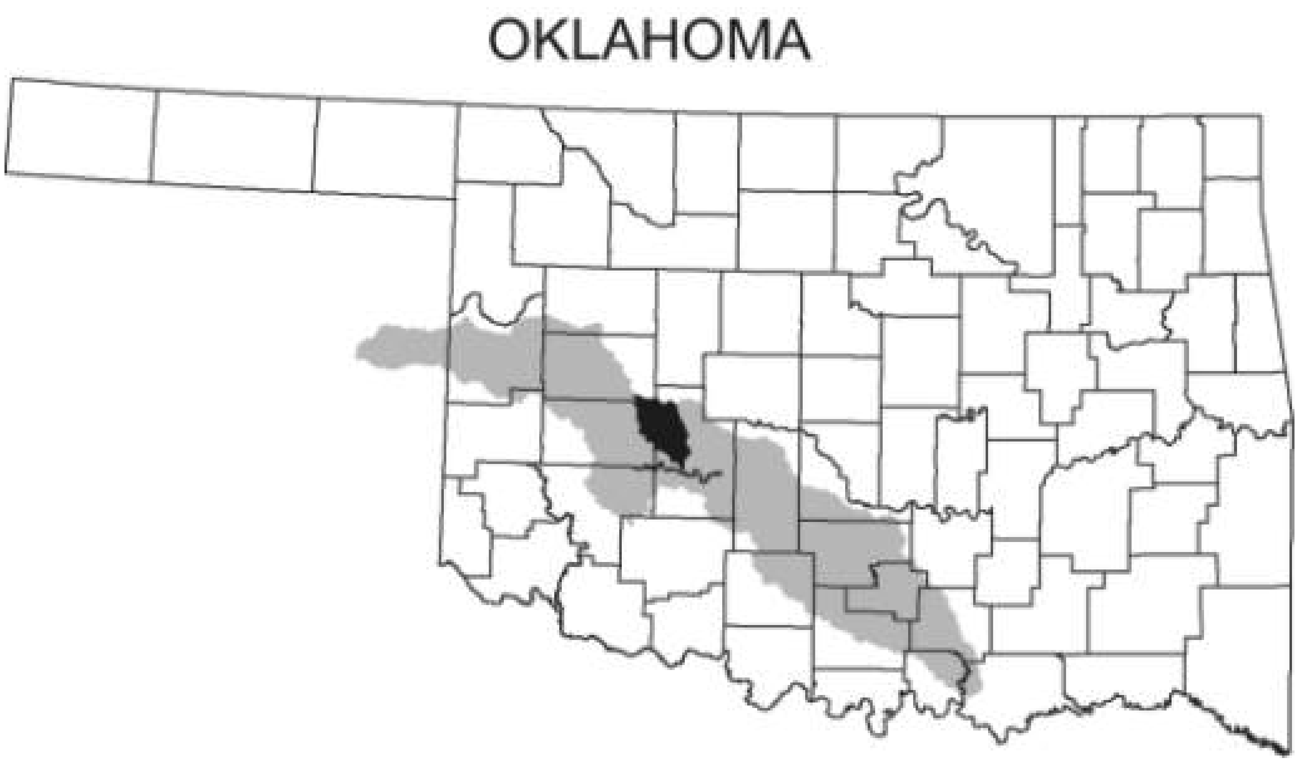
Prepared in cooperation with the Bureau of Reclamation

Ground-water quality, levels, and flow direction near Fort Cobb Reservoir, Caddo County, Oklahoma, 1998-2000

Water-Resources Investigations Report 01–4076



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

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

Ground-water quality, levels, and flow direction near Fort Cobb Reservoir, Caddo County, Oklahoma, 1998-2000

By C.J. Becker

Water-Resources Investigations Report 01–4076

Prepared in cooperation with the Bureau of Reclamation

U.S. Department of the Interior
GALE A. NORTON, Secretary

U.S. Geological Survey
CHARLES G. GROAT, Director

The use of firm, trade, and brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

UNITED STATES GOVERNMENT PRINTING OFFICE: OKLAHOMA CITY 2001

For additional information write to:

District Chief
U.S. Geological Survey
Water-Resources Division
202 NW 66 St., Bldg. 7
Oklahoma City, OK 73116

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Box 25286
Federal Center
Denver, CO 80225

Becker, C.J.—Ground-water quality, levels, and flow direction near Fort Cobb Reservoir, Oklahoma, 1998-2000—USGS/WRIR 01–4076

Printed on recycled paper

CONTENTS

Abstract 1
Introduction 1
Purpose and scope 2
Approach and methods 2
Description of the study area 5
Acknowledgments 14
Ground-water quality 14
Levels 17
Flow direction 17
Discussion 18
Summary 18
References cited 19

ILLUSTRATIONS

Figures 1-2. Maps showing:
1. Study area, Fort Cobb Reservoir, and Cobb Creek subbasin, Caddo County, Oklahoma 3
2. Location of swine feeding operation and wells used for this study 4
Figure 3. Graph showing daily mean water level in well MWR-A and daily precipitation at the Fort Cobb Mesonet station, April 14, 1999, to May 31, 2000 11
Figures 4-6. Maps showing:
4. Potentiometric surface and direction of ground-water flow in study area, December 1998 12
5. Potentiometric surface and direction of ground-water flow in the study area, August 1999 13
6. Land use and land cover in the study area, near Fort Cobb Reservoir 15
Figure 7. Graph showing ranges of the nitrogen isotopes nitrogen-14 and nitrogen-15 expressed as $\delta^{15}N$ parts per thousand relative to atmospheric nitrogen in water samples in the study area and in common sources of nitrate 17

TABLES

1. Location information and depth-to-water measurements for wells in the study area 6
2. Measured water properties and concentrations of major ions, nutrients, trace elements, nitrogen isotopes, pesticides, and bacteria counts in water samples collected April and June 2000, from observation wells in the study area 8
3. Pesticides and pesticide metabolites analyzed for in ground-water samples collected April 12, 2000, from observation wells BD–1 and MW–B in the study area 10
4. Land use and land cover in the study area and the Cobb Creek subbasin 14

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
Length		
inch (in)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
Area		
square mile (mi^2)	2.590	square kilometer
Volume		
gallon (gal)	0.003785	cubic meter
Flow rate		
foot per mile (ft/mi)	0.1894	meter per kilometer
foot per day (ft/d)	0.3048	meter per day
gallon per minute (gal/min)	0.06309	liter per second
gallon per day (gal/d)	0.003785	cubic meter per day
inch per year	25.4	millimeter per year
Mass		
pound (lb)	0.4536	kilogram

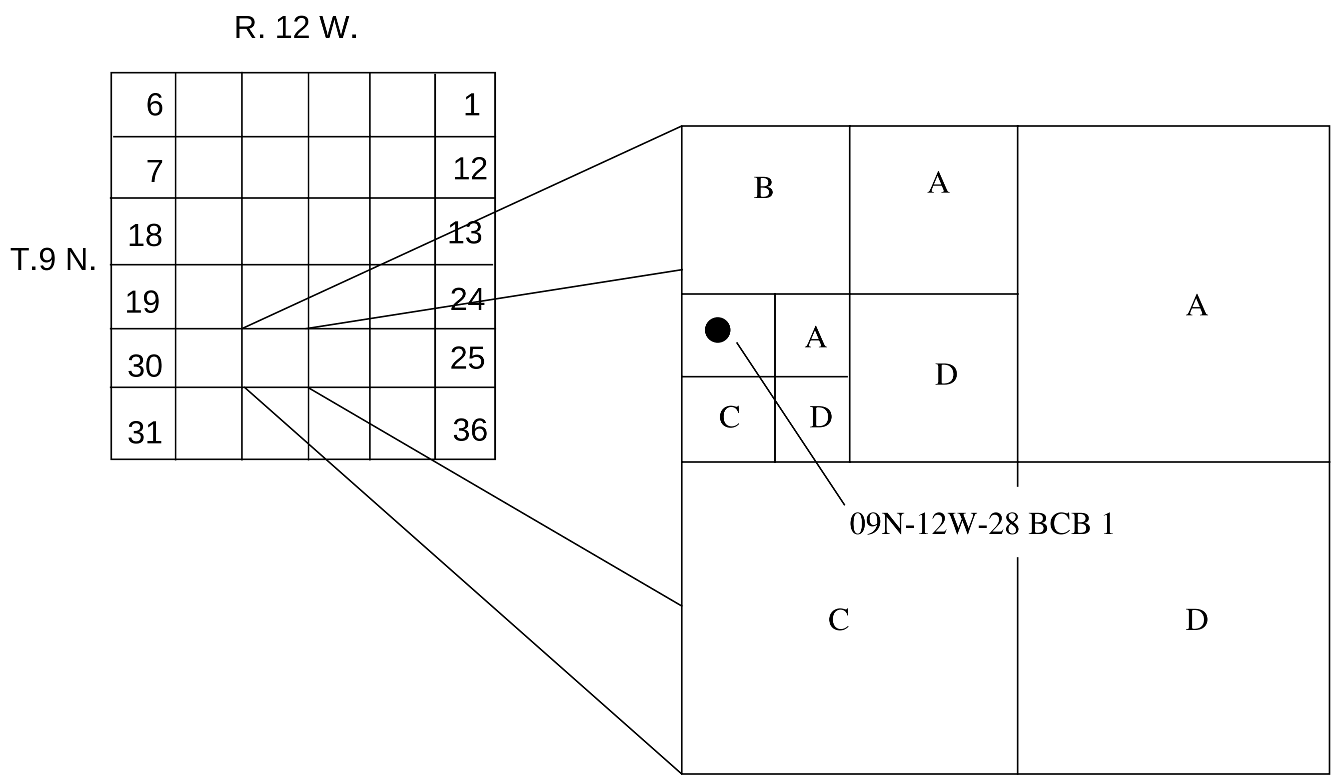
Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Altitude, as used in this report, refers to distance above sea level.

