (Reid and Wood, 1976, p. 235). All green plants require nitrate, but higher concentrations potentially can accelerate algal growth that may lead to taste and odor problems in drinking water. Aquatic organisms can tolerate dissolved nitrite plus nitrate concentrations much higher than found in severely contaminated surface water; therefore, no water-quality criteria have been established for the protection of aquatic life.

Human health-based regulations have been established for dissolved nitrite plus nitrate concentrations in drinking water because of the potential adverse health effects to infants (U.S. Environmental Protection Agency, 1986). A Maximum Contaminant Level (MCL) of 10 mg/L of nitrite plus nitrate as nitrogen has been established for Kansas drinking water by KDHE (1994).

The median concentration of dissolved nitrite plus nitrate as nitrogen for samples collected in December 1998 from the Marion Lake watershed was 0.33 mg/L (table 2). Most dissolved nitrite plus nitrate as nitrogen concentrations in water from sampling sites in the Marion Lake watershed were less than 0.51 mg/L (fig. 4). Water from sampling site 2, downstream from the wastewater-treatment facility at Canton, had a concentration of 10 mg/L of dissolved nitrite plus nitrate as nitrogen, but the concentration had decreased to 0.25 mg/L in water from sampling site 3. Although the concentration in water from sampling site 2 equaled the KDHE drinking-water criterion, water from the North Cottonwood River is not used as a public-water supply. The dissolved nitrite plus nitrate as nitrogen concentration in water from sampling site 18 (2.6 mg/L) was more than seven times higher than the watershed median concentration (0.33 mg/L). This relatively high concentration may be a result of agricultural practices—fertilizer application (synthetic or manure), pasturing of livestock, and (or) confined feeding operations.

