

Prepared in cooperation with the
Oklahoma Water Resources Board

Contamination of Wells Completed in the Roubidoux Aquifer by Abandoned Zinc and Lead Mines, Ottawa County, Oklahoma

Water-Resources Investigations Report 95-4150



Cover: Photo credit: Photo taken by Scott Christenson, U.S. Geological Survey, shows a U.S. Geological technician sampling a well.

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By Scott Christenson

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Conversion Factors and Datum

Multiply	By	To obtain
Length		
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
Area		
square kilometer (km ²)	0.3861	square mile (mi ²)
Volume		
liter (L)	0.2642	gallon (gal)

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

$$^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32$$

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.

Contamination of Wells Completed in the Roubidoux Aquifer by Abandoned Zinc and Lead Mines, Ottawa County, Oklahoma

By Scott Christenson

Abstract

The Roubidoux aquifer in Ottawa County Oklahoma is used extensively as a source of water for public supplies, commerce, industry, and rural water districts. Water in the Roubidoux aquifer in eastern Ottawa County has relatively low dissolved-solids concentrations (less than 200 mg/L) with calcium, magnesium, and bicarbonate as the major ions. The Boone Formation is stratigraphically above the Roubidoux aquifer and is the host rock for zinc and lead sulfide ores, with the richest deposits located in the vicinity of the City of Picher. Mining in what became known as the Picher mining district began in the early 1900's and continued until about 1970. The water in the abandoned zinc and lead mines contains high concentrations of calcium, magnesium, bicarbonate, sulfate, fluoride, cadmium, copper, iron, lead, manganese, nickel, and zinc. Water from the abandoned mines is a potential source of contamination to the Roubidoux aquifer and to wells completed in the Roubidoux aquifer.

Water samples were collected from wells completed in the Roubidoux aquifer in the Picher mining district and from wells outside the mining district to determine if 10 public supply wells in the mining district are contaminated. The chemical analyses indicate that at least 7 of the 10 public supply wells in the Picher mining district are contaminated by mine water. Application of the Mann-Whitney test indicated that the concentrations of some chemical constituents that are indicators of mine-water contamination are different in water samples from wells in the mining area as compared to wells outside the mining area. Application of the Wilcoxon signed-rank test showed that the concentrations of some chemical constituents that are indicators of mine-water contamination were higher in current (1992-93) data than in historic (1981-83) data, except for pH, which was lower in current than in historic data. pH and sulfate, alkalinity, bicarbonate, magnesium, iron, and tritium concentrations consistently indicate that the Cardin, Commerce 1, Commerce 3, Picher 2, Picher 3, Picher 4, and Quapaw 2 wells are contaminated.

Introduction

The Roubidoux aquifer in northeastern Oklahoma is used extensively as a source of water for public supplies, commerce,

industry, and rural water districts. Much of the water use from the aquifer in Oklahoma occurs in Ottawa County (fig. 1). The Roubidoux aquifer consists of the Cotter and Jefferson City Dolomites, the Roubidoux Formation, and the Gasconade Dolomite. The primary water-yielding geologic unit is the Roubidoux Formation, which is found at depths ranging from 230 to 320 meters below land surface in Ottawa County.

The Boone Formation is stratigraphically above the Roubidoux aquifer and crops out in eastern Ottawa County. The Boone Formation in Ottawa County is the host rock for zinc and lead sulfide ores, with the richest deposits located in the vicinity of the City of Picher. Mining in what became known as the Picher mining district began in the early the 1900's and continued until about 1970. The term "Picher mining district" has no formal definition but is used herein to mean the area that overlies the mines near Picher (fig. 2). The mines were dewatered during mining operations but later filled with water when pumping ceased. Mine water contains large concentrations (as compared to concentrations in water from wells completed in the Boone Formation outside the Picher mining district) of calcium, magnesium, iron, zinc, sulfate, cadmium, copper, fluoride, lead, manganese, and nickel (Christenson, Parkhurst, and Fairchild, 1994).

Water began flowing from the abandoned mines in the late 1970's. When the U.S. Environmental Protection Agency created the Superfund Program in the early 1980's to clean up hazardous sites across the United States, the area in the vicinity of the Picher mining district was added to the list. The site generally is called the Tar Creek Superfund site because many of the mines discharge into the Tar Creek drainage basin.

Water from the abandoned mines is a potential source of contamination to the Roubidoux aquifer and to wells completed in the Roubidoux aquifer. In particular, the 10 public-supply wells for the cities of Cardin, Commerce, Picher, and Quapaw (fig. 3), which are located within the Picher mining district, are the wells most likely to be contaminated by water from the abandoned mines. The names of these 10 wells (as shown on figure 3) are Cardin, Commerce 1, Commerce 2, Commerce 3, Commerce 4, Picher 2, Picher 3, Picher 4, Quapaw 2, and Quapaw 4.

Purpose and Scope

Many different aspects of the Tar Creek Superfund site have been investigated. The purpose of this report is to docu-

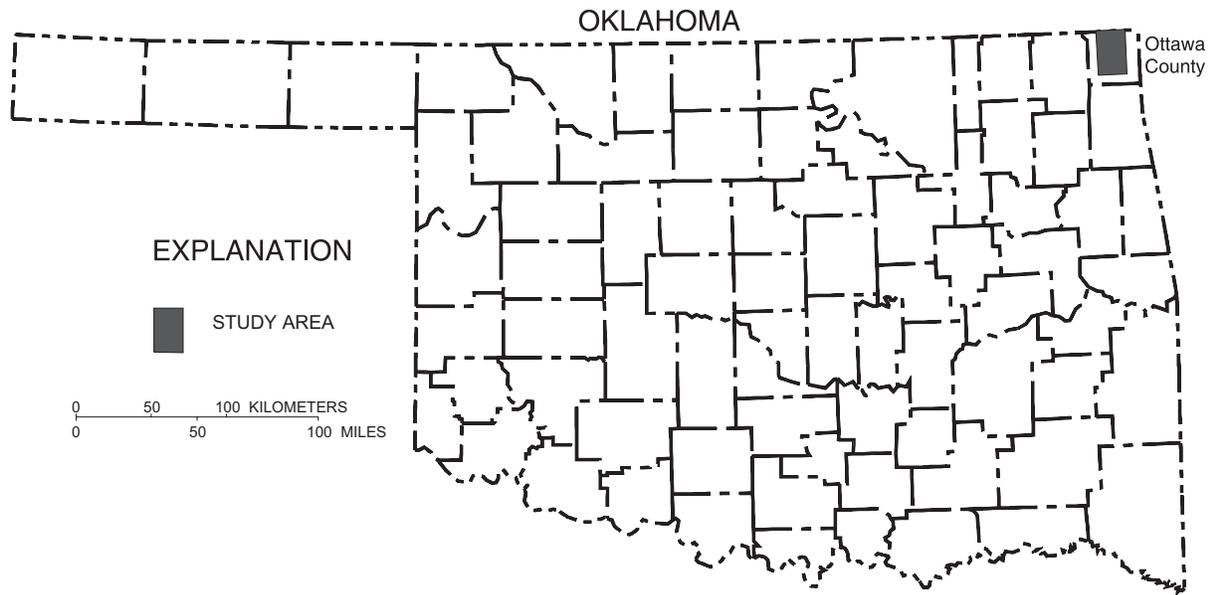


Figure 1. Location of the study area.

ment an investigation, conducted by the U.S. Geological Survey in cooperation with the Oklahoma Water Resources Board, of contamination by mine water of wells completed in the Roubidoux aquifer. The specific objective of the investigation was to determine whether the 10 public-supply wells completed in the Roubidoux aquifer in the Picher mining district are contaminated by water from the abandoned mines.

The scope of the work included measuring water levels in wells in Ottawa County and the surrounding counties to construct a potentiometric-surface map, and collecting water samples for chemical analysis at the wellhead from the 10 public-supply wells in the Picher mining district using the existing pumps. Additional wells completed in the Roubidoux aquifer outside the mining district also were sampled at the wellhead to determine background chemical concentrations.

Acknowledgments

The author is indebted to many people throughout the study area for their cooperation and assistance in obtaining water samples and water levels. In particular, Jim Brittle, City of Quapaw, Ron Childers and Ken Leggett, City of Commerce,

Jackie Crafton, Ottawa County Rural Water District 4, and Jack Ross, City of Picher, provided repeated access to public-supply wells. Other well owners provided access to their wells on a one-time basis for measuring water levels or to collect a water sample. This study would not have been possible without their cooperation and assistance. A special, heartfelt thanks goes to Bert Bledsoe at the U.S. Environmental Protection Agency's Robert S. Kerr Environmental Research Laboratory, who performed the chemical analyses of filtered samples that proved crucial to this investigation.

Description of the Study Area

The study area (fig. 1) was defined to be the area that includes the Picher mining district, the central part of the cone of depression in the potentiometric surface in the Roubidoux aquifer created by municipal ground-water withdrawals for the City of Miami, and the wells used to provide background water-quality samples outside the Picher mining district. The study area is contained entirely within Ottawa County in northeast



Figure 2. Location of abandoned mines in the study area.