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

EXPLANATION OF THE SITE-NUMBERING SYSTEM

Well locations in this report are specified by a local site-numbering system, which is based on the public land-survey location in Oklahoma. The local site-numbering system consists of the township number, north or south; range number, east or west; and the section number. Each section is divided into four quarters, A, B, C, and D. The township numbers are north of the third parallel and the range numbers are west of the Indian Meridian. A section is equal to one square mile and fractional parts are given from larger to smaller quartered areas of the section. The final digit (1) is the sequential number of a well within the smallest fractional subdivision (10 acres, in the example shown) relative to other wells in the same subdivision. The diagram shown below illustrates the location of a well described as: 09N-12W-28 BCB 1.



Ground-Water Quality, Levels, and Flow Direction Near Fort Cobb Reservoir, Caddo County, Oklahoma, 1998-2000

By C.J. Becker

Abstract

Fort Cobb Reservoir in northwest Caddo County Oklahoma is managed by the Bureau of Reclamation for water supply, recreation, flood control, and wildlife. Excessive amounts of nitrogen in the watershed have the potential to cause long-term eutrophication of the reservoir and increase already elevated concentrations of nitrogen in the Rush Springs aquifer. The U.S. Geological Survey in cooperation with the Bureau of Reclamation studied ground water in the area surrounding a swine feeding operation located less than 2 miles upgradient from Fort Cobb Reservoir in Caddo County, Oklahoma. Objectives of the study were to (1) determine if the operation was contributing nitrogen to the ground water and (2) measure changes in ground-water levels and determine the local ground-water flow direction in the area surrounding the swine feeding operation.

Nitrate concentrations (28.1 and 31.5 milligrams per liter) were largest in two ground-water samples from a well upgradient of the wastewater lagoon. Nitrate concentrations ranged from 4.30 to 8.20 milligrams per liter in samples from downgradient wells. Traces of ammonia and nitrite were detected in a downgradient well, but not in upgradient wells. $\delta 15N$ values indicate atmospheric nitrogen, synthetic fertilizer, or plants were the predominate sources of nitrate in ground water from the downgradient wells. The $\delta 15N$ values in these samples are depleted in nitrogen-15, indicating that animal waste was not a significant contributor of nitrate.

Manganese concentrations (1,150 and 965 micrograms per liter) in samples from a downgradient well were substantially larger than concentrations in samples from other wells, exceeding the secondary drinking-water standard of 50 micrograms per liter. Larger concentrations of bicarbonate, magnesium, fluoride, and iron and a higher pH were also measured in water from a downgradient well.

Ground-water levels in an observation well were higher from April to mid-July and lower during the late summer and in the fall due to a seasonal decrease in precipitation, increase in water withdrawals, and increase in evapotranspiration. Ground water near the wastewater spray field moved south-southeast toward Willow Creek along a gradient of about 50 feet per mile.

Analysis of ground-water samples suggest that commercial fertilizer is contributing nitrate upgradient of the swine feeding operation and that wastewater from the lagoon is contributing reduced forms of nitrogen, ammonia and nitrite. Additional downgradient wells would be needed to (1) determine if the swine feeding operation is adding excessive amounts of nitrogen to ground water, (2) determine the vertical dimension of wastewater flow, and (3) the extent of wastewater downgradient of the lagoon.

INTRODUCTION

The number of confined animal feeding operations near reservoirs has increased in Oklahoma, resulting in increased concern about the effects of these operations on water quality. One water-quality concern in both surface water and ground water is the increased concentration of nitrogen. Fort Cobb Reservoir in northwest Caddo County Oklahoma is managed by the Bureau of Reclamation for water supply, recreation, flood control, and wildlife (fig. 1). Excessive amounts of nitrogen in the watershed have the potential to cause long-term eutrophication of the reservoir and increase already elevated concentrations of nitrogen in the Rush Springs aquifer.Ground water from the Rush Springs aquifer is the sole source of water for domestic use for rural homesteads in the watershed. Becker and Runkle (1998, pgs. 19 and 24) reported that 50 percent of 64 ground-water samples from the Rush Springs aquifer exceeded the drinking-water standard for nitrate of 10 milligrams per liter.

Land use in the Fort Cobb watershed is mostly irrigated agriculture and the long-term use of commercial fertilizer on the sandy permeable soils may be responsible for much of the elevated nitrate concentrations measured in the Rush Springs aquifer. The major sources of nitrogen in ground water are precipitation, fertilizer application (both commercial and manure), and sewage disposal. Precipitation deposits about 1.3 to 1.7 tons of nitrogen per square mile per year in Caddo County (Mueller and Helsel, 1996, pg. 10). The application of nitrogen derived from commercial fertilizer in Caddo County was about 11.2 tons per square mile per year (1987 through 1996) (Dan Storm, Oklahoma State University, written commun., 2001) application of manure was about 5.3 tons per square mile per year (1997 only) (Barbara Ruddy, U.S. Geological Survey, written commun., 2001).

A swine feeding operation (fig. 2) began functioning in July 1997 about two miles north of Fort Cobb Reservoir. The facility is a finishing operation for about 4,000 pigs with an average weight of 150 pounds each (Agricultural Engineering Associates, 1997). Wastewater from four swine barns is discharged into an earthen lagoon that is about 430 feet by 320 feet and about 25 feet deep. The lagoon was lined with a mixture of sodium bentonite clay and soil 18 inches thick during construction (Ham and DeSutter, 2000). A water-balance study was conducted between May 27 and June 9, 2000, to determine the rate at which wastewater was seeping through the lagoon liner (Ham and DeSutter, 2000). The study showed an average seepage rate of 11.6 inches per year, equivalent to an average volume of 2,663 gallons per day. Wastewater from the lagoon is removed during the growing season and applied by center pivot irrigation to 83.4 acres in the eastern half of the southwest quarter of section 16 (fig. 2). About 18,478 pounds (9.24 tons) of nitrogen in lagoon wastewater from the swine feeding operation is applied annually (Agricultural Engineering Associates, 1997).

In response to concerns the U.S. Geological Survey in cooperation with the Bureau of Reclamation studied ground water in an area surrounding the swine feeding operation located near Fort Cobb Reservoir in Caddo County, Oklahoma (fig. 2). Objectives of the study were to (1) determine if the operation was contributing nitrogen to the ground water and (2) measure changes in ground-water levels and determine the local ground-water flow direction in the area surrounding the swine feeding operation.

Purpose and Scope

The purpose of this report is to show ground-water quality, changes in ground-water levels, and direction of ground-water flow north of Fort Cobb Reservoir surrounding a swine feeding operation. Water-quality constituents were measured in ground-water samples from five observation wells installed near the swine feeding operation. Ground-water levels were measured continuously in a ground-water level observation well near a swine feeding operation from April 1999 to May 2000. Depth-to-water measurements during December 1998 and August 1999 were used to construct two potentiometric-surface maps to determine the direction of ground-water flow for a 14 square mile area bounded by Lake Creek, Willow Creek, State Highway 152 and Fort Cobb Reservoir.

Approach and Methods

Five observation wells were installed and sampled to describe the ground-water quality in the area surrounding the swine feeding operation (table 1). Two wells, MW-B and MW-C, were installed upgradient to a depth of about 70 feet with the bottom 20 feet of the wells screened. Three observation wells, BD-1, BD-2, and BD-3, were installed downgradient to a depth of about 55 feet with the bottom 10 feet screened. All five wells were completed with the