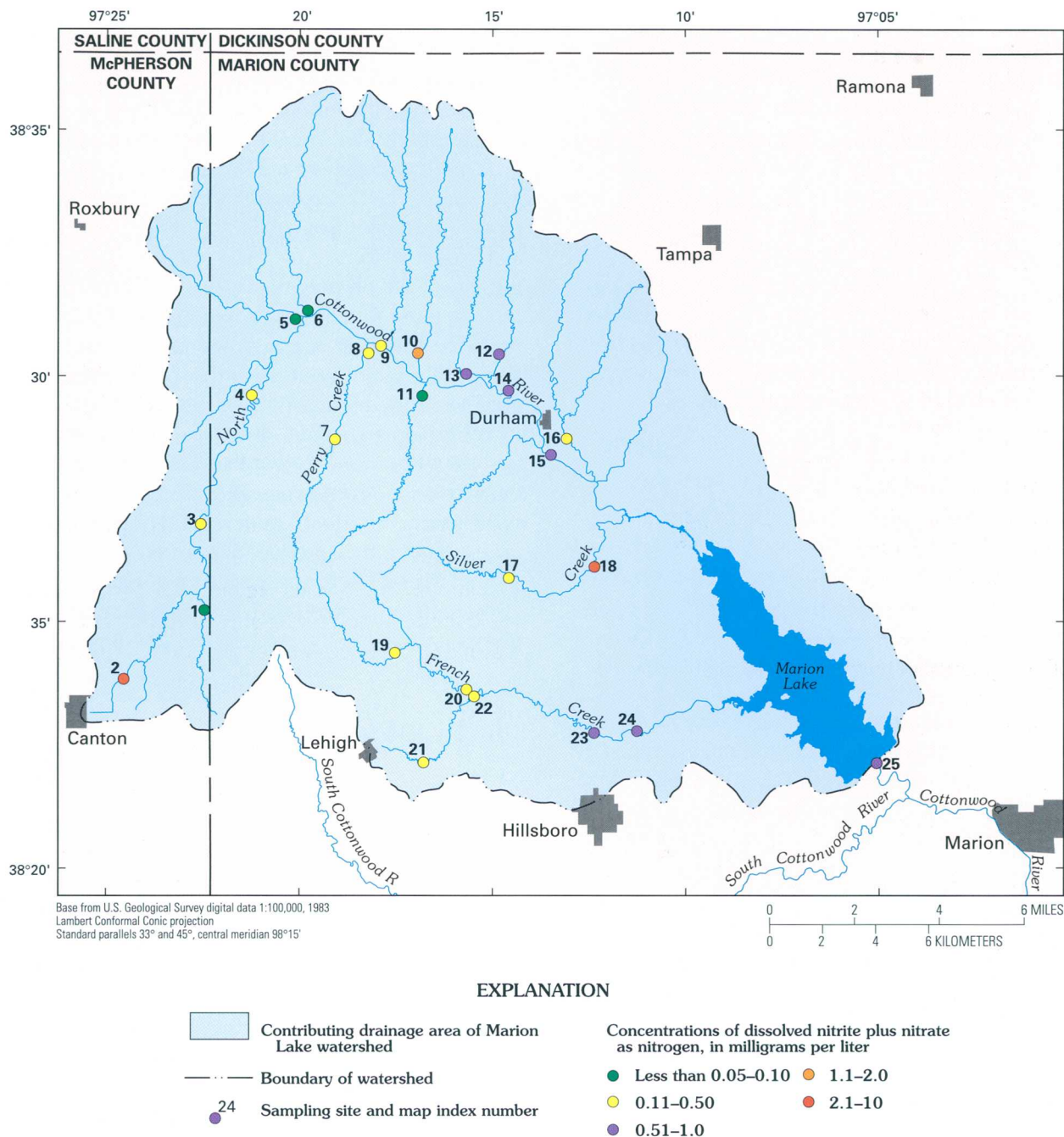


Figure 4. Distribution of nitrite plus nitrate as nitrogen concentrations in December 1998 samples.

Ammonia

Water from 17 of the 25 sampling sites had dissolved ammonia as nitrogen concentrations less than the detection level of 0.02 mg/L. The concentration of dissolved ammonia as nitrogen in water from sampling site 2 was 0.49 mg/L. Studies have shown that concentrations of dissolved ammonia as nitrogen ranging from 0.44 to 19 mg/L were acutely toxic to

19 freshwater invertebrate species (U.S. Environmental Protection Agency, 1986) and, at concentrations between 0.07 and 3.8 mg/L, were acutely toxic to 29 species of freshwater fish (U.S. Environmental Protection Agency, 1986). Downstream in water from sampling site 3, dissolved ammonia as nitrogen concentrations had decreased to 0.11 mg/L and were less than the detection level (0.02 mg/L) in water from sampling site 4.

Dissolved ammonia as nitrogen is a reduced form of nitrogen, and subsequent instream oxidation to nitrite and nitrate can cause a reduction in dissolved-oxygen concentrations. This may have occurred in water from sampling site 2, where the dissolved-oxygen concentration, 6.8 mg/L, was the lowest of the 25 sampling sites measured in the watershed. The concentration of dissolved ammonia as nitrogen in water from sampling site 25, the outflow from Marion Lake, was 0.06 mg/L. The dissolved ammonia in the outflow sample probably is related to natural in-lake processes, but the concentration did not exceed the KDHE (1994) water-temperature and pH-dependent chronic water-quality criterion of approximately 1.7 mg/L.

Total Phosphorus

Phosphorus is known to occur in several forms, but the forms of greatest concern in natural water are elemental phosphorus and orthophosphate. In water, and under slightly alkaline conditions, which exist throughout most of the Marion Lake watershed, calcium phosphate probably is prevalent (Reid and Wood, 1976, p. 236). Elemental phosphorus may be toxic to aquatic organisms and may bioaccumulate in much the same manner as mercury (U.S. Environmental Protection Agency, 1986). Excessive phosphorus in water bodies can accelerate eutrophication (nutrient enrichment) that is characterized by extensive algal growth (algal blooms) that may reduce the aesthetic and recreational value of water, produce taste and odor problems in drinking water, and, in severe cases, stress or kill aquatic organisms resulting from dissolved-oxygen depletion when algal blooms die.

To minimize the potential for eutrophication, the USEPA has recommended a goal of no more than 0.10 mg/L total phosphorus concentrations in flowing surface water (U.S. Environmental Protection Agency, 1986). The median concentration of total phosphorus for samples collected in December 1998 from the Marion Lake watershed was 0.08 mg/L. Additionally, water from 21 of the 25 sites sampled was less than the USEPA guideline of 0.10 mg/L (fig. 5). The relatively high concentrations of total phosphorus in water from sampling sites 2 (2.5 mg/L) and 21 (0.30 mg/L) probably were due to their location downstream from wastewater-treatment facilities. Total phosphorus concentrations in water from sampling sites located downstream from sampling sites 2 and 21 were all less than the 0.10-mg/L guideline. This substantial

decrease in total phosphorus concentrations probably is the result of a combination of dilution, in-channel deposition, and biological uptake.