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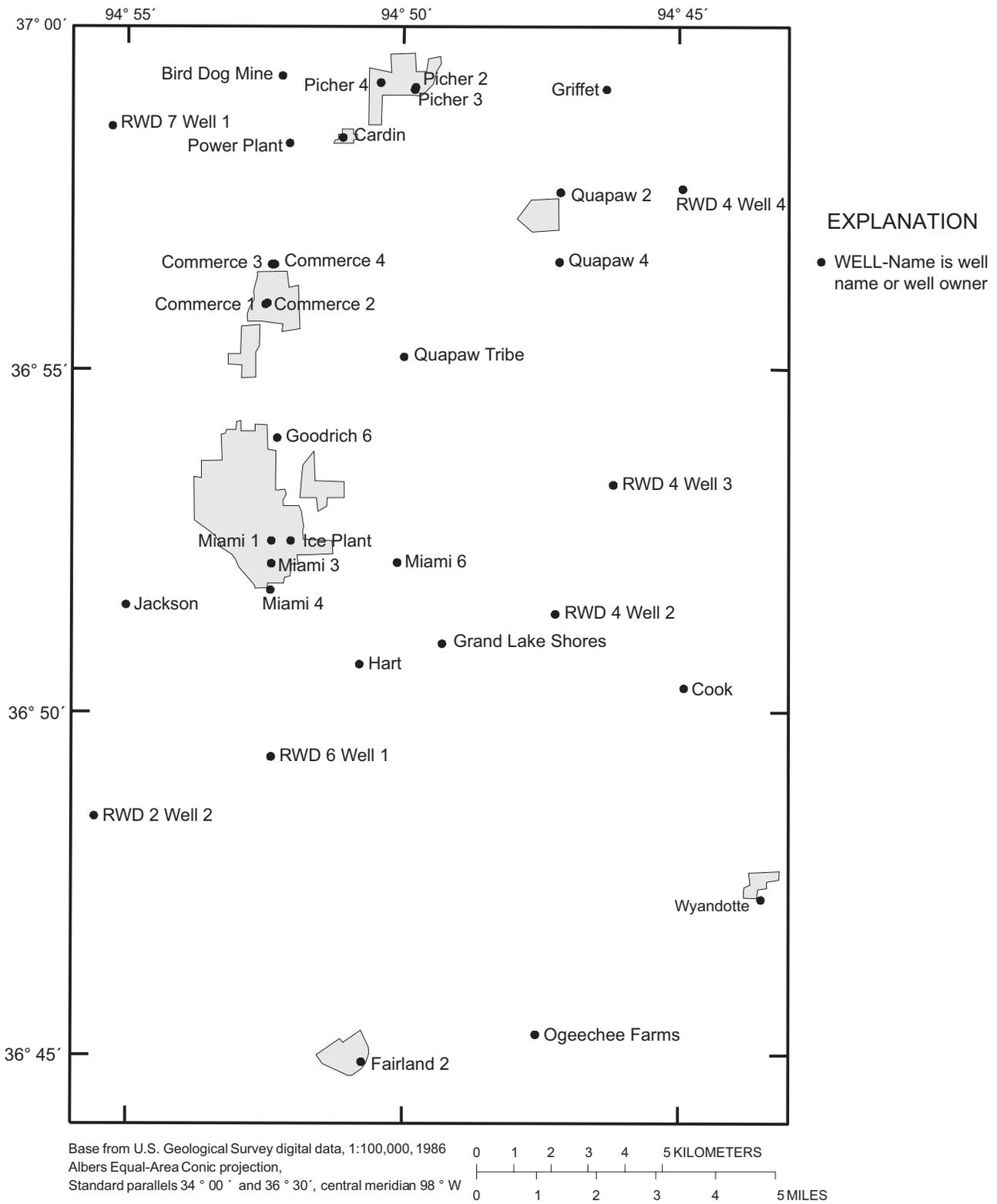


Figure 3. Location of wells.

Oklahoma and covers about 570 square kilometers. Water levels were measured in some wells outside of the study area to ensure that the potentiometric-surface map of the Roubidoux aquifer was accurate at the edges of the map.

Definition of the Roubidoux Aquifer

The term “Roubidoux aquifer” is used in this report to describe those geologic units, including the Cotter and Jefferson City Dolomites, the Roubidoux Formation, and the Gasconade Dolomite, in northeastern Oklahoma in which deep wells are completed. The Roubidoux Formation is a distinct geologic unit recognized in the subsurface in Arkansas, Missouri, Kansas, and Oklahoma, and on the surface in Missouri. Wells that are completed in the Roubidoux Formation generally are left open to the overlying Cotter and Jefferson City Dolomites. In addition, wells that are drilled to the Roubidoux Formation are sometimes drilled into the underlying Gasconade Dolomite in order to increase the well’s yield. Because the wells with the greatest yield are completed in the Roubidoux Formation, it is inferred that the Roubidoux Formation contributes most of the water.

Geohydrology

Understanding the geohydrology of the study area is essential to understanding the susceptibility of the Roubidoux aquifer to contamination by water from the abandoned mines. The geohydrology of the study area was described by Christenson, Parkhurst, and Fairchild (1994), and much of the discussion of geohydrology presented herein is quoted directly from their report. The wells in this report that are used to describe the geohydrology of the study area are the same wells described by Christenson, Parkhurst, and Fairchild (1994) but are limited to the wells in Ottawa County.

The thickness, lithology, and water-bearing characteristics of the major geologic units in Ottawa County are listed in table 1. The stratigraphic nomenclature used in this report was compiled from both the Oklahoma Geological Survey and the U.S. Geological Survey.

Stratigraphy

The lowermost geologic unit in the Roubidoux aquifer is the Ordovician-age Gasconade Dolomite. The Gasconade Dolomite consists of cherty dolomite, sandstone, and sandy dolomite. A basal sandstone, the Gunter Sandstone Member, is composed of about 6 meters of sandstone and sandy dolomite. Many wells in Missouri and Arkansas are completed with the Gunter Sandstone Member as the primary water-contributing geologic unit. The overall thickness of the Gasconade Dolomite in Ottawa County ranges from 8 to 100 meters and averages 70 meters.

The Ordovician-age Roubidoux Formation overlies the Gasconade Dolomite. The Roubidoux Formation consists of

cherty dolomite that ranges in thickness in Ottawa County from 20 to 75 meters with an average thickness of 49 meters. The Roubidoux Formation contains 2 or 3 layers of sandstone, each about 4.5 to 6 meters thick.

The Ordovician-age Jefferson City Dolomite overlies the Roubidoux Formation. The Jefferson City Dolomite is a cherty dolomite with a thickness in

Ottawa County ranging from 65 to 130 meters and averaging about 90 meters. The Cotter Dolomite overlies the Jefferson City Dolomite. The Cotter and Jefferson City Dolomites are lithologically similar, and are not differentiated in many wells in Ottawa County. The Cotter Dolomite is a cherty dolomite with sandy and argillaceous zones. The Cotter Dolomite ranges in thickness from 35 to 170 meters, with an average thickness of 76 meters. The Swan Creek sandstone is identified in some wells at the base of the Cotter Dolomite. The Swan Creek sandstone is a sandstone or sandy dolomite, as much as 9 meters thick.

The Chattanooga Shale, of Devonian and Mississippian age, overlies the Ordovician-age geologic units. It is a black carbonaceous shale, ranging in thickness in Ottawa County from 0 to 10 meters and averaging 3 meters. In a few locations, the Northview Shale and the Compton Limestone of Mississippian age overlie the Chattanooga Shale. The Northview Shale is a greenish-black or dull-blue shale, and the Compton Limestone is a shaley limestone. The combined thickness of these two formations in Ottawa County is 10 meters or less. The Chattanooga Shale is absent in the Picher mining district (Christenson, Parkhurst, and Fairchild, 1994).

Overlying the Northview Shale is the Boone Formation, a sequence of cherty limestone strata of Mississippian age that crops out in the eastern half of the study area. The Boone Formation ranges in thickness in Ottawa County from 80 to 110 meters and averages 98 meters thick. The Boone Formation is on the surface in the eastern part of the study area. The Boone Formation contains zinc and lead ores that were mined extensively in northeastern Oklahoma, southeastern Kansas, and southwestern Missouri from about 1890 to 1960.

Overlying the Boone Formation are other Mississippian formations, undivided for this study. These undivided formations consist of limestone, shale, siltstone, and fine-grained sandstone that range in thickness from 0 to 30 meters in Ottawa County (Reed, Schoff, and Branson, 1955). Stratigraphically above the Mississippian-age formations are rocks of Pennsylvanian age, also undivided for this study. These rocks are mostly shales, siltstones, sandstones, limestones, and a few thin coal seams. These formations are less than 60 meters thick, and crop out in the western part of the study area (Reed, Schoff, and Branson, 1955).