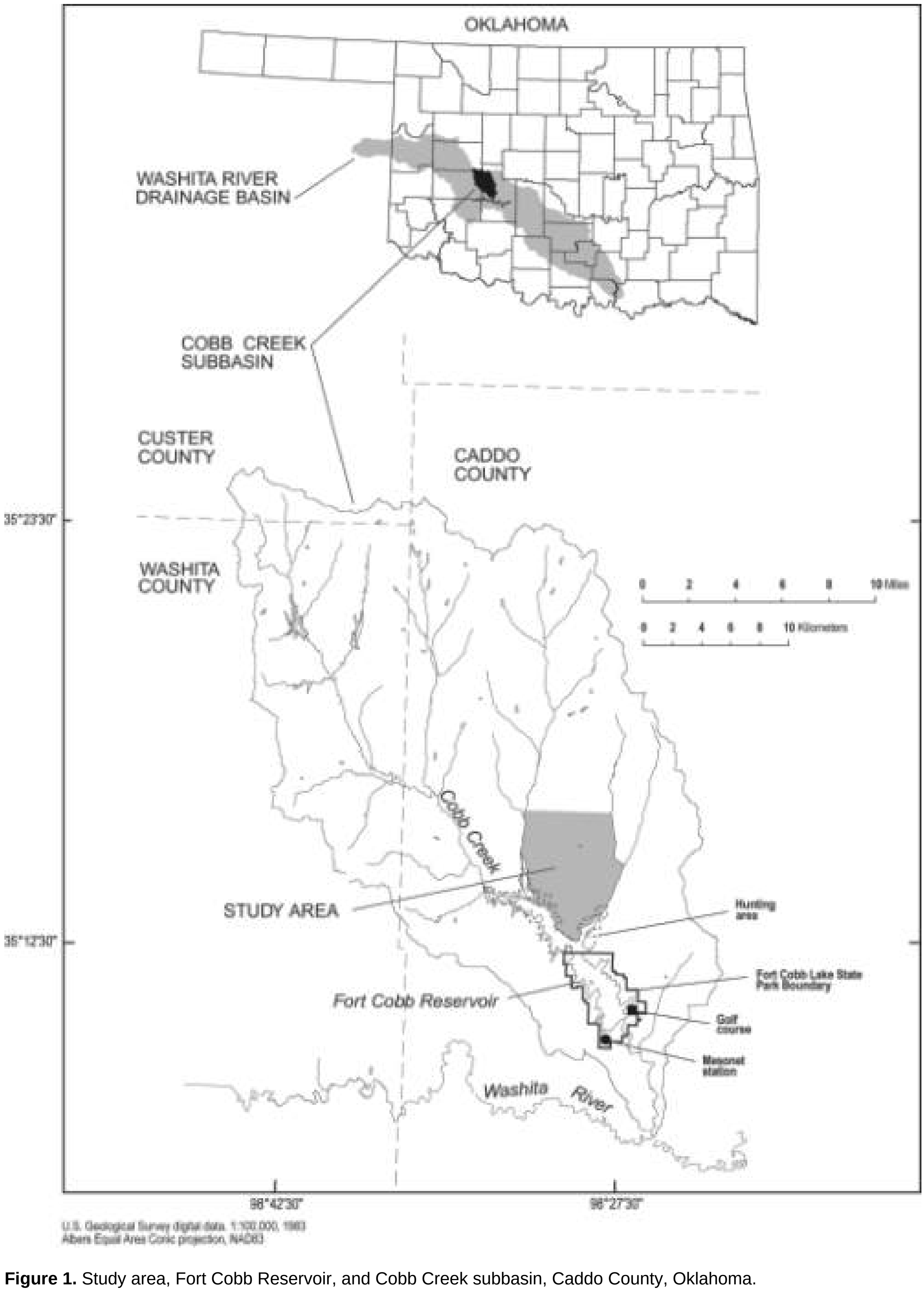


Figure 1. Study area, Fort Cobb Reservoir, and Cobb Creek subbasin, Caddo County, Oklahoma.

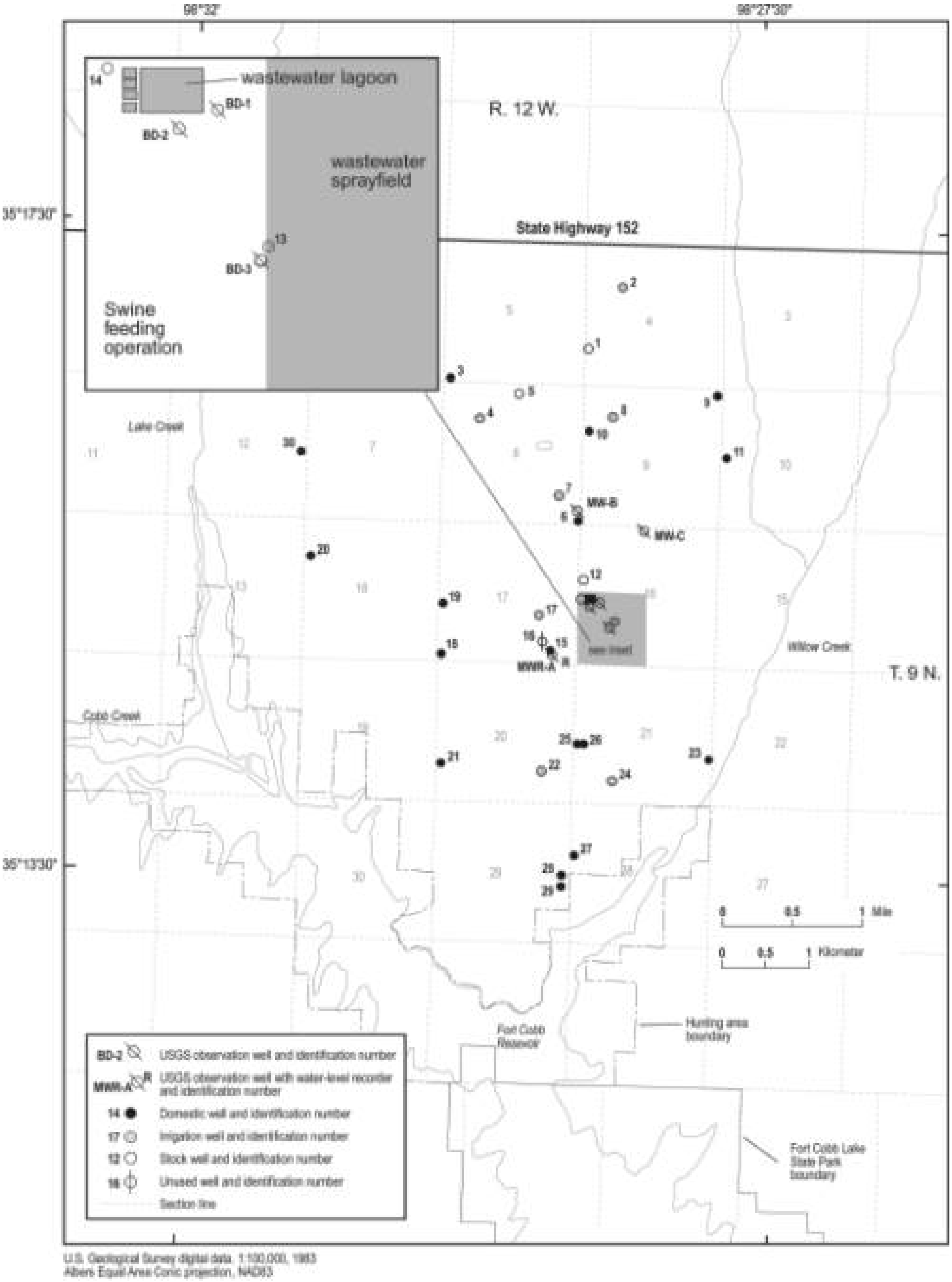


Figure 2. Location of swine feeding operation and wells used for this study.

top of the screened interval intersecting the water table.

Observation wells were sampled April 5-18, 2000, and again June 12-19, 2000, except for well BD-3. Observation well BD-3 had an insufficient volume of water to sample because the adjacent irrigation well was operating. Ground water was sampled using methods described in Wilde and others (1999). Field measurements of specific conductance, pH, and dissolved oxygen were performed using methods described in Wilde and Radtke (1998).

Water samples were analyzed for major ions, nutrients, and the trace elements copper, selenium, and zinc at the U.S. Geological Survey National Water Quality Laboratory in Lakewood, Colorado (table 2). Major ion concentrations were measured using methods described in Fishman and Friedman (1989) and in Fishman (1993). Nutrient concentrations were measured using methods described in Fishman (1993). Copper, selenium, and zinc concentrations were measured using methods described in Garbarino (1999) and Faires (1993). Water samples also were analyzed for the ratio of stable nitrogen isotopes nitrogen-15 to nitrogen-14 in nitrate (April samples only) at the Stable Isotope Laboratory, Boston University, Boston, Massachusetts, using methods described by Downs and Michener (1999).

Water samples collected from wells BD-1 and MW-B on April 12, 2000, were analyzed for a suite of pesticides commonly used in Caddo County and pesticide metabolites (table 3). The analyses were performed at the U.S. Geological Survey Organic Geochemistry Research Laboratory in Lawrence, Kansas, using gas chromatography/mass spectrometry as described in Zimmerman and Thurman (1999) and liquid chromatography/mass spectrometry as described in Hostetler and Thurman (1999) and Ferrer and others (1997).

Water samples collected in June were cultured for *Escherichia coli*, fecal streptococci, and fecal coliform using methods described in Myers and Wilde (1997).

A ground-water level observaiton well, MWR-A, was installed to measure variation in ground-water levels near the swine feeding operation (fig. 3). The well was equipped with a pressure transducer and data logger for depth-to-water measurements and a data collection platform for satellite transmission of measurements to the U.S. Geological Survey National Water Information System. Ground-water levels were measured continuously from April 14, 1999, to May 31, 2000.

Depth-to-water measurements for 30 wells during December 1998 and for 27 wells during August 1999 (table 1) were used to construct potentiometric-surface maps (figs. 4 and 5). The average total depth of domestic wells was about 100 feet, whereas, the average total depth of irrigation wells was about 300 to 350 feet. Wells in the northern part were generally deeper than wells in the southern part of the study area. The differential altitude of the land-surface near each well was determined with a global positioning system and was relative to a selected point in the study area and corresponding altitude from the U.S. Geological Survey 1:24,000-scale topographic quadrangle.

Description of the Study Area

The 14 square mile study area is in the Cobb Creek subbasin of the Washita River drainage basin in northwest Caddo County and is bounded by Lake Creek, Willow Creek, State Highway 152, and the Fort Cobb Reservoir (fig. 1). Fort Cobb Reservoir was constructed in 1959 and has an average surface area of 4,100 acres. A public hunting area and a State Park with public use areas, including a golf course, are adjacent to the reservoir (Oklahoma Tourism Department, 2000). Fort Cobb Reservoir is in the Central Flyway for migratory waterfowl. The estimated number of waterfowl at the reservoir averaged 66,331 ducks and 10,527 geese a day between mid-November and late January during 1991-2000 (Michael O'Meilia, Oklahoma Department of Wildlife Conservation, written commun., 2001).