The concentration of total phosphorus in water from sampling site 25, outflow from Marion Lake, was 0.19 mg/L and higher than the recommended USEPA guideline. The concentration of total phosphorus in most lakes ranges from about 0.01 to 0.03 mg/L (Reid and Wood, 1976, p. 237). The relatively high concentration of total phosphorus in the outflow of Marion Lake, relative to the sites upstream from the lake, probably is a result of past flows into Marion Lake. In Kansas, the majority of water that enters a reservoir does so during periods of high streamflow (runoff) in its contributing streams. Total phosphorus concentrations in stream runoff can be several to many times higher than in low flow because of additional non-point-source contributions of natural or human-related (crop and livestock production) origins (Putnam, 1997). Therefore, runoff periods will have a greater effect in determining long-term concentrations of total phosphorus in a reservoir than will low-flow periods.

PESTICIDES

Pesticides are a general classification of synthetic organic compounds used to control the growth of undesirable plants (herbicides) or insects (insecticides). They are an integral part of modern agricultural production and include organic compounds containing chlorine, nitrogen, or phosphorus.

Atrazine

Atrazine is a triazine herbicide used extensively in the Midwest to control weeds in the production of corn and grain sorghum. Atrazine has a solubility in water of 70 mg/L (at 22 °C), is relatively stable under environmental pH conditions (6.0–9.0 standard units), and degrades in soil through photolysis and microbial activity (U.S. Environmental Protection Agency, 1989). If used excessively, atrazine may threaten public-water supplies and pose adverse effects to human health as well as to aquatic life. Therefore, KDHE (1994) has established an MCL of 3.0 µg/L (annual average) for atrazine in drinking water.

Water samples from all 25 sampling sites were analyzed for dissolved atrazine using the immunoassay method (Thurman and others, 1990). GC/MS was