Structural Geology

The study area is located on the western flank of the Ozark uplift. The regional dip in the western Ozarks generally is west-

Table 1. Generalized geologic nomenclature and water-yielding characteristics of Ordovician-age and younger rocks in Ottawa County

[Modified from Christenson, Parkhurst, and Fairchild (1994, table 1). L/s, liters/second]

System	Geologic unit	Thickness (meters)	Lithologic description	Water-yielding characteristics	
Pennsylvanian	Pennsylvanian rocks, undivided	0–60	Shale, siltstone, sandstone, limestone, and a few thin coal seams.	Wells yield less than 3 L/s.	
Mississippian	Mississippian rocks, undivided	0–30	Limestone, shale, siltstone, and sandstone.	Wells yield less than 1 L/s.	
	Boone Formation	80–110	Chert and fine- to coarse-grained gray, light gray, and bluish limestone	Wells generally yield less than 1 L/s but may yield as much as 50 L/s.	
	Northview Shale and Compton Limestone	0–10	Greenish-black or dull-blue shale, and gray, nodular, shaley limestone.	Does not yield significant quantities of water to wells.	
Devonian and Mississippian	Chattanooga Shale	0–10	Black, carbonaceous, fissile shale.	Does not yield significant quantities of water to wells.	
Ordovician	Roubidoux aquifer	Cotter Dolomite and Swan Creek sandstone	35–170	Light buff to brown cherty dolomite with several sandy and argillaceous zones; Swan Creek sandstone identified in some wells is sandstone or sandy dolomite at base.	Wells generally yield less than 1 L/s. but may yield as much as 25 L/s.
		Jefferson City Dolomite	65–130	Light buff, gray, and brown very cherty dolomite.	Water-yielding characteristics not known.
		Roubidoux Formation	20–75	Light-colored, cherty dolomite with 2 or 3 layers of sandstone, 4.5 to 6 meters thick.	Principal aquifer in Ottawa County. Wells yield 6 to over 60 L/s.
		Gasconade Dolomite and Gunter Sandstone Member	8–100	Light-colored, medium to coarsely crystalline, cherty dolomite; Gunter Sandstone Member is sandstone or sandy dolomite at base	Not known to yield significant amounts of water from geologic units above Gunter Sandstone Member. Gunter Sandstone Member yields moderate amount of water.

ward and averages about 5 meters per kilometer. Minor folding and faulting cause small, local variations in the regional dip. McKnight and Fischer (1970) discuss the possible role of the minor structural features in the formation of the zinc- and lead-ore deposits.

Hydraulic Properties

Knowledge of the hydraulic properties of the geohydrologic units in the study area is necessary to understand the potential for contamination of the Roubidoux aquifer from abandoned zinc and lead mines. For this report, the term “hydraulic properties” includes well yield, specific capacity, transmissivity, storage terms, and conductance terms.

The water-yielding characteristics of the geologic units within the Roubidoux aquifer and the overlying geologic units are summarized in table 1. Essentially, the Roubidoux Formation probably supplies much of the water to wells completed in the Roubidoux aquifer. The Gasconade Dolomite, which underlies the Roubidoux Formation, is inferred to contribute some water because wells with significant yields in Missouri and Arkansas are completed exclusively in this geologic unit. The Gunter Sandstone Member of the Gasconade Dolomite probably contributes most of the water to wells completed in the Gasconade Dolomite (Christenson, Parkhurst, and Fairchild, 1990). The Cotter and Jefferson City Dolomites, which overlie the Roubidoux Formation, may contribute some water to wells completed in the Roubidoux aquifer in Ottawa County. Determining the yield of the Cotter and Jefferson City Dolomites is difficult because the majority of wells in Ottawa County that are completed in the Roubidoux aquifer are open to the Roubidoux Formation in addition to the Cotter and Jefferson City Dolomites. The limited information that is available indicates that the Cotter and Jefferson City Dolomites alone do not yield large quantities of water to wells (Christenson, Parkhurst, and Fairchild, 1994).

An analysis of the hydraulic properties of the Roubidoux aquifer is presented in Christenson, Parkhurst, and Fairchild (1994). They investigated the hydraulic properties of the Roubidoux aquifer by analyzing an aquifer test performed in 1944 on wells operated by the B.F. Goodrich Company in Miami and by a digital-model analysis of the cone of depression that was developed around Miami in 1981. They estimated that the transmissivity of the Roubidoux aquifer in the vicinity of Miami to be between 120 and 210 square meters per day (Christenson, Parkhurst, and Fairchild, 1994, p. 23).

Christenson, Parkhurst, and Fairchild (1994) also estimated the leakance (that is, the vertical hydraulic conductivity divided by the thickness) of the geologic units overlying the Roubidoux aquifer. These geologic units consists of the Cotter and Jefferson City Dolomites and, outside the Picher mining district, the Chattanooga Shale. The leakance of these geologic units determines the potential for ground water to flow between the Boone Formation and the Roubidoux aquifer. If the leakance is very small, the potential for water to flow between the

Boone Formation and the Roubidoux aquifer is small. Conversely, if the leakance is large, the potential for flow is large.

A large range in leakance can explain the observed data (the change in head in the aquifer during the 1944 aquifer test and the shape of the cone of depression around Miami). Christenson, Parkhurst, and Fairchild (1994, p. 23) estimated that the leakance was within a range between 0 and 0.13 per day, with a best-estimate value in a range from 4.3×10^{-8} and 7.7×10^{-8} per day. Thus, it is difficult to determine the potential for water to flow between the Boone Formation (and the abandoned zinc and lead mines) and the Roubidoux aquifer, based only on what is currently known about the hydraulic properties of the geologic units overlying the Roubidoux aquifer.

Potentiometric Surface

A potentiometric-surface map of the Roubidoux aquifer was constructed by measuring water levels in 49 wells completed in the Roubidoux aquifer (fig. 4). Most wells were measured between October 27 and 29, 1992, but a few wells to which access was difficult were measured in the following weeks (table 2). The potentiometric-surface map shows a significant cone of depression, centered around Miami, in response to ground-water withdrawals from the Roubidoux aquifer. Christenson, Parkhurst, and Fairchild (1994, p. 12) estimated ground-water withdrawals from the Roubidoux aquifer in Oklahoma in 1981 were about 18 million liters per day, of which 90 percent was withdrawn in Ottawa County. In that year, approximately 75 percent of the ground water withdrawn from the Roubidoux aquifer in Ottawa County was pumped by Miami and the B.F. Goodrich Company. The B.F. Goodrich Company closed its tire-manufacturing operation in Miami in early 1986, and water use in Ottawa County decreased at that time. Water levels have recovered about 30 meters near the center of the cone of depression since the cessation of tire manufacturing and associated ground-water withdrawals, as can be seen in the hydrograph of an observation well located within Miami (fig. 5). Comparison of the potentiometric-surface map in figure 4 to a similar map in Christenson, Parkhurst, and Fairchild (1994, fig. 9) confirms that the potentiometric surface in the Roubidoux aquifer recovered about 30 meters at Miami between 1981 and 1993.

No potentiometric-surface map was prepared for the Boone Formation for the current investigation. However, observation of water levels in mine and air shafts in the Picher mining district during 1993 shows that water levels in the Boone Formation are only a few (less than 10) meters below land surface. Thus, in the Picher mining district a downward hydraulic gradient exists between the Boone Formation and the Roubidoux aquifer.

Well Construction

The type of construction of the 10 public-supply wells inside the Picher mining district is a possible contributing factor