The study area is a sparsely populated agricultural area, with three to four homesteads per square mile. There are numerous houses on the north side of the reservoir and the local population increases during the summer months because of an increase in lake-related activities. Households and businesses in the study area use septic tank systems.

Agriculture is the primary land use in the study area and wheat and peanuts are the principal crops grown. Land use and land cover information (U.S. Environmental Protection Agency, 2000a) show that the largest percent of land in the study area and in the Cobb Creek subbasin is used to cultivate row crops and small grains (72 and 63 percent). Grassland and

Table 1. Location information and depth-to-water measurements for wells in the study area

[Well types: D, domestic; I, irrigation; O, USGS observation: R, USGS observation well with water-level recorder; S, livestock; U, unused; --, not available]

Identification number (figure 1)	Legal description	USGS site identification number	Well type	Land-surface altitude (feet above sea level)	Depth to water 12/98 (feet below land surface)	Depth to water 8/99 (feet below land surface)
MW-B	09N-12W-08 DDD2	351545098285701	O	1,501 [b]	--	--
MW-C	09N-12W-16 BAAA 2	351542098282501	O	1,495 [b]	--	--
BD-1	09N-12W-16 CBAD 1	351506098284001	O	1,472 [b]	--	--
BD-2	09N-12W-16 CB 1	351504098284601	O	1,475 [b]	--	--
BD-3	09N-12W-16 C 2	351502098284001	O	1,475 [b]	--	--
MWR-A	09N-12W-17 DDD 1	351452098290601	R	1,460.0	--	38.18
1	09N-12W-04 CBC 1	351650098285301	S	1,541.8	60.91	61.54
2	09N-12W-04 B 1	351712098284101	I	1,540 [b]	55.55	--
3	09N-12W-05 CCC 1	351635098300301	D	1,508.2	47.07	47.87
4	09N-12W-08 B 1	351622098294201	I	1,501.5	36.93	42.45
5	09N-12W-08 ABB 1	351633098292601	S	1,516.3	48.04	49.36
6	09N-12W-08 DDD 1	351543098285701	D	1,506.8	55.49	55.76
7	09N-12W-08 D 1	351555098291101	I	1,505.1	50.64	51.39
8	09N-12W-09 BB 1	351628098284401	I	1,515.4	43.12	45.80
9	09N-12W-09 AAA 1	351630098275301	D	1,525.4	74.61	75.12
10	09N-12W-09 BCB 1	351618098285301	D	1,518.4	51.96	52.20
11	09N-12W-10 CBBB 1	351608098274901	D	1,517.3	82.24	82.75
12	09N-12W-16 BCB 1	351523098285501	S	1,512.4	69.04	68.65
13	09N-12W-16 C 1	351507098284101	I	1,480.5	46.05	46.93
14	09N-12W-16 CBB 1	351514098285301	S	1,492.5	56.72	58.60
15	09N-12W-17 DD 1	351454098290501	D	1,460.4	37.33	37.45
16 [1]	09N-12W-17 DDC 1	351453098290701	U	1,463.8	40.09	40.16
17	09N-12W-17 D 1	351505098291401	I	1,464.7	38.07	--
18	09N-12W-17 CCC 1	351453098295801	D	1,443.4	31.37	31.82
19	09N-12W-17 CBB 1	351512098295501	D	1,458.6	36.96	37.18
20	09N-12W-18 BBC 1	351531098310101	D	1,425.8	28.70	29.26
21	09N-12W-20 CBC 1	351414098295801	D	1,427.0	43.53	43.97

Table 1. Location information and depth-to-water measurements for wells in the study area —Continued

Identification number (figure 1)	Legal description	USGS site identification number	Well type	Land-surface altitude (feet above sea level)	Depth to water 12/98 (feet below land surface)	Depth to water 8/99 (feet below land surface)
22	09N-12W-20 DD 1	351411098290401	I	1,426.4	33.17	33.69
23	09N-12W-21 DAD 1	351416098275301	D	1,377.5	7.05	7.49
24	09N-12W-21 CDB 1	351409098283901	I	1,432.6	50.56	50.18
25	09N-12W-21 CBB 1	351421098285301	D	1,432.0	28.46	29.68
26	09N-12W-21 CBB 2	351421098285302	D	1,431.1	26.06	--
27	09N-12W-28 BCB 1	351341098285401	D	1,410 [b]	50.6	--
28	09N-12W-29 DAA 1	351328098285801	D	1,400 [b]	51.03	50.89
29	09N-12W-29 DAD 1	351322098285701	D	1,400 [b]	52.28	52.08
30 [a]	09N-13W-12 DAA 1	351607098310201	D	1,467.9	61.17	64.32

[1]Irrigation well was operating adjacent to well during 8/99 measurement.
[b]Land-surface altitude was estimated from USGS 1:24,000 topographic quadrangle.

Table 2. Measured water properties and concentrations of major ions, nutrients, trace elements, nitrogen isotopes, pesticides, and bacteria counts in water samples collected April and June 2000, from observation wells in the study area

Identification number	Sample date	Specific conduc-tance (µs/cm)	pH (standard units)	Dissolved oxygen (mg/L)	Alkalinity (mg/L as $CaCO_3$)	Total dis-solved solids (mg/L)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Silica (mg/L as SIO_2)	Nitrite (mg/L as N)	Nitrate nitrite (mg/L as N)	Ammonia (mg/L as N)	Ortho-phos-phorus (mg/L as P)	Copper (µg/L as Cu)
Upgradient wells																			
MW–B	04/06/2000	225[c]	6.5 [c]	7.5	93	160	16	6.5	18	4.9	13	0.77	0.28	36	< 0.010	1.84	< 0.020	0.066	< 1.0
MW–B	06/12/2000	226	6.6	7.2	94	163	18	7.4	19	3.6	12	.49	.21	37	< .010	1.95	< .020	.059	< 1.0
MW–C	04/05/2000	467[c]	6.9 [c]	9.4	104	353	42	19	31	3.8	29	13	.22	28	< .010	28.1 [f]	< .020	.051	< 1.0
MW–C	06/14/2000	546[c]	6.9 [c]	8.6	107	377	45	22	30	3.8	29	14	.19	29	< .010	31.5 [f]	< .020	.054	--
Downgradient wells																			
BD–1	04/11/2000	674[c]	7.6 [c]	--	136	365	65	18	39	3.9	130	32	.42	29	.022	7.38	< .020	.048	2.6
BD–1	06/15/2000	690[c]	7.0 [c]	7.9	128	443	74	20	34	2.6	140	33	.35	32	< .010	6.79	< .020	.066	< 1.0
BD–2	04/18/2000	601	7.5	--	258	365	63	22	24	8.3	22	11	.47	31	.064	6.37	.254	.038	< 1.0
BD–2	06/19/2000	725[c]	7.4 [c]	4.8	342	440	87	30	17	6.6	22	16	.20	34	.029	4.30	.227	.046	< 1.0
BD–3	04/12/2000	465[c]	7.1	--	107	271	44	14	22	4.3	71	13	.33	38	< .010	8.20	< .020	.050	< 1.0

Table 2. Measured water properties and concentrations of major ions, nutrients, trace elements, nitrogen isotopes, pesticides, and bacteria counts in water samples collected April and June 2000, from observation wells in the study area—Continued

Iron (µg/L as Fe)	Manganese (µg/L as Mn)	Selenium (µg/L as Se)	Zinc (µg/L as Zn)	$\delta^{15}N$ (parts per thousand relative to atmospheric nitrogen) [1]	Pesticide metabolite (µg/L) [b]	*Escherichia coli* (colonies per 100 mil)	Fecal coliform (colonies per 100 mil)	Fecal streptococci (colonies per 100 mil)
				Upgradient wells				
E 5.1	16	2	2.1	+ 2.43	ND	--	--	--
< 10	49	2	2.7	--	--	60 [d]	2 [d, e]	10 [d]
E 5.1	6.2	1	3.2	+ 5.57	ND	--	--	--
< 10	12	--	< 20	--	--	5 [d]	2 [d, e]	3 [d]
				Downgradient wells				
< 10	2.3	M	1.1	– .09	metolachlor ethane sulfonic acid 0.66	--	--	--
< 10	2.7	E 1	3.4	--	--	3 [d]	2 [d, e]	4 [d]
< 10	1,150	2	8.4	– .56	ND	--	--	--
20	965	2	4.1	--	--	10 [d]	8 [d]	2 [d, e]
< 10	32	M	1.2	+ 1.88	ND	--	--	--

[1] Analyses were performed at the Stable Isotope Laboratory, Boston University, Boston, Massachusetts.

[b] Analyses were performed at the U.S. Geological Survey Organic Geochemistry Research Laboratory, Lawrence, Kansas.

[c] Field measurement.

[d] Estimates are based on non-ideal colony count.

[e] Less than the calculated number per 100 milliliters.

[f] Measured concentration exceeds U.S. Environmental Protection Agency primary drinking water standard of 10 milligrams per liter (U.S. Environmental Protection Agency, 2000).