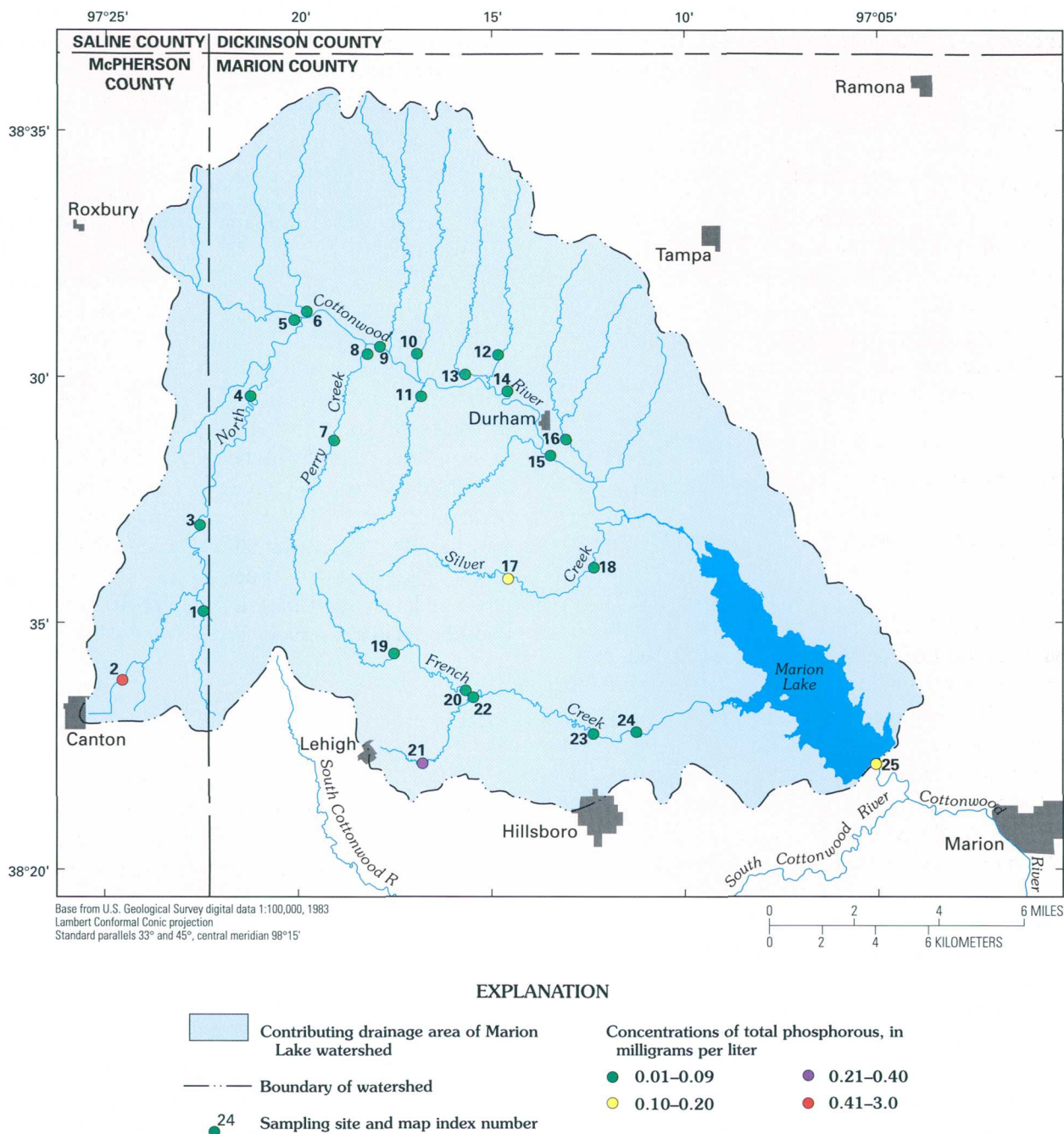


Figure 5. Distribution of total phosphorus concentrations in December 1998 samples.

used to analyze atrazine in water from three sampling sites to confirm the immunoassay method and to determine the presence of other pesticide constituents. The median concentration of dissolved atrazine in water from sampling sites in the Marion Lake watershed was 0.05 µg/L. In the calculation of this median, concentrations less than the analytical detection level of 0.10 µg/L were arbitrarily set at a concentration equal to one-half of the detection level (0.05 µg/L). Atrazine

concentrations did not exceed 1.0 µg/L in water from any sampling site, and concentrations in water from five of the seven sampling sites with detectable concentrations were less than 0.51 µg/L (fig. 6). Low concentrations of deethylatrazine, a degradation product of atrazine, also were detected in water from the outflow of Marion Lake. KDHE has not established a drinking-water criterion for deethylatrazine.

It is evident that, although atrazine may be used extensively in the watershed, during periods of low flow concentrations of atrazine are considerably less than the 3.0 µg/L MCL (annual average) for atrazine in drinking water. Atrazine is usually applied in the spring and early summer months, and the sampling period occurred in December. However, in studies done in northeast Kansas (Pope and others, 1997) and along the Little Arkansas River near Halstead and

Sedgwick, Kansas (Christensen and Ziegler, 1998), atrazine in surface water increased substantially during periods of runoff (most commonly spring and early summer). Concentrations of atrazine were frequently 100 times greater during high flow than during low flow, and annual averages in a reservoir (Perry Lake) were greatly affected by those runoff concentrations (Pope and others, 1997). This potential for higher concentrations during runoff probably explains