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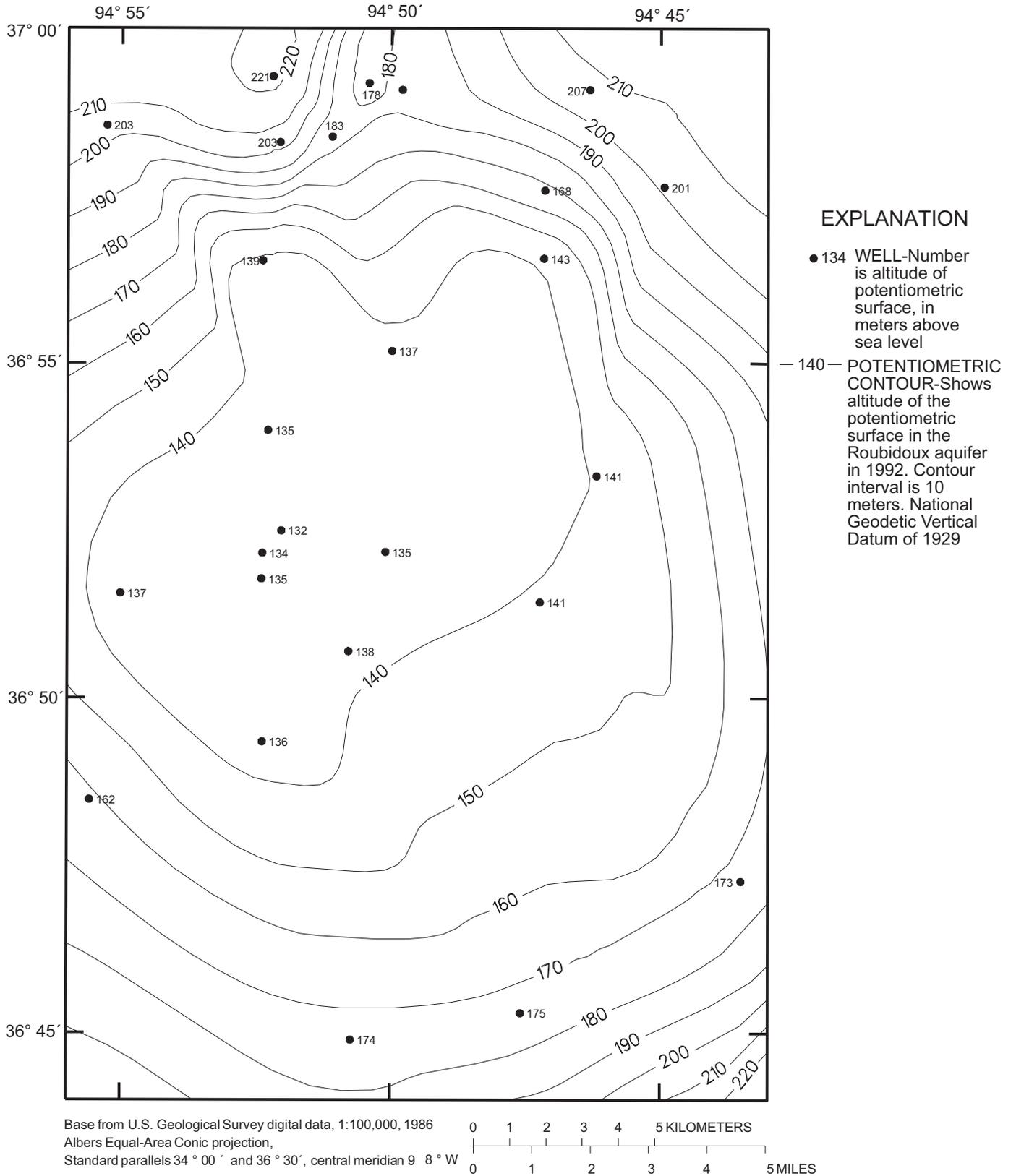


Figure 4. Altitude of the potentiometric surface in the Roubidoux aquifer in the study area in 1992.

Table 2. Geohydrologic information about sampled wells and wells used to construct the potentiometric-surface map of the Roubidoux aquifer

Owner or well name	Site Identifier	Latitude (North American Datum of 1927)	Longitude (North American Datum of 1927)	Altitude of well (meters)	Depth of well (meters)	Depth to water (meters)	Date of measurement	Altitude of potentio- metric surface (meters)
Afton, City of, Well 2	364137094575902	36°41'36"	94°57'58"	239	274	32.51	10-27-1992	206
Baxter Springs, City of, Well 6	370244094441201	37°02'44"	94°44'12"	250		37.36	10-28-1992	213
Bernice, City of	363740094553101	36°37'41"	94°55'31"	282	439	76.96	10-27-1992	205
Bird Dog Mine	365917094520901	36°59'17"	94°52'12"	251	386	30.06	12-02-1992	221
Bluejacket, City of	364808095043501	36°48'07"	95°04'36"	250	319	43.96	10-27-1992	206
Cardin, City of	365823094510701	36°58'23"	94°51'06"	248	351	64.68	10-28-1992	183
Cherokee County RWD 3 Well 2	370432094481301	37°04'32"	94°48'13"	261		48.30	10-28-1992	213
Commerce, City of, Well 1	365600094523001	36°55'57"	94°52'30"	244	320			
Commerce, City of, Well 2	365557094522701	36°55'58"	94°52'28"	244	340			
Commerce, City of, Well 3	365627094522201	36°56'32"	94°52'23"	247	439	108.28	10-29-1992	139
Commerce, City of, Well 4	365627094522101	36°56'32"	94°52'20"	247	381			
Cook, Joe	365018094451101	36°50'21"	94°44'54"	253	314	86.49	10-28-1992	167
Craig County RWD 3	365000095010101	36°50'02"	95°01'00"	267	412	62.66	10-27-1992	204
Fairland, City of, Well 2	364454094504401	36°44'54"	94°50'44"	258	381	83.61	10-28-1992	174
Galena, City of, Well 1	370415094380501	37°04'16"	94°37'54"	277	360	90.00	10-28-1992	187
Goodrich Rubber Company Well 6	365402094522201	36°54'00"	94°52'17"	237	349	101.98	10-27-1992	135
Grand Lake Shores	365100094491701	36°51'00"	94°49'17"	235	274			
Griffet, George	365908094462501	36°59'05"	94°46'19"	259	320	52.49	10-27-1992	207
Hart, Jack	365042094504701	36°50'42"	94°50'47"	241	315	103.19	12-02-1992	138
Haskell, John	365440095065701	36°54'41"	95°06'57"	262	458	27.22	10-27-1992	235
Helmick, D.	364323094585101	36°43'24"	94°58'49"	241	349	38.87	10-27-1992	202
Hickory Meadows - Grove, OK	363921094474301	36°39'21"	94°47'43"	236	329	30.57	10-27-1992	205
Jackson, Bill	365133094545901	36°51'34"	94°55'01"	235	344	98.29	12-02-1992	137
Koenig, R. J.	364155094451001	36°41'56"	94°45'10"	235	259	7.62	10-27-1992	227
Lewis, Frank	363439095020901	36°34'42"	95°02'12"	241	594	31.07	10-27-1992	210
Miami, City of, Ice Plant Well	365229094520201	36°52'30"	94°52'02"	235	454	103.10	10-29-1992	132
Miami, City of, Well 1	365229094522101	36°52'30"	94°52'23"	241	376			
Miami, City of, Well 3	365206094522201	36°52'10"	94°52'23"	238	382	104.17	12-11-1992	134
Miami, City of, Well 4	365146094522201	36°51'47"	94°52'24"	235	340	100.48	12-11-1992	135
Miami, City of, Well 6	365213094500701	36°52'11"	94°50'06"	244	465	109.50	11-18-1992	135
Miami Votech School	364349094554501	36°43'49"	94°55'46"	244	338	46.63	10-27-1992	197
Neill Cattle Company Well 1	365013095070501	36°50'16"	95°07'07"	271	210	66.18	10-27-1992	205

Table 2. Geohydrologic information about sampled wells and wells used to construct the potentiometric-surface map of the Roubidoux aquifer—Continued

Owner or well name	Site Identifier	Latitude (North American Datum of 1927)	Longitude (North American Datum of 1927)	Altitude of well (meters)	Depth of well (meters)	Depth to water (meters)	Date of measurement	Altitude of potentio- metric surface (meters)
Noel, City of, Well 2	363234094290301	36°32'33"	94°29'04"	255	259	76.61	10-27-1992	178
Ogeechee Farms	364516094473501	36°45'18"	94°47'35"	255	382	80.36	10-28-1992	175
Ottawa County RWD 2 Well 1	364829094553501	36°48'29"	94°55'35"	258	434	96.18	07-30-1992	162
Ottawa County RWD 4 Well 2	365128094471301	36°51'26"	94°47'14"	279	363	137.58	10-29-1992	141
Ottawa County RWD 4 Well 3	365319094461101	36°53'19"	94°46'11"	256	316	115.06	10-29-1992	141
Ottawa County RWD 4 Well 4	365738094445601	36°57'38"	94°44'56"	274	335	73.16	10-29-1992	201
Ottawa County RWD 6 Well 1	364921094522201	36°49'21"	94°52'23"	245	367	108.80	10-27-1992	136
Ottawa County RWD 7 Well 1	365833094551901	36°58'33"	94°55'17"	250	367	47.07	10-27-1992	203
Peoria RWD 3 Well 1	365445094400701	36°54'46"	94°40'06"	294	355	78.86	10-29-1992	215
Picher, City of, Well 2	365905094494602	36°59'07"	94°49'47"	251	343			
Picher, City of, Well 3	365905094494603	36°59'05"	94°49'48"	251	343	68.13	10-28-1992	183
Picher, City of, Well 4	365911094502501	36°59'11"	94°50'25"	253	340	74.82	10-28-1992	178
Powerhouse	365818094520401	36°58'18"	94°52'04"	250	314	46.86	10-28-1992	203
Quapaw, City of, Well 2	365734094471001	36°57'35"	94°47'09"	256	366	88.00	10-29-1992	168
Quapaw, City of, Well 4	365633094471001	36°56'34"	94°47'10"	258	411	115.06	10-28-1992	143
Quapaw Tribe	365513094495501	36°55'11"	94°49'59"	251	366	114.00	10-29-1992	137
Seneca, City of, Well 3	365017094355501	36°50'17"	94°35'58"	297	443	40.33	10-28-1992	257
Welch, City of, Well 1	365242095051701	36°52'44"	95°05'16"	258	366	54.85	10-28-1992	203
Wyandotte, City of, RWD 1	364717094433101	36°47'16"	94°43'30"	233	335	59.55	10-28-1992	173