Table 3. Pesticides and pesticide metabolites analyzed for in ground-water samples collected April 12, 2000, from observation wells BD–1 and MW–B in the study area

[Metolachlor ethane sulfonic acid was measured at a concentration of 0.66 microgram per liter in water from well BD–1. No other pesticides or pesticide metabolites were detected at a concentration above 0.05 micrograms per liter]

Pesticide	Pesticide metabolite	
acetochlor	acetochlor ethane sulfonic acid	acetochlor oxanilic acid
alachlor	alachlor ethane sulfonic acid	alachlor oxanilic acid
ametryn		
atrazine	deisopropylatrazine	deethylatrazine
cyanazine	cyanazine amide	
dimethenamid	dimethenamid ethane sulfonic acid	dimethenamid oxanilic acid
flufenacet	flufenacet ethane sulfonic acid	flufenacet oxanilic acid
metolachlor	metolachlor ethane sulfonic acid	metolachlor oxanilic acid
metribuzin		
pendimethalin		
prometon		
prometryn		
propachlor		
propazine		
simazine		
terbutryn		

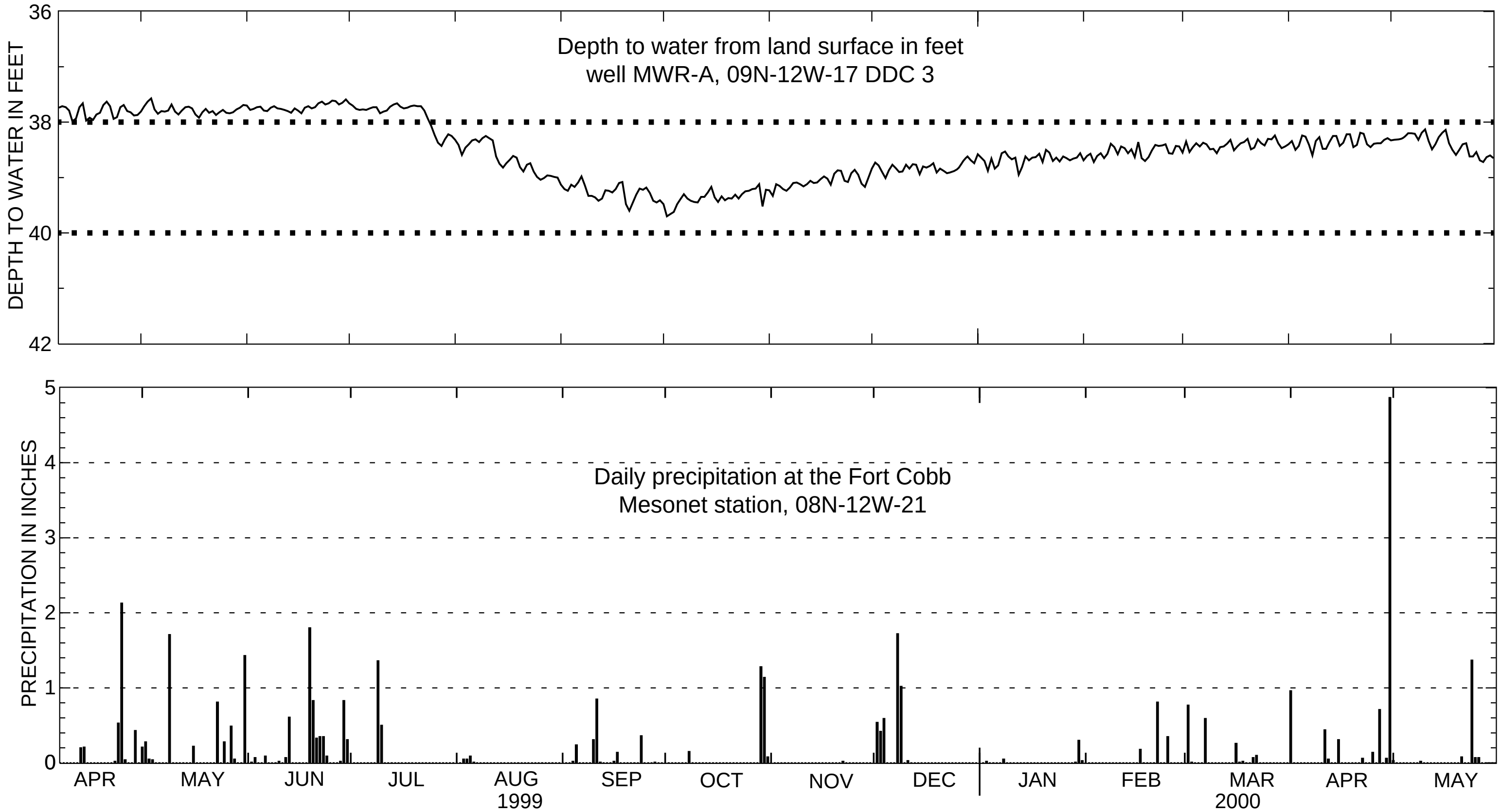


Figure 3. Daily mean water level in well MWR-A and daily precipitation at the Fort Cobb Mesonet station, April 14, 1999, to May 31, 2000.

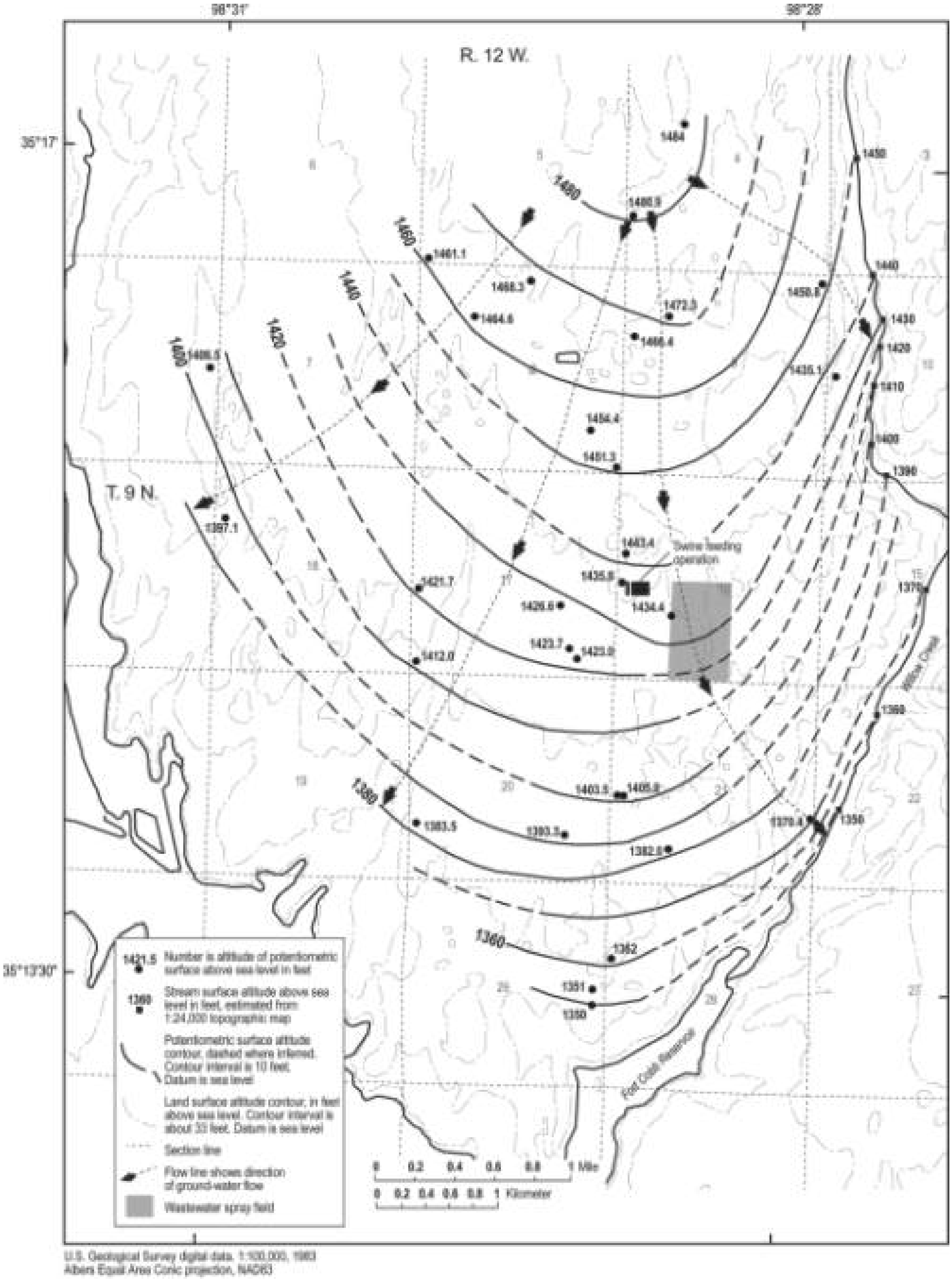
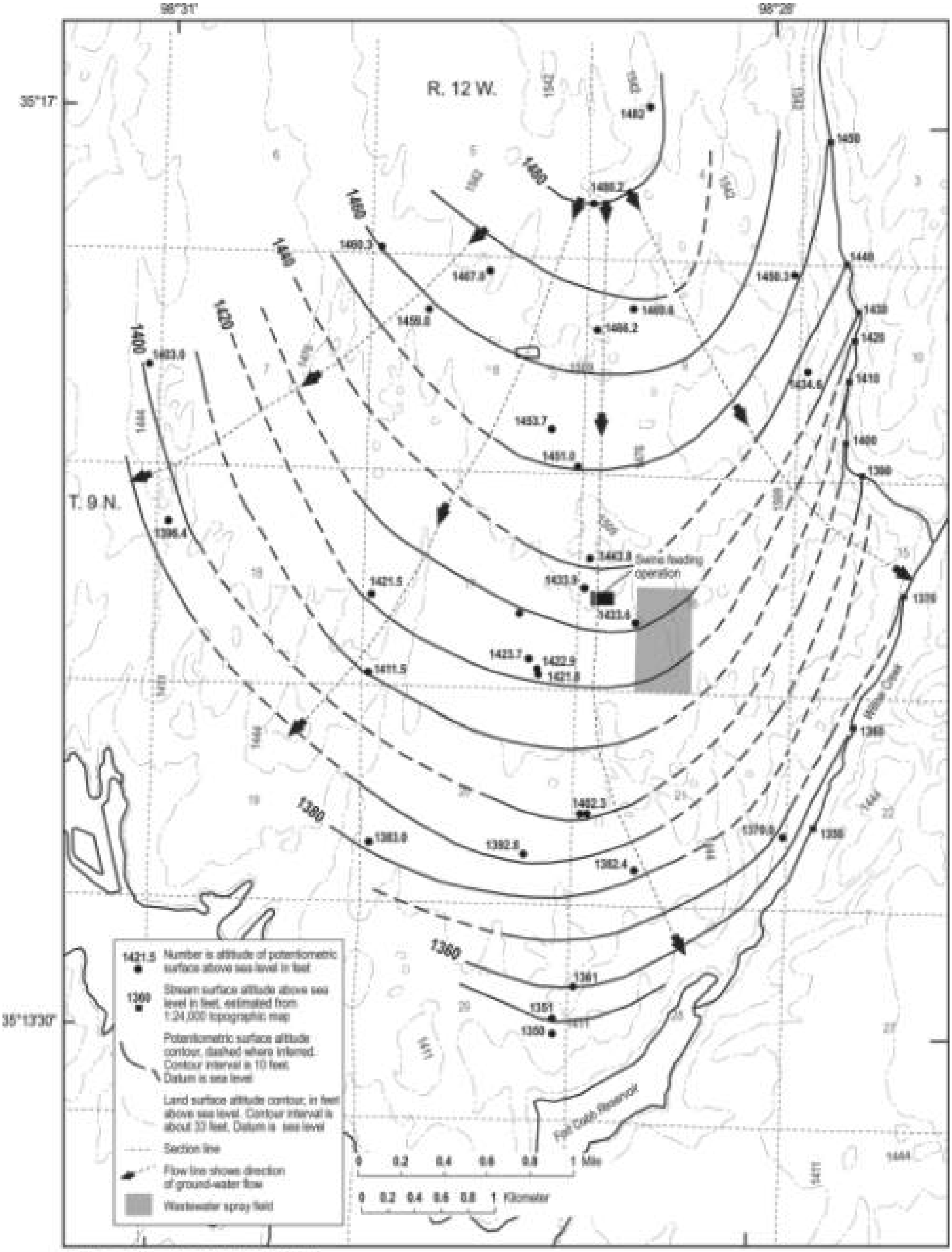