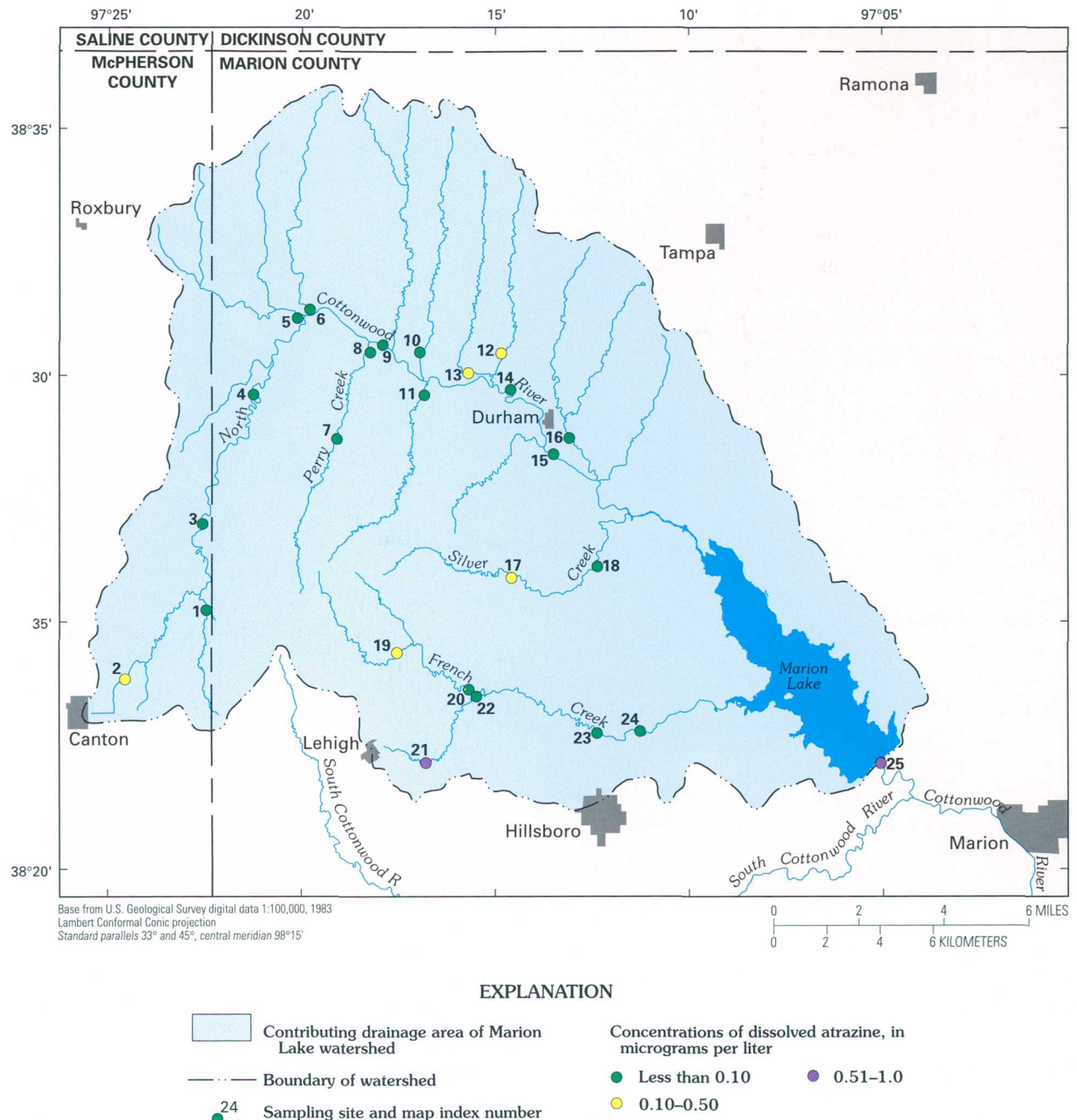


Figure 6. Distribution of dissolved atrazine concentrations determined by enzyme-linked immunosorbent assay in December 1998 samples.

why the outflow of Marion Lake had the highest concentration of dissolved atrazine of any sampling site in the watershed for reasons similar to those previously described in regards to total phosphorus.

Metolachlor

Metolachlor is a pre-emergent herbicide used in the production of corn, grain sorghum, and soybeans. It has a solubility in water of 530 mg/L (at 20 °C), and an MCL of 70 µg/L in drinking water (U.S. Environmental Protection Agency, 1995). Metolachlor, along with several other pesticides (table 3), was analyzed in samples from three sites in the Marion Lake watershed using GC/MS (Zimmerman and Thurman, 1999) (table 2). Aside from atrazine and its degradation product, deethylatrazine, metolachlor was detected in one sample and was the only other pesticide detected in water from sampling sites in the watershed. The concentration of metolachlor in water from the outflow of Marion Lake was 0.07 µg/L, slightly higher than the detection limit of 0.05 µg/L.

FECAL COLIFORM BACTERIA

Fecal coliform bacteria is indigenous to all warm-blooded animals. Therefore, the presence of these bacteria may indicate fecal contamination in surface water and also may indicate the presence of other pathogenic organisms. The contamination may come from municipal wastewater discharges, leachate from domestic septic systems, runoff or ground-water seepage from livestock-producing areas (pasture and confined feedlots), or wildlife populations.

Water-quality criteria have been established for fecal coliform because of potential concerns to human health. KDHE (1994) has established a criterion of 2,000 col/100 mL (colonies per 100 milliliters of water) for noncontact recreation, where little chance of ingestion of surface water is probable. Activities such as fishing, boating, wading, and hunting fall into this category. Marion Lake, however, is classified for contact recreation where ingestion of surface water is possible and is subject to a fecal coliform criterion of 200 col/100 mL.