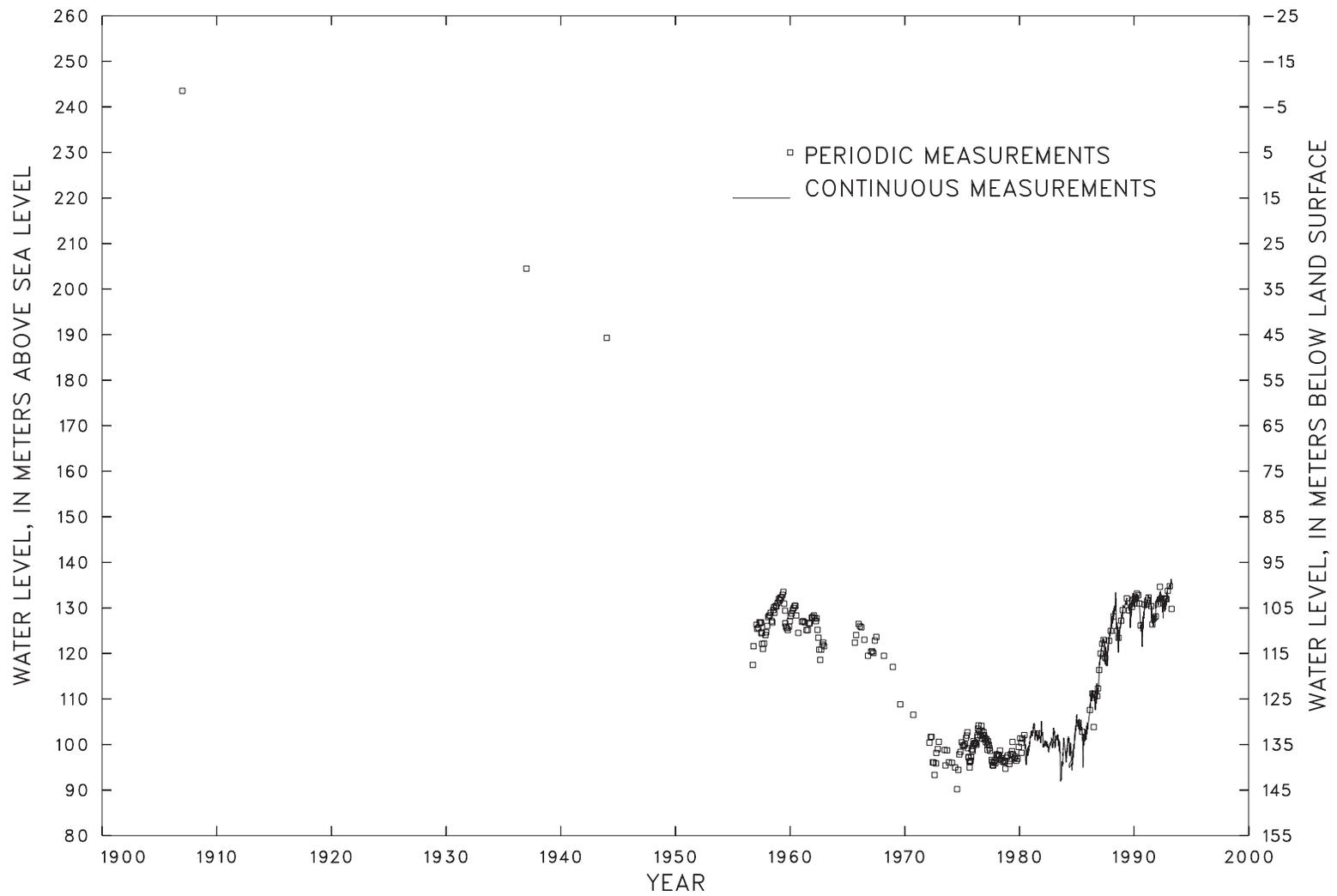


Figure 5. Hydrograph of well 365229094520201 at Miami, Oklahoma.

12 Contamination of Wells Completed in the Roubidoux Aquifer by Abandoned Zinc and Lead Mines, Ottawa County, Oklahoma

in the potential contamination of the wells and the Roubidoux aquifer by water from the abandoned mines. Wells in the Picher mining district are constructed such that the casings do not extend to the Roubidoux Formation. Wells are cased through the Boone Formation and partially into the Cotter and Jefferson Dolomites, but the wells are left open in the lower part of the Cotter and Jefferson City Dolomites, the Roubidoux Formation, and, for wells that extend below the Roubidoux Formation, in the Gasconade Dolomite. No well screens or perforations are required because the Ordovician-age geologic units are competent enough that the well bore stays open without casing. Wells completed in this manner will produce water that is a mixture of water from all geologic units in the open interval of the well.

Water from the abandoned mines could be entering the wells in the Picher mining district by several possible paths: (1) discontinuities in the casing, (2) water migrating in the annular space between the casing and the well bore and entering the well at the foot of the casing, (3) water flowing downward through the geologic units below the abandoned mines and flowing laterally into the well, and (4) some combination of factors one through three. Some of the older wells, such as Commerce 1 and 2, were constructed in the early 1900's using percussion methods (Reed, Schoff, and Branson, 1955). When these older wells were drilled, it is possible that no cement was used to fill the annular space between the casing and the well bore or that the cement has deteriorated. The newest wells, such as Picher 4 and Quapaw 4, were constructed within the last 15 years using modern drilling and completion methods. The casings of these wells are cemented in place, which reduces the possibility of water migrating in the annular space between the casing and well bore.

In all wells, especially older wells, the casings and the cement can deteriorate over time and allow water from shallower depths, including the mined zones in the Boone Formation, to enter the well. The casing of Picher 1 failed in 1985. The well began producing water with large concentrations of sulfate, iron, and dissolved solids. The pump was removed and geophysical logs revealed a break in the casing. The well was plugged and abandoned, and a new well (Picher 4) was drilled (Christenson, Parkhurst, and Fairchild, 1994, p. 32).

History of Abandoned Zinc and Lead Mines

The ore in the Picher mining district consists of sphalerite, galena, dolomite, and jasperoid (McKnight and Fischer, 1970). Accessory metallic minerals are chalcopyrite, enargite, luzonite, marcasite, and pyrite. Considerable calcite and locally a little quartz and barite occur in the ore, and large calcite crystals are present in caves adjacent to ore bodies. The zinc to lead ratio for the ore, based on the total production of the field, is about four to one, although some mines produced zinc exclusively and some small mines produced lead predominantly (McKnight and Fischer, 1970).

Zinc and lead ores were first discovered in the Picher mining district in 1901 just east of the City of Quapaw, and the first

recorded output of sulfide concentrates was in 1904 (McKnight and Fischer, 1970). Zinc sulfide was found in cuttings from the town well at Quapaw in or just before 1907. The next discoveries of ore were made near the City of Commerce in the years 1905 through 1907. By following the trend in the mineralization to the northeast from Commerce, the main part of the ore body was discovered in 1912 (McKnight and Fischer, 1970).

Production of ores increased rapidly in the years between 1911 and 1920, caused in part by demands created by World War I. Production dipped slightly in 1921, but increased again until 1925, when the production of both zinc and lead concentrates peaked. Moderate production levels were sustained until the late 1950's when yield declined sharply. This decline in production was caused by depletion of the ore deposits and depressed metals markets. Most of the large mining operations abandoned the Picher mining district in the late 1950's except for the Eagle-Picher Company (McKnight and Fischer, 1970). Small amounts of ore were produced until the mid-1970's (R. Jarman, Oklahoma Water Resources Board, written commun., 1983).

The mines of the main part of the Picher mining district are included within an area that is about 14 kilometers long from east to west and about 13 kilometers north to south and extends into southern Kansas. The extent of the mined area in Oklahoma is shown in figure 2.

Ore was mined in the Picher mining district to a maximum depth of 150 meters (McKnight and Fischer, 1970). Dewatering of the Boone Formation was necessary in order to mine the ores. When mining operations ceased, the abandoned mines filled with water that entered the mines as ground-water seepage and as streamflow into abandoned mine and air shafts, particularly during periods of runoff after precipitation. The mines filled completely in the late 1970's and the mines began discharging water at the land surface.

Background Water Quality

The objective of this investigation was to determine whether the 10 public-supply wells in the Picher mining district completed in the Roubidoux aquifer were contaminated by water from the abandoned zinc and lead mines. Before conducting the field investigation, background information regarding the water quality in the Roubidoux aquifer and the abandoned zinc and lead mines was compiled.

Roubidoux Aquifer

The water quality of the Roubidoux aquifer for the entire area in Oklahoma where the Roubidoux aquifer is used for drinking-water supplies was described by Christenson, Parkhurst, and Fairchild (1994). They found that the water quality of the Roubidoux aquifer changed from eastern to western Ottawa County. The ground water in eastern Ottawa County has relatively low dissolved-solids concentrations (less than 200 mg/L) with calcium, magnesium, and bicarbonate as the

major ions. Ground water in western Ottawa County has relatively high dissolved-solids concentrations (greater than 800 mg/L) with sodium and chloride as the major ions. This transition from low dissolved solids, calcium magnesium bicarbonate water to higher dissolved solids, sodium chloride water also occurs with depth. Sodium chloride waters are below calcium magnesium bicarbonate waters. In eastern Ottawa County the transition occurs below the base of the Roubidoux Formation, and in western Ottawa County the transition occurs above the top of the Roubidoux Formation.