Figure 4. Potentiometric surface and direction of ground-water flow in study area, December 1998.



U.S. Geological Survey digital data, 1:100,000, 1983
Albers Equal Area Conic projection, NAD83

Figure 5. Potentiometric surface and direction of ground-water flow in the study area, August 1999.

land used for pasture and hay are the next most common land cover and land use (fig. 6 and table 4).

Table 4. Land use and land cover in the study area and the Cobb Creek subbasin (U.S. Environmental Protection Agency, 2000a)

Land use / land cover	Percent in the study area	Percent in the Cobb Creek subbasin
Water	1	2
Residential and commercial development	< 1	<1
Barren earthen material	< 1	<1
Deciduous, evergreen, and mixed forest	7	3
Shrub land	1	3
Grassland	12	23
Pasture and hay	7	6
Row crops and small grains	72	63
Urban and recreational grasses	0	<1

The topography in the study area is characterized by permeable, wind blown sand that forms gently rolling hills and steep-walled canyons along Lake and Willow Creeks. Soils in the northwest corner of the study area are of the Pond Creek and Cobb association and are described as deep and moderately deep, loamy, and nearly level to sloping soils on uplands. Soils in the rest of the study area are of the Dougherty and Eufaula association and are described as deep, sandy, very gently sloping to rolling soils on the uplands (U.S. Department of Agriculture-Soil Conservation Service, 1973). The Pond Creek soils have moderately slow permeability, Cobb and Dougherty soils are moderately permeable, and the Eufaula soils are rapidly permeable.

Privately-owned wells completed in the Rush Springs aquifer supply water for irrigation, stock, and domestic uses in the study area. Center-pivot irrigation is used extensively during the summer growing season. In 1995, about 95 percent of water withdrawals from the Rush Springs aquifer were used for irrigation (Tortorelli, 2000).

The Rush Springs aquifer crops out throughout the study area and is a massive to highly cross-bedded, flat-lying sandstone with some interbedded dolomite or gypsum (Becker and Runkle, 1998, pg. 7). Well yields vary, but some irrigation wells are reported to yield more than 1,000 gallons per minute (Becker and Runkle, 1998). Hydraulic conductivities of the Rush Springs aquifer have been estimated to range from 1 to 10 feet per day (Becker, 1998, pg. 12).

Acknowledgments

The author thanks the owner and operator of Bar D Swine Corporation for allowing access to property and wells. The author thanks the many well owners in the study area for allowing access to their wells and especially Mr. and Mrs. Eugene King, Mr. and Mrs. Garland Griffin, and Mr. and Mrs. Tommy Schoolcraft for allowing the installation of ground-water observation wells on their property.

GROUND-WATER QUALITY

Nitrate nitrogen (referred to as nitrate) is the most common nitrogen compound in water, whereas, ammonia nitrogen and nitrite nitrogen (referred to as ammonia and nitrite) generally occur only in oxygen-depleted water, such as wastewater from lagoons or septic tanks. Ammonia, the predominant nitrogen ion in swine wastewater, was measured in seven swine lagoon samples (Dana Kolpin, U.S. Geological Survey, written commun., 2000) at concentrations of 620 to 2,000 milligrams per liter. Background concentrations of ammonia in ground water, based on analysis of nationally distributed ground-water studies, were generally less than 0.1 milligram per liter and for nitrate were generally less than 2.0 milligrams per liter (Mueller and Helsel, 1996, pgs. 14-15). It also was found that nitrate concentrations in agricultural areas were generally greater (Mueller and Helsel, 1996, pg. 17).

Nitrate concentrations (28.1 and 31.5 milligrams per liter) were largest in the two ground-water samples from upgradient well MW-C (table 2), indicating a source of nitrate upgradient of the wastewater lagoon. Nitrate concentrations ranged from 4.30 to 8.20 milligrams per liter in samples from downgradient wells. Traces of ammonia and nitrite were detected in downgradient well BD-2, but not in upgradient wells. Ammonia was measured in samples from well BD-2 at concentrations of 0.254 and 0.227 milligram per liter, suggesting that wastewater from the