The median density of fecal coliform for the samples collected in December 1998 from the Marion Lake watershed was 200 col/100 mL. Water from all but one sampling site (site 2) in the Marion Lake

Table 3. Pesticides analyzed but not detected in water samples from the Marion Lake watershed, central Kansas, December 1–2, 1998

[Immunoassay method from Thurman and others (1990); GC/MS, gas chromatography/mass spectrometry, method from Zimmerman and Thurman (1999). µg/L, microgram per liter]

Pesticides analyzed by	
Immunoassay (detection level = 0.10 µg/L)	GC/MS (detection level = 0.05 µg/L)
Alachlor	Acetochlor
Alachlor ESA	Alachlor
Aldicarb	Ametryn
Carbofuran	Cyanazine
Chlorpyrifos	Cyanazine amide
Chlorthalnil	Deisopropylatrazine
Cyanazine	Metribuzin
Cyclodienes	Prometon
2,4-D	Prometryn
Metolachlor	Propachlor
	Propazine
	Simazine
	Terbutryn

watershed had fecal coliform densities less than or equal to the 2,000-col/100 mL noncontact-recreational criterion (fig. 7, table 2). The fecal coliform density in water from sampling site 2 on the North Cottonwood River was 3,300 col/100 mL, which probably is a result of discharge from the wastewater-treatment facility located near Canton. The outflow from the lake, sampling site 25, had a fecal coliform density of 54 col/100 mL, substantially less than the KDHE contact-recreational criterion of 200 col/100 mL. The source of the relatively high fecal coliform density (2,000 col/100 mL) in water from sampling site 10, a tributary to the North Cottonwood River, is not known but may be associated with livestock production.

SUMMARY AND IMPLICATIONS FOR MARION LAKE

This report describes water-quality conditions in the Marion Lake watershed during a low-flow period in December 1998. Sampling 25 surface-water sites during a 2-day period provided insight into spatial variability of water-quality constituents and allowed for between-site comparisons during stable low-flow