Christenson, Parkhurst, and Fairchild (1994) calculated descriptive statistics for many chemical constituents from water samples collected for their study in the early 1980's, from samples taken by the Oklahoma State Department of Health, and from chemical analyses on file at the U.S. Geological Survey. Their descriptive statistics are reproduced herein as table 3. The statistics include the entire area in northeast Oklahoma in which the Roubidoux aquifer is used for drinking water supplies. Some of the larger concentrations are from samples taken from wells that have been affected by water from the abandoned lead and zinc mines, from wells west of the transition to sodium chloride water, and from deep wells completed below the transition to sodium chloride water. Thus, the larger concentrations (the 95th percentile and maximum value in table 3) are not representative of water in the areas where the Roubidoux aquifer is used extensively for drinking water supplies.

Abandoned Zinc and Lead Mines

The quality of water in the abandoned zinc and lead mines was documented by Playton, Davis, and McClafin (1980) and in Parkhurst (1987). Playton, Davis, and McClafin (1980) sampled while the mines were still filling, and Parkhurst (1987) sampled after the mines were full and discharging. For both investigations, the mines were sampled by lowering samplers into mine shafts, so only the water in the vicinity of the mines shafts was sampled. Playton, Davis, and McClafin (1980) present summary statistics, and part of these statistics are reproduced in table 4 (Parkhurst (1987) did not present summary statistics). Christenson, Parkhurst, and Fairchild (1994) found that mine water contains high concentrations of calcium, magnesium, bicarbonate, sulfate, fluoride, cadmium, copper, iron, lead, manganese, nickel, and zinc. For this report, these constituents are considered potential indicators of contamination by mine water. Because water from the mines has low pH, the field parameters alkalinity and pH also are considered to be potential indicators of mine-water contamination.

Playton, Davis, and McClafin (1980) sampled mines across the Picher mining district and found that water in the mines was not uniform. They found no obvious areal trend or seasonal variation in water quality, but they did find that water in the mines was stratified. With increasing sampling depth, specific conductance and water temperature tended to increase, and pH tended to decrease. Concentrations of dissolved solids and chemical constituents, such as total and dissolved metals

and dissolved sulfate, also increased with depth (Playton, Davis, and McClafin, 1980).

Comparison Between Water in the Roubidoux Aquifer and the Abandoned Mines

The information on background water quality shows that the water quality in much of the Roubidoux aquifer is suitable for most uses, including human consumption, but the water in the abandoned zinc and lead mines is of very poor quality and, without treatment, is not suitable for human consumption. Water in the abandoned mines has low pH and high concentrations, relative to water in the Roubidoux aquifer, of alkalinity, calcium, magnesium, bicarbonate, sulfate, cadmium, copper, fluoride, iron, lead, manganese, nickel, and zinc. Water in the Roubidoux aquifer potentially could be degraded if water from the abandoned mines migrates to the Roubidoux aquifer. The chemical contrast between the two waters is large. If water from the abandoned mines is entering the public-supply wells in the mining district, the constituent concentrations in water samples from public-supply wells probably are affected.

Water-Quality Field Investigation

After establishing that the waters in the Roubidoux aquifer and the abandoned mines were geochemically different, an investigation was designed to collect and analyze water-quality data from the study area to meet the objective of this study.

Investigation Design

The objective of this investigation was to determine whether the 10 public-supply wells in the Picher mining district were contaminated by water from the abandoned zinc and lead mines. To meet this objective, hypothesis testing was used to compare: (1) current (1992-93) water quality in the Picher mining district wells to background wells, and (2) current (1992-93) to historic (1981-83) water quality in the Picher mining district wells.

To obtain data representative of the background water quality of the Roubidoux aquifer at the time of this investigation, 10 wells outside the mining district were sampled. The 10 background wells were selected based on several factors:

1. All 10 background wells are completed in the Roubidoux aquifer outside the Picher mining district.
2. All 10 background wells are located along strike with the 10 wells in the Picher mining district. The Roubidoux aquifer in the background wells is at about the same depth as the wells in the mining district. The geohydrology and geochemistry are inferred to be similar in the background and mining district wells.
3. The background wells all are located on the south side of

Table 3. Summary statistics of physical properties, major ions, nutrients, and trace elements for water samples from wells completed in the Roubidoux aquifer in northeast Oklahoma

[Modified from Christenson, Parkhurst, and Fairchild (1994, table 3). Statistics calculated using only the most recent analysis available to Christenson, Parkhurst, and Fairchild (1994), for each constituent for each well. If analyses were available for different sampling depths from the same well, the most recent analysis for each constituent from each sample depth of the well was included. Constituents and physical parameters: $\mu\text{S/cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; $\mu\text{g/L}$, micrograms per liter; pCi/L, picocuries per liter. Method: 1, no censored data, ordinary percentile calculation; 2, censored data present, percentiles calculated using methods of Helsel and Cohn (1988); 3, no calculation, more than 80 percent of the data were censored; 4, no calculation, less than 20 analyses for the constituent. Largest MRL: largest minimum reporting level (percentiles less than this value were estimated using the methods of Helsel and Cohn (1988), percentiles greater than this value are the same as ordinary percentile calculation); --, no censored data for this constituent. Percentiles: --, indicates no statistic was calculated; Maximum value: --, indicates all data were censored for this constituent]

Constituents and properties	Method	Sample size	Largest MRL	Minimum value	Percentiles					Maximum value
					5	25	50	75	95	
Specific conductance ($\mu\text{S/cm}$ at 25°C)	1	96	--	140	284	369	566	1,086	9,226	125,000
pH (standard units)	1	89	--	5.2	6.6	7.6	7.9	8.0	8.2	9.3
Hardness, total (mg/L as CaCO_3)	1	81	--	58	78	123	142	171	291	1,550
Alkalinity, total (mg/L as CaCO_3)	1	79	--	119	121	129	143	159	221	594
Alkalinity, total, laboratory (mg/L as CaCO_3)	1	61	--	116	117	125	135	152	220	435
Dissolved solids, residue at 180°C (mg/L)	1	86	--	88	143	200	290	519	3,994	113,000
Dissolved solids, residue at 105°C (mg/L)	4	8	--	153	--	--	--	--	--	718
Calcium, dissolved (mg/L)	1	78	--	14	18	29	32	42	83	440
Magnesium, dissolved (mg/L)	1	78	--	1.1	3.1	11	14	16	26	110
Sodium, total (mg/L)	4	8	10	<10	--	--	--	--	--	60
Sodium, dissolved (mg/L)	1	73	--	1.4	4.4	16	54	110	342	3,200
Sodium plus potassium, dissolved (mg/L)	4	19	--	3.2	--	--	--	--	--	2,830
Potassium, dissolved (mg/L)	1	71	--	.4	1.2	2.1	2.8	3.7	8.1	25
Sulfate, dissolved (mg/L)	1	94	--	3	7.4	13	16	22	97	2,000
Chloride, dissolved (mg/L)	1	93	1	<1	2.9	15	55	190	2,162	65,000
Fluoride, total (mg/L)	4	9	--	.2	--	--	--	--	--	.8
Fluoride, dissolved (mg/L)	1	84	--	.1	.1	.4	.7	1.4	4.1	13
Silica, dissolved (mg/L)	1	71	--	7.4	8	9	10	10	13	36
Nitrogen, nitrate, dissolved (mg/L as N)	1	23	--	0	0	.01	.05	.2	.8	1.0
Nitrogen, nitrite plus nitrate, total (mg/L as N)	4	9	.5	.1	--	--	--	--	--	.1

Table 3. Summary statistics of physical properties, major ions, nutrients, and trace elements for water samples from wells completed in the Roubidoux aquifer in northeast Oklahoma—Continued