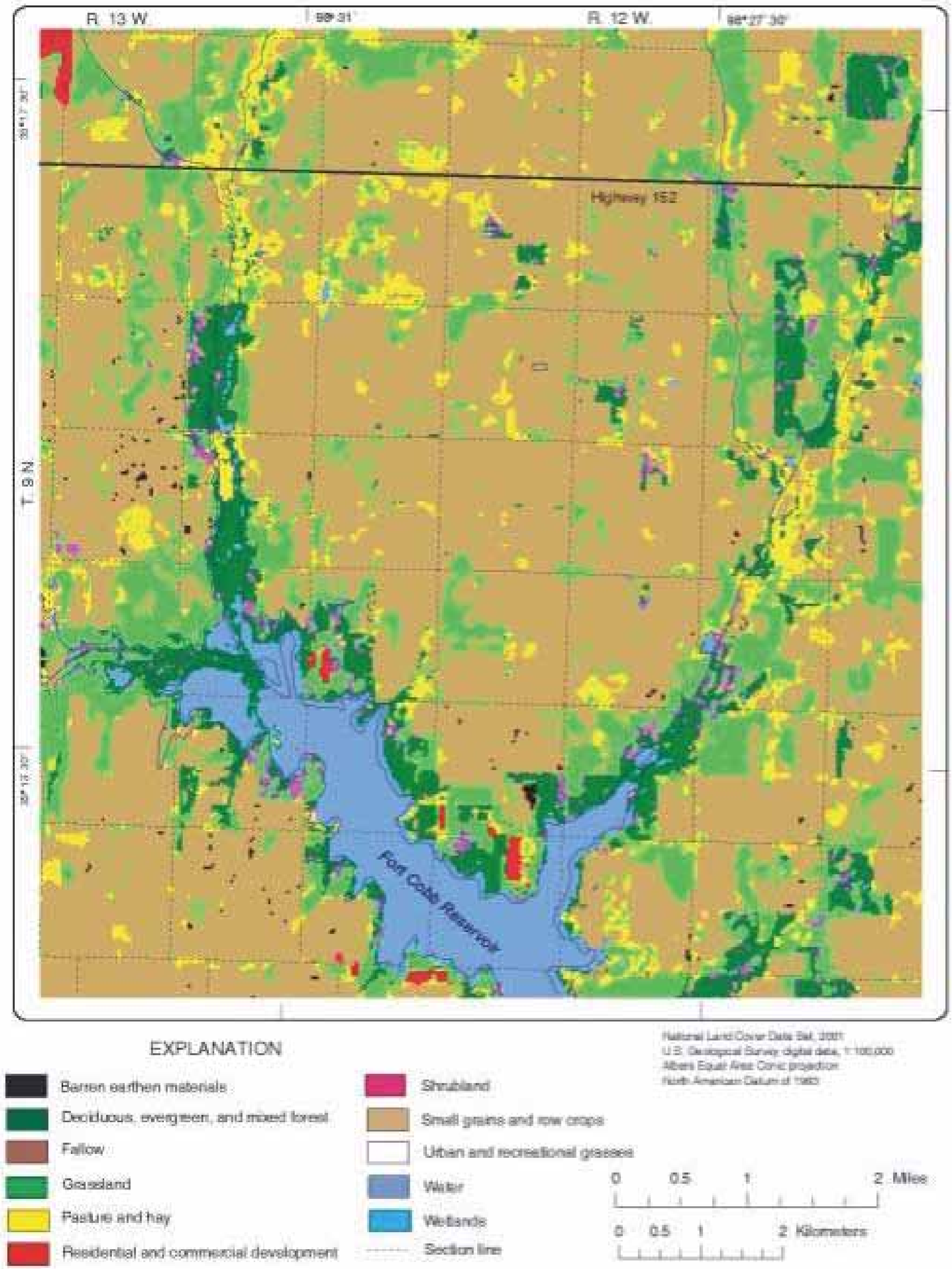


Figure 6. Land use and land cover in the study area, near Fort Cobb Reservoir. The Landsat thematic mapper scenes used to construct this image are from March 1987 to April 1994.

lagoon is contributing nitrogen to ground water. Nitrite was detected in the April sample from BD-1 (0.022 milligram per liter) and in both samples from BD-2 (0.064 and 0.029 milligram per liter) (table 2). The relatively small proportion of nitrate in water from well BD-2 may be attributed to the low dissolved oxygen content of the water. The low dissolved oxygen concentration indicates that the nitrification process may be impeded and that minimal amounts of ammonia and nitrite, from lagoon wastewater, are converted to nitrate at this location.

Ammonia concentrations larger than 0.01 milligram per liter have been measured previously by the U.S. Geological Survey in the Rush Springs aquifer. As reported by Becker (1994, pg. 28), out of 42 wells, ground water from nine had ammonia concentrations ranging from 0.11 to 0.35 milligram per liter. All nine wells were more than 100 feet deep. Ground water from one 38-foot deep well had an ammonia concentration of 1.35 milligrams per liter. The source of ammonia in these wells in unknown.

Background concentration of phosphorus in ground water is usually less than 0.1 milligram per liter (Mueller and Helsel, 1996, pg. 15). Concentrations of ortho-phosphorus in ground-water samples in this study did not exceed a few tenths of a milligram per liter. There was no significant difference in ortho-phosphorus concentrations between upgradient and downgradient samples. Concentrations ranged from 0.038 (BD-2) to 0.066 milligram per liter (MW-B and BD-1) (table 2).

The ratio of the stable nitrogen isotopes nitrogen-15 to nitrogen-14 in nitrate, reported as δ15N in parts per thousand relative to atmospheric nitrogen, helps differentiate animal waste (which includes waste from humans and swine) from other nitrate sources such as synthetic fertilizer. Most synthetic nitrogen fertilizers are derived from atmospheric nitrogen (N2), which is depleted in nitrogen-15 (Kreitler, 1975). As a result, the ratio of nitrogen-15 to nitrogen-14 in nitrate leached from synthetic fertilizers is similar to atmospheric nitrogen, with δ15N values ranging from -3 to +2 parts per thousand (fig. 7). Nitrate leached from soils is relatively enriched with nitrogen-15, with δ15N values ranging from +2 to +8 parts per thousand. Nitrate derived from animal wastes is more enriched with nitrogen-15, with δ15N values ranging from +10 to +20 parts per thousand (Kreitler, 1975).

Ground water from upgradient well MW-B had a δ15N value (2.43 parts per thousand) slightly above the range for atmospheric nitrogen and synthetic fertilizer, which may represent a mixture of nitrate from these sources and other sources enriched with nitrogen-15, such as soils and plants. Nitrate in ground water from upgradient well MW-C was the most enriched with nitrogen-15, with a δ15N value of 5.57 parts per thousand. This value for δ15N is within a range encompassing soil and plant sources of nitrate. The nitrate in ground water from MW-C may be from soil and plant sources or a mixture of sources that include fertilizer and animal waste. δ15N values indicate atmospheric nitrogen, synthetic fertilizer, or plants were the predominate sources of nitrate in ground water from the downgradient wells BD-1, BD-2, and BD-3 (fig. 7) (table 2). The δ15N values in these samples are depleted in nitrogen-15, indicating that animal waste was not a significant contributor of nitrate.

Dissolved oxygen concentrations, measured in June 2000, ranged from 4.8 to 9.4 milligrams per liter, with the lowest concentration of oxygen measured in the water sample from downgradient well BD-2 (table 2). Manganese concentrations (1,150 and 965 micrograms per liter) in samples from well BD-2 were substantially larger than concentrations in samples from other wells, exceeding the secondary drinking-water standard of 50 micrograms per liter (U.S. Environmental Protection Agency, 2000b). The larger concentrations were probably related to the low dissolved oxygen content of the water. Solubility of manganese can increase as the oxygen content of the water decreases. Larger concentrations of bicarbonate, magnesium, fluoride, and iron and a higher pH were also measured in water from well BD-2. Dissolved solids concentration in samples from the upgradient wells, MW-B and MW-C, ranged from 160 to 377 milligrams per liter. The dissolved solids concentration in water from downgradient wells ranged from 271 to 443 milligrams per liter (table 2). All samples had dissolved solids concentrations less than the secondary drinking-water standard of 500 milligrams per liter (U.S. Environmental Protection Agency, 2000b).

Pesticide analyses showed metolachlor ethane sulfonic acid, a metabolite of metolachlor, was measured at a concentration of 0.66 microgram per liter in water from well BD-1 (table 3). Metolachlor is a broad spectrum herbicide used for general weed

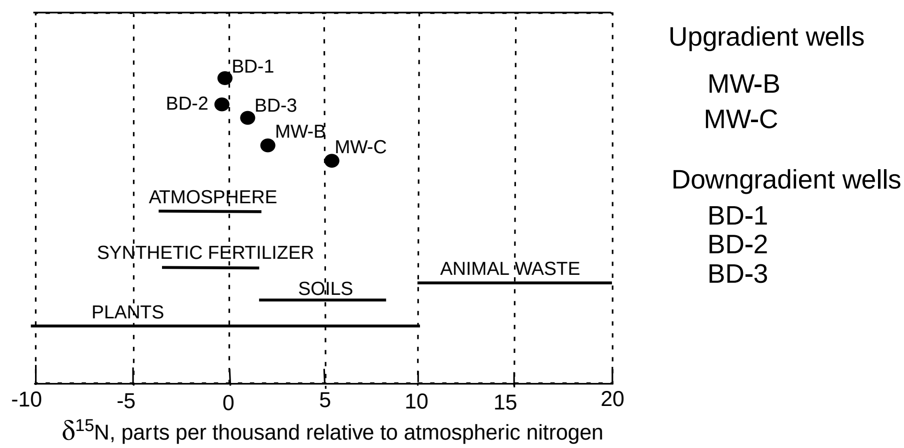


Figure 7. Ranges of the nitrogen isotopes nitrogen-14 and nitrogen-15 expressed as $\delta^{15}N$ parts per thousand relative to atmospheric nitrogen in water samples and in common sources of nitrate (from Kreitler, 1975).

control on many crops. No other pesticides or pesticide metabolites were detected at a concentration above 0.05 microgram per liter in water from wells BD-1 and MW-3. Pesticides and pesticide metabolites analyzed for are shown on table 3.

Ground-water samples collected in June 2000 were analyzed for *Escherichia coli*, fecal coliform, and fecal streptococci. *Escherichia coli* bacteria were counted at populations less than 10 colony forming units per 100 milliliters in water from wells MW-C, BD-1, and BD-2 and were counted at 60 colony forming units per 100 milliliters in water from well MW-B. Fecal coliform, and fecal streptococci bacteria were counted at populations less than 10 colony forming units per 100 milliliters in water from wells (table 2).

LEVELS

Ground-water levels at well MWR-A were higher from April to mid-July and lower during the late summer and in the fall due to a seasonal decrease in precipitation, increase in water withdrawals, and increase in evapotranspiration. Ground-water levels varied 2.1 feet over the time period measured, with the highest in June (37.6 feet below land surface) and lowest in September (39.7 feet below land surface) (fig. 3). Ground-water levels are shown on a hydrograph with daily precipitation measured by the Oklahoma Climatological Survey at a Mesonet station near the Fort Cobb Reservoir dam (figs. 1 and 3) (Amy Cameron, Oklahoma Climatological Survey, written commun., 2000). The Mesonet station is south of the reservoir and about 6.5 miles south of well MWR-A.

Irrigation wells were operating adjacent wells 17 and 30, during August 1999 measurements (table 1). A comparison of depth to water measurements from December 1998 and August 1999 shows that pumpage from irrigation wells had a minimal effect on water levels indicating a high storage coefficient and transmissivity for the aquifer.