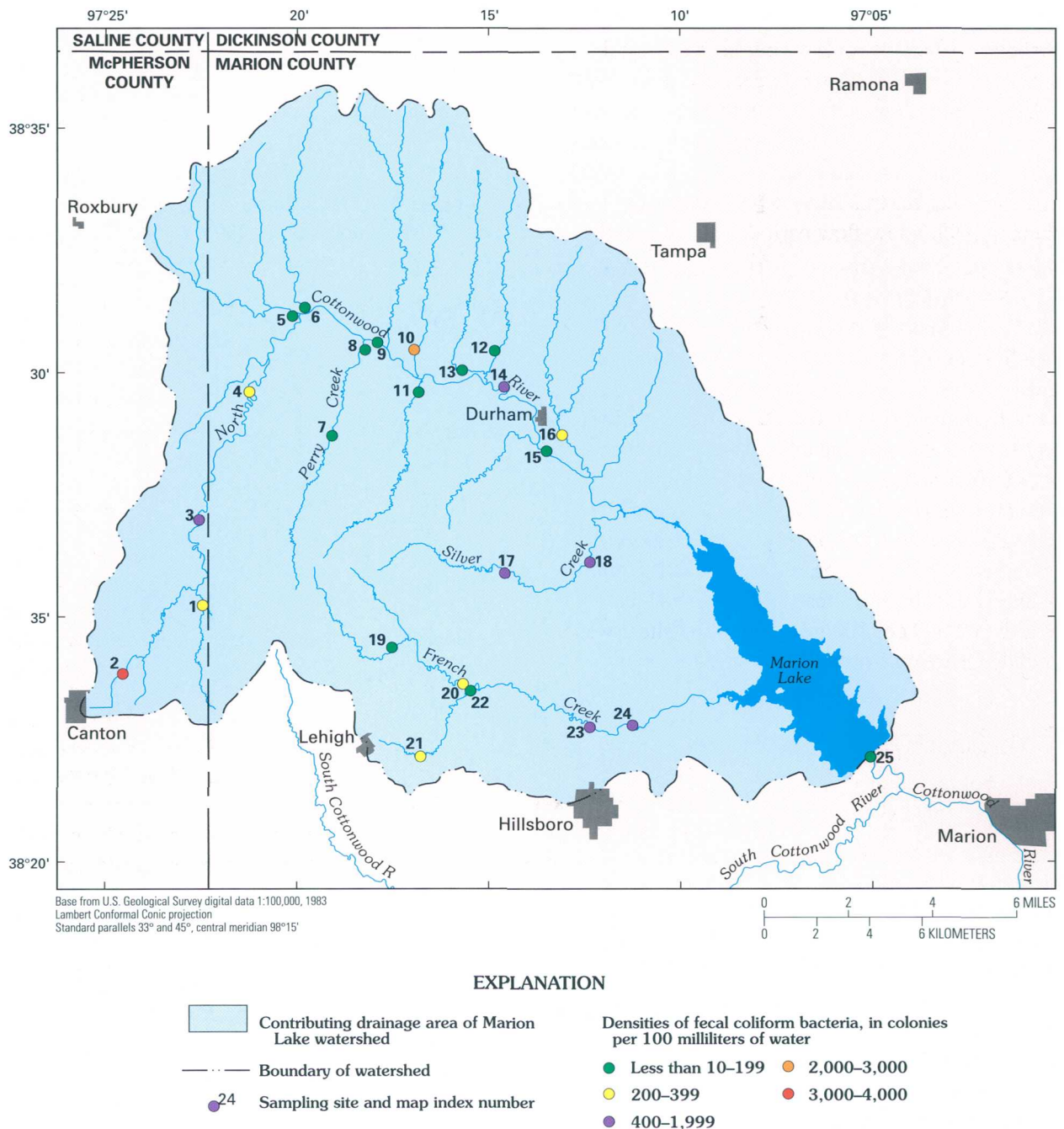


Figure 7. Distribution of fecal coliform bacteria densities in December 1998 samples.

conditions. Analysis of a variety of organic and inorganic constituents allowed for an evaluation of low-flow conditions in the watershed, and possible relations to, both point and nonpoint sources.

Results of this study indicate that some water-quality concerns exist in the watershed. The median dissolved-solids concentration in the watershed was higher than U.S. Environmental Protection Agency (USEPA) Secondary Maximum Contaminant Level

drinking-water guidelines, which could have an effect on the variety and abundance of plants and animals within Marion Lake. Median nutrient concentrations, both nitrogen and phosphorus compounds, were less than USEPA guidelines. However, the concentration of total phosphorus in the lake outflow was higher than the USEPA guideline of 0.10 mg/L; that constituent could be an indicator of potential future water-quality problems for Marion Lake.

Pesticide usage in many Midwestern agricultural watersheds is typically high during the spring and early summer when crops are seeded. Combined with seasonal precipitation, pesticides commonly are transported with surface-water runoff to receiving streams that may discharge to lakes or reservoirs. The water-quality sampling for this study was done during December 1998, a low-flow period nearly 8 months after the typical first pesticide applications to cropland. Pesticide concentrations were low in receiving water throughout the watershed but may be much higher during times of the year when pesticides are used.

The median density of fecal coliform bacteria in the water from all sampling sites was less than the Kansas Department of Health and Environment criterion for noncontact recreation and less than the contact-recreational criterion in water from the Marion Lake outflow site. However, water from two sampling sites, sites 2 and 10, had fecal coliform densities greater than 2,000 col/100 mL. Sampling site 2 was located downstream from a wastewater-treatment facility, and site 10 may be affected by livestock production common to the area. The transport of fecal coliform bacteria in water may be greater during periods of high streamflow than during the low-flow period investigated in December 1998.

Physical and biologic processes within Marion Lake may be masking some long-term water-quality issues that have broad implications. Constituents such as nutrients and fecal coliform bacteria commonly are transported into the lake in highest concentrations during periods of high flow, and detection or extent of effects on water quality in Marion Lake may not be evident by sampling lake outflow. Phosphorus, for example, is hydrophobic and much of that transported into the lake is deposited in bottom sediment. Therefore, long-term concentrations of phosphorus may be substantially less in the outflow of the lake than in the inflow. Additionally, the accumulation of phosphorus in bed sediment creates the potential for subsequent solubilization of phosphorus into the overlying water and may have implications for accelerated eutrophication of Marion Lake. Evaluation of hydrophobic constituents within the lake-bed sediment may help address whether human-related activities within the Marion Lake watershed benefit the long-term ecological health of the watershed, or whether changes in activities are warranted.

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