Constituents and properties	Method	Sample size	Largest MRL	Minimum value	Percentiles					Maximum value
					5	25	50	75	95	
Aluminum, dissolved (µg/L)	3	80	100	<60	--	--	--	--	--	48,000
Arsenic, total (µg/L)	4	8	10	0	--	--	--	--	--	--
Arsenic, dissolved (µg/L)	3	64	10	<10	--	--	--	--	--	14
Barium, total (µg/L)	4	9	100	<100	--	--	--	--	--	100
Cadmium, total (µg/L)	4	10	2	<1	--	--	--	--	--	2
Cadmium, dissolved (µg/L)	3	80	4	<1	--	--	--	--	--	710
Chromium, total (µg/L)	4	9	10	<10	--	--	--	--	--	50
Chromium, dissolved (µg/L)	3	80	12	<1	--	--	--	--	--	23
Copper, total recoverable (µg/L)	4	9	4	<4	--	--	--	--	--	35
Copper, dissolved (µg/L)	3	80	60	<12	--	--	--	--	--	320
Iron, total (µg/L)	2	21	100	0	1.1	8.7	37	154	8,030	8,700
Iron, dissolved (µg/L)	2	80	20	<8	2.7	30	60	160	9,580	260,000
Lead, total (µg/L)	4	10	20	<5	--	--	--	--	--	25
Lead, dissolved (µg/L)	3	78	10	<5	--	--	--	--	--	29
Manganese, total (µg/L)	4	10	20	<10	--	--	--	--	--	70
Manganese, dissolved (µg/L)	2	80	10	<2	0	.1	1.2	10	1,910	4,400
Mercury, total recoverable (µg/L)	4	9	.5	<.5	--	--	--	--	--	--
Mercury, dissolved (µg/L)	3	64	.5	<.5	--	--	--	--	--	5
Molybdenum, dissolved (µg/L)	4	9	2	<1	--	--	--	--	--	--
Selenium, total (µg/L)	4	9	5	<1	--	--	--	--	--	--
Silver, total (µg/L)	4	9	3	<2	--	--	--	--	--	3
Zinc, total (µg/L)	4	11	2	0	--	--	--	--	--	1,700
Zinc, dissolved (µg/L)	2	81	20	<10	.5	4.8	26	56	3,560	84,000
Alpha radioactivity, dissolved (pCi/L)	2	64	23.8	<2.9	.2	.8	2.3	6.6	27	57
Alpha radioactivity, suspended (pCi/L)	2	30	.4	.3	.1	.3	.4	.4	2.4	3.2
Alpha radioactivity, dissolved (µg/L as U natural)	2	64	35	<4.2	.2	1.1	3.3	9.8	40	84
Alpha radioactivity, suspended (µg/L as U natural)	3	61	.4	<.4	--	--	--	--	--	4.7
Beta radioactivity, dissolved (pCi/L as Cs-137)	2	64	13	<2	1	2.4	4.2	7.4	21	25
Beta radioactivity, suspended (pCi/L as Sr/Yt-90)	3	64	1.5	<.4	--	--	--	--	--	2.8
Beta radioactivity, suspended (pCi/L as Cs-137)	3	64	1.5	<.4	--	--	--	--	--	2.7
Beta radioactivity, dissolved (pCi/L as Sr/Yt-90)	2	64	12	<2	1	2.3	4	7.1	20	24
Radium-226, dissolved, planchet count (pCi/L)	4	9	--	3.4	--	--	--	--	--	14
Radium-228, dissolved (pCi/L)	4	9	3	<2	--	--	--	--	--	--

Table 4. Summary statistics of physical properties, major ions, nutrients, and trace elements for water samples from mine shafts in the Picher mining district

[Modified from Playton, Davis, and McClafin (1980, table 9). Constituents and properties: $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter]

Constituents and properties	Sample size	Minimum	50th percentile	Maximum
Specific conductance (field, $\mu\text{S}/\text{cm}$ 25°C)	139	740	2,680	4,950
pH (field measured, standard units)	147	3.4	6.4	8.6
Temperature (field measured, °C)	149	13.0	15.0	18.0
Turbidity (NTU)	77	0	23	400
Hardness, total (mg/L)	77	410	1,800	2,500
Hardness, noncarbonate (mg/L)	77	250	1,800	2,500
Acidity (mg/L as CaCO_3)	66	0	320	1,340
Alkalinity (mg/L as CaCO_3)	77	0	23	308
Dissolved solids (mg/L, residue at 180°C)	74	622	3,410	5,920
Calcium, dissolved (mg/L)	77	120	480	600
Magnesium, dissolved (mg/L)	77	13	134	290
Sodium, dissolved (mg/L)	77	7.1	44	200
Sodium, percent	77	1.0	6.0	26
Sodium adsorption ratio	77	.1	.5	25
Potassium, dissolved (mg/L)	77	1.3	3.8	9.2
Bicarbonate (mg/L)	77	0	33	375
Carbonate (mg/L)	77	0	0	0
Sulfate, dissolved (mg/L)	77	320	2,070	3,500
Chloride, dissolved (mg/L)	77	.5	6.3	85
Fluoride, dissolved (mg/L)	77	.1	1.9	15
Silica, dissolved (mg/L)	77	4.9	11.7	22
Nitrite, dissolved (mg/L as N)	44	.00	.00	.04
Nitrate, dissolved (mg/L as N)	44	.00	.04	.42
Ammonia, dissolved (mg/L as N)	44	.00	.18	.65
Aluminum, dissolved ($\mu\text{g}/\text{L}$)	77	0	460	42,000
Aluminum, total ($\mu\text{g}/\text{L}$)	77	10	1,700	280,000
Arsenic, dissolved ($\mu\text{g}/\text{L}$)	44	0	1.0	11
Arsenic, total ($\mu\text{g}/\text{L}$)	44	0	1.6	14
Barium, dissolved ($\mu\text{g}/\text{L}$)	44	0	0	600
Barium, total ($\mu\text{g}/\text{L}$)	44	0	0	600
Boron, dissolved ($\mu\text{g}/\text{L}$)	77	30	140	560
Boron, total ($\mu\text{g}/\text{L}$)	77	50	200	1,700
Cadmium, dissolved ($\mu\text{g}/\text{L}$)	77	1	80	1,200
Cadmium, total ($\mu\text{g}/\text{L}$)	77	10	180	1,100
Chromium, dissolved ($\mu\text{g}/\text{L}$)	44	0	16	140
Chromium, total ($\mu\text{g}/\text{L}$)	44	0	17	150
Cobalt, dissolved ($\mu\text{g}/\text{L}$)	44	0	50	800
Cobalt, total ($\mu\text{g}/\text{L}$)	44	50	200	850

Table 4. Summary statistics of physical properties, major ions, nutrients, and trace elements for water samples from mine shafts in the Picher mining district—Continued

Constituents and properties	Sample size	Minimum	50th percentile	Maximum
Copper, dissolved ($\mu\text{g/L}$)	44	1	8	260
Copper, total ($\mu\text{g/L}$)	44	10	20	240
Iron, dissolved ($\mu\text{g/L}$)	77	0	39,000	330,000
Iron, total ($\mu\text{g/L}$)	77	0	52,000	150,000
Lead, dissolved ($\mu\text{g/L}$)	77	0	63	500
Lead, total ($\mu\text{g/L}$)	77	0	310	500
Lithium, dissolved ($\mu\text{g/L}$)	77	20	130	300
Manganese, dissolved ($\mu\text{g/L}$)	77	10	1,870	14,000
Manganese, total ($\mu\text{g/L}$)	77	10	2,400	15,000
Mercury, dissolved ($\mu\text{g/L}$)	44	.0	.22	1.30
Mercury, total ($\mu\text{g/L}$)	44	.0	.20	1.40
Molybdenum, dissolved ($\mu\text{g/L}$)	44	0	0	2
Molybdenum, total ($\mu\text{g/L}$)	44	0	0	3
Nickel, dissolved ($\mu\text{g/L}$)	77	3	600	5,000
Nickel, total ($\mu\text{g/L}$)	77	50	1,000	8,000
Selenium, dissolved ($\mu\text{g/L}$)	44	0	1	3
Selenium, total ($\mu\text{g/L}$)	44	0	1	3
Vanadium, dissolved ($\mu\text{g/L}$)	74	.0	1.0	200
Zinc, dissolved ($\mu\text{g/L}$)	77	640	103,000	490,000
Zinc, total ($\mu\text{g/L}$)	74	730	106,000	490,000
Carbon, total organic (mg/L)	44	.0	2.1	8.0
Suspended solids (mg/L, residue at 110°C)	76	0	20	216

the cone of depression created by ground-water withdrawals by Miami (fig. 4). The mining district is located entirely on the north side of the cone of depression, and thus the background wells do not produce water from the abandoned mines.

The names of these 10 background wells (as shown on figure 3) are Cook, Fairland 2, Grand Lake Shores, Miami 1, Miami 3, Miami 6, Ogeechee Farms, RWD 4 Well 2, RWD 4 Well 3, and RWD 6 Well 1. The water samples collected during this investigation indicated that the Cook well was producing at least some water from the Boone Formation, based on the temperature of the produced water and the results of the chemical analyses, even though the well was originally drilled to the Roubidoux Formation. The temperature of the water produced by this well was about 3°C cooler than water produced from the Roubidoux aquifer; geothermal heating increases the temperature of water in the Roubidoux aquifer. The calcium concentrations in water samples from the Cook well are higher and the magnesium concentrations are lower than other background wells, which is consistent with a water source in the Boone For-

mation, a limestone (calcium carbonate), instead of the Roubidoux Formation, a dolomite (calcium-magnesium carbonate). Thus, the data from the Cook well were not used in any analysis of water-quality data. Also, RWD 4 Well 4, located on the eastern edge of the Picher mining district, originally was considered to be a background well. However, this rural water district well is located on the edge of the Picher mining district and at least eight abandoned mines occur within the same section (1 square mile) as this well (McKnight and Fischer, 1970). Thus, it is not clear if this well is inside or outside the mining area, and the data from this well were not used in any analysis of water-quality data.

Other considerations influenced the investigation design. Chemical analyses of water samples collected from the wells in the Picher mining district on a periodic basis by the Oklahoma Water Resources Board and the Oklahoma State Department of Health prior to this investigation indicated that constituent concentrations changed considerably between sample-collection trips (U.S. Environmental Protection Agency, written commun., 1989). Thus, monthly sampling was used to examine the change in constituent concentrations between sample-collec-

tion trips. The 10 public-supply wells in the Picher mining district were sampled once a month for six months; however, the background wells were sampled only once.