FLOW DIRECTION

General ground-water flow direction during December 1998 and August 1999 was from north to south toward Fort Cobb Reservoir and toward Lake and Willow Creeks along the east and west sides of the study area (figs. 4 and 5). The potentiometric surface gradient was about 30 feet per mile where the land surface is relatively flat and increased to about 40 to 50 feet per mile where the land surface is steeper adjacent to Lake and Willow Creeks. Ground water near the wastewater spray field moved south-southeast toward Willow Creek along a gradient of about 50 feet per mile.

DISCUSSION

Analysis of ground-water samples suggest that commercial fertilizer is contributing nitrate upgradient of the swine feeding operation and that wastewater from the lagoon is contributing reduced forms of nitrogen, ammonia and nitrite. However, the number of wells sampled and the number of ground-water samples collected are insufficient to determine the swine feeding operation long- term contribution of nitrogen to ground water.

The extent of wastewater movement is unknown, as a vertical ground-water flow component may cause wastewater to flow below the screened interval in downgradient wells. Additional downgradient wells would be needed to (1) determine if the swine feeding operation is adding excessive amounts of nitrogen to ground water, (2) determine the vertical dimension of wastewater flow, and (3) the extent of wastewater downgradient of the lagoon.

SUMMARY

Fort Cobb Reservoir in northwest Caddo County Oklahoma is managed by the Bureau of Reclamation for water supply, recreation, flood control, and wildlife. Excessive amounts of nitrogen in the watershed have the potential to cause long-term eutrophication of the reservoir and increase already elevated concentrations of nitrogen in the Rush Springs aquifer. The U.S. Geological Survey in cooperation with the Bureau of Reclamation studied ground water in the area surrounding a swine feeding operation located less than 2 miles upgradient from Fort Cobb Reservoir in Caddo County, Oklahoma.

Water-quality parameters were measured in ground-water samples from five observation wells installed near the swine feeding operation. Ground-water levels were measured in a ground-water level monitoring well near the swine feeding operation from April 1999 to May 2000. Depth-to-water measurements during December 1998 and August 1999 were used to construct two potentiometric-surface maps to determine the direction of ground-water flow for a 14 square mile area bounded by Lake Creek, Willow Creek, State Highway 152, and Fort Cobb Reservoir.

Nitrate concentrations (28.1 and 31.5 milligrams per liter) were largest in the two ground-water samples from upgradient well MW-C. Nitrate concentrations ranged from 4.30 to 8.20 milligrams per liter in samples from downgradient wells. Traces of ammonia and nitrite were detected in downgradient well BD-2, but not in upgradient wells.

Ground water from upgradient well MW-B had a δ15N value (2.43 parts per thousand) slightly above the range for atmospheric nitrogen and synthetic fertilizer, which may represent a mixture of nitrate from these sources and other sources enriched with nitrogen-15, such as soils and plants. Nitrate in ground water from upgradient well MW-C was the most enriched with nitrogen-15, with a δ15N value of 5.57 parts per thousand. The nitrate in ground water from MW-C may be from soil and plant sources or a mixture of sources that include fertilizer and animal waste. δ15N values indicate atmospheric nitrogen, synthetic fertilizer, or plants were the predominate sources of nitrate in ground water from the downgradient wells BD-1, BD-2, and BD-3.

Manganese concentrations (1,150 and 965 micrograms per liter) in samples from well BD-2 were substantially larger than concentrations in samples from other wells, exceeding the secondary drinking-water standard of 50 micrograms per liter. Larger concentrations of bicarbonate, magnesium, fluoride, and iron and a higher pH were also measured in water from well BD-2.

Pesticide analyses showed metolachlor ethane sulfonic acid, a metabolite of metolachlor, was measured at a concentration of 0.66 microgram per liter in water from well BD-1

Ground-water levels at well MWR-A were higher from April to mid-July and lower during the late summer and in the fall due to a seasonal decrease in precipitation, increase in water withdrawals, and increase in evapotranspiration. Ground-water levels varied 2.1 feet over the time period measured, with the highest in June (37.6 feet below land surface) and lowest in September (39.7 feet below land surface)

Ground water near the wastewater spray field moved south-southeast toward Willow Creek along a gradient of about 50 feet per mile.

Analysis of ground-water samples suggest that commercial fertilizer is contributing nitrate upgradient of the swine feeding operation and that wastewater from the lagoon is contributing reduced forms of nitrogen, ammonia and nitrite. However, the number of wells sampled and the number of ground-water samples collected are insufficient to determine the swine feeding operation long-term contribution of nitrogen to ground water. Additional downgradient wells would be needed to (1) determine if the swine feeding operation is adding excessive amounts of nitrogen to ground water, (2) determine the vertical dimension of wastewater flow, and (3) the extent of wastewater downgradient of the lagoon.

REFERENCES CITED

Agricultural Engineering Associates, 1997, Pollution prevention plan, animal waste management plan, best management practices: Application for permit to operate a confined animal feeding operation, available for viewing at the Oklahoma Department of Agriculture, revised July 24, 1997; viewed March 2, 1999.

Becker, C.J., 1994, Distribution and variability of nitrogen and phosphorus in the alluvial, High Plains, Rush Springs, and Blaine aquifers in Western Oklahoma: U.S. Geological Survey; Open-File Report 94-41, 30 p.

Becker, M.F, 1998, Steady-state simulation of ground-water flow in the Rush Springs aquifer, western Oklahoma: U.S. Geological Survey Water- Resources Investigations Report 98-4082, 18 p.

Becker, M.F. and Runkle, D.L., 1998, Hydrogeology, water quality, and geochemistry of the Rush Springs aquifer, western Oklahoma: U.S. Geological Survey Water-Resources Investigations Report 98-4081, 37 p.

Downs, M., Michener, R., Fry, B., and Nadelhoffer, K., (1999), Routine measurement of dissolved inorganic 15N in precipitation and stream water: Environmental Monitoring and Assessment, v. 55, p. 211-220.

Faires, L.M., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory--Determination of metals in water by inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 92-634, 28 p.

Ferrer, Imma, Thurman, E.M., and Barcelo, Damia, 1997, Identification of ionic chloroacetanilite--Herbicide metabolites in surface water and ground water by HPLC/MS using negative ion spray: Analytical Chemistry, v. 69, no. 22, p. 4547-4553.

Fishman, M.J., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory--Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93-125, 217 p.

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Garbarino, J.R., 1999, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory -- Determination of dissolved arsenic, boron, lithium, selenium, strontium, thallium, and vanadium using inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 99-093, 31 p.

Ham, J.M. and DeSutter, T.M., 2000, Seepage losses from a swine waste lagoon in Caddo County, Oklahoma; Agriculture Engineering Associates, Uniontown, Kansas, in cooperation with Department of Agronomy, Kansas State University, Manhattan, Kansas. Report submitted to the Oklahoma Department of Agriculture, 7 p.

Hostetler, K.A., and Thurman, E.M., 1999, Determination of chloroacetanilide herbicide metabolites in water using high-performance liquid chromatography-diode array detection and high-performance liquid chromatography/mass spectrometry, in Morganwalp, D.W., and Buxton, H.T., eds., U.S. Geological Survey Toxic Substances Hydrology Program--Proceedings of the technical meeting, Charleston, South Carolina, March 8-12, 1999, volume 2 of 3--Contamination of hydrologic systems and related ecosystems: U.S. Geological Survey Water Resources Investigations Report 99-4018B, p. 345-353.

Kreitler, C.W., 1975, Determining the source of nitrate in ground water by nitrogen isotope studies: Bureau of Economic Geology, University of Texas at Austin, Report of Investigations, No. 83, 57 p.

Mueller, D.K., and Helsel, D.R., 1996, Nutrients in the Nations's waters--Too much of a good thing?: U.S. Geological Survey Circular 1136, 24 p.

Myers, D.N., and Wilde, F.D., 1997, Methods for determination of biological indicators: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A7, 38 p.

Oklahoma Tourism Department, 2000, accessed August 16, 2000, at URL http:/www.touroklahoma.com /Pages/stateparks/parks/fclspbig.html

Tortorelli, R.L., 2000, Estimated freshwater withdrawals in Oklahoma, 1995, U.S. Geological Survey, Oklahoma City, OK, accessed August 16, 2000, at URL http://ok.water.usgs.gov/public/wateruse/wateruse.html

United States Department of Agriculture-Soil Conservation Service, 1973, Soil Survey of Caddo County, Oklahoma, 70 p.

U.S. Environmental Protection Agency, 2000a, Multi-Resolution Land Characteristics Consortium, National land cover data, accessed August 1, 2000, at URL http://www.epa.gov/mrlc/nlcd.html

U.S. Environmental Protection Agency, 2000b, Current Drinking Water Standards, Office of Ground Water and Drinking Water, accessed August 18, 2000, at URL www.epa.gov/safewater/mcl.html

Wilde, F.D. and Radtke, 1998, Methods for field measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6.0-A6.5, 135 p.

Wilde, F.D., Radtke, D.B. Gibs, J., and Iwatsubo, R.T., 1999, Methods for the collection of water samples: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A4, 103 p.

Zimmerman, L.R., and Thurman, E.M., 1999, Method of analysis by the U.S. Geological Survey Organic Geochemistry Research Group--Determination of triazine and chloroacetanilide herbicides in water by solid-phase extraction and capillary-column gas chromatography/mass spectrometry with selected-ion monitoring: U.S. Geological Survey Open-File Report 98-634, 21 p.