All wells were sampled at the wellhead using the existing water-supply pumps. The water produced at the wellhead is a mixture of any water that enters the well from any geologic unit.

The sampling was conducted between August 17, 1992, and January 28, 1993. The location of all wells sampled is shown in figure 3. All samples were analyzed for major ions and trace metals. The samples for all wells were sent to two different laboratories to quantify the analytical variance. Although not originally part of the investigation design, samples from 10 wells collected during the December sample-collection trip were analyzed for tritium. Tritium is an indicator of the presence of young (post-1952) ground water.

Field Procedures

Wellhead sampling was a four-phase process: (1) purging the well, (2) field analysis, (3) sampling, and (4) sample preservation. All well purging was accomplished using pumps already in the well, and samples were taken as close to the wellhead as possible. The field chemical parameters of the water, for all wells, were measured continuously during the purging process using a flow-through measuring chamber. The well was considered purged when the field parameters were stable. The field parameters were considered stable when three consecutive measurements, taken at intervals of 5 minutes or more, differed by less than the following amounts: Water temperature, 0.2°C; specific conductance, 5 percent (or 5 $\mu\text{S}/\text{cm}$ (microsiemens per centimeter at 25°C) when less than 100 $\mu\text{S}/\text{cm}$); and pH, 0.1 units. Some wells were operating when the sampling team arrived, and these wells were sampled after verifying the field parameters were stable.

Specific conductance was measured using a portable specific conductance meter with automatic temperature compensation. The specific conductance meter calibration was checked daily, or whenever field conditions warranted, using standard specific conductance solutions that bracketed the measured field values. Water temperature was measured to the nearest 0.1°C using a thermistor circuit within the specific conductance meter. All thermistor circuits were checked daily using an American Society for Testing and Materials mercury thermometer. pH in the flow-through chamber was determined after the inflow valve was closed and the pressure in the chamber equilibrated with atmospheric pressure. pH was measured using a portable pH meter with automatic temperature compensation and a Ross combination electrode. The pH meters were calibrated at every site before starting measurements and checked after all measurements were completed using standard buffer solutions that bracketed the expected field pH values; the calibration then was corroborated using a third buffer solution. Dissolved oxygen concentrations were measured using a portable meter that was calibrated at the beginning of each day, or when field conditions warranted, in water-saturated air using a cali-

bration wand. Alkalinity of the water was determined by the electrometric method, which uses an incremental titration of 0.16-normal standardized sulfuric acid past the carbonate-bicarbonate inflection point (at an approximate pH of 8.3) and the bicarbonate-carbonic acid inflection point (at an approximate pH of 4.5). The titration was done in duplicate or until agreement within two percent was achieved.

Stabilization of field parameters marked the beginning of the sample-collection phase. At least three samples were collected at each well; one unfiltered sample was sent to a laboratory designated by the U.S. Environmental Protection Agency through the Contract Laboratory Program and two samples, one of unfiltered water and one of filtered water (for dissolved constituents), were sent to the U.S. Environmental Protection Agency's Robert S. Kerr Environmental Research Laboratory in Ada, Oklahoma. Samples collected for the analysis of dissolved constituents were filtered through a 142-millimeter diameter, 0.45-micron pore size, cellulose-nitrate membrane filter, using an acrylic in-line filter holder. On rare occasions the sediment load in the water from the well was significant, so the sample was filtered through a disposable, 700-square centimeter, 0.45-micron pore size, pleated, cartridge filter before any other treatment. The acrylic in-line filter holder was soaked in nitric acid and rinsed with water known to contain very low concentrations of the inorganic constituents of interest. The water used for cleaning equipment is referred to in this report as "inorganic blank water" and its chemical composition is shown in table 5.

Two aliquots were collected for each sample, one for cations and one for anions. The bottles used to collect the cations were cleaned prior to transportation to the wells by rinsing with ultra-pure nitric acid, followed by rinsing with inorganic blank water.

Samples were stabilized as quickly as possible after collection. Samples for cations were preserved with ultra-pure nitric acid, and samples for anions were placed in coolers and chilled. Cation samples sent to the Contract Laboratory Program also were chilled because of the requirements of the Contract Laboratory Program. All samples were collected during the first part of a week and shipped to the different laboratories by an express courier service so that all samples were at the laboratory during the same week the samples were collected. The chemical analyses for all environmental samples, including duplicate samples, are listed in appendix 1.

Quality-Assurance Sampling

Quality-assurance sampling was used to evaluate the quality of the environmental samples. The quality-assurance samples included blank samples and duplicate samples.

Blank Samples

Blank samples (or simply "blanks") are solutions that have low concentrations of the constituents of interest and are used

to determine if water samples are being contaminated by the sampling or analytical process. The laboratories that analyzed samples use several different types of blank samples as part of the analytical process, but these laboratory blanks are not discussed in this report.

All blanks used for the wellhead sampling program were prepared using the same inorganic blank water used to clean equipment (table 5). Two different types of blanks were used in the wellhead sampling program. *Trip blanks* are blank solutions that are put in the same type of bottle as that used for water samples and stored with the sample bottles both before and after sample collection. Trip blanks are prepared in a laboratory and are never opened in the field. Trip blanks identify contaminants that might be introduced directly by the sample bottle or by diffusion into the sample bottle while it is being transported. One trip blank was prepared for each monthly sample-collection trip. *Field blanks* are blank samples that were prepared in the field at the sampled well by processing blank water in exactly the same manner as an environmental sample. Field blanks identify sources of contamination at the sampling site, such as windblown particulates. Field blanks of unfiltered samples were prepared simply by opening a sealed bottle of inorganic blank water and filling a sample bottle. For filtered samples the field blanks were prepared by pumping inorganic blank water directly from the inorganic blank water bottle into the sample bottle using a peristaltic pump. The peristaltic pump introduced an extra piece of equipment that was not used for environmental samples, but was necessary in order to pump the water through the filter (water pressure from the well pump pushed the water through the filter for the environmental samples). The only part of the peristaltic pump that contacts the blank sample is a short length of silicon tubing, which is cleaned in a laboratory prior to field work and transported to the site in a sealed plastic bag. Two field blanks were prepared for each of the first five monthly sample-collection trips. The first field blank was prepared at the first well of each trip, prior to collecting environmental samples, and the second field blank was prepared at the last well of each sample-collection trip, after the last environmental sample. The reasoning for this sequence of field blanks was to check the degree of field-induced contamination at the beginning and end of each sample-collection trip, and in particular to see if contamination increased during the course of the trip. An additional field blank was prepared on the sixth monthly sample-collection trip because the 10 additional background wells were sampled.

The results of the blank samples (Appendix 2) were examined to determine whether contamination was a problem in the sampling program. Ideally, the blank samples will show no detectable concentrations for any chemical constituent analyzed. However, preparing water for blank samples that contains only water molecules is impossible with current technology, and the minimum reporting level for analytical instruments and methods is decreasing continually. Thus, small concentrations of some chemical constituents may be measured in blank samples (particularly blank samples prepared under field conditions), but if the concentrations in blank samples are less than

the concentrations in environmental samples, the results of the environmental samples are still useful for assessing the water quality of the sampled environment.

The results of the blank samples show that some of the constituents that are potential indicators of mine-water contamination are affected by sampling contamination. Cadmium in filtered samples, copper in unfiltered samples, and lead in filtered and unfiltered samples had sampling contamination problems because these constituents were found at concentrations greater than the minimum report level in at least one blank sample, and the concentrations in blank samples were in the same range as the concentrations in environmental samples. Because of these sampling contamination problems, these three constituents were not used in any analysis of environmental data. Further discussion of the results of the blank samples is presented with the discussion of the analysis of the environmental sample data.

Duplicate Samples

Another type of quality-assurance sampling utilized during the wellhead sampling program was the use of duplicate samples. Duplicate samples consist of two or more sets of samples collected from the same source during the same sample-collection trip and analyzed in the same manner. The purpose of duplicate sampling is to determine the precision of the sampling and analytical procedures. In this study, the duplicate sample was collected immediately following the normal sample without using a splitting device, which might have introduced contaminants.

For each duplicate sample, the relative percent difference between the duplicate and the environmental sample was calculated, as follows:

$$RPD = \frac{|C_1 - C_2|}{\frac{(C_1 + C_2)}{2}} \times 100 \quad (1)$$

where RPD is the relative percent difference, C_1 is the concentration of the environmental sample, and C_2 is the concentration of the duplicate sample. The results of the calculations of relative percent difference are shown in table 6.

The relative percent difference between environmental and duplicate samples are all less than 5.4 percent for calcium and magnesium. This small difference indicates that the sampling and analytical procedures produce consistent data, and confidence in the measurement is enhanced. The relative percent difference also is small for manganese analyses (all less than 13.3 percent), although not as small as for calcium and magnesium.

Sulfate analyses had a few measurements with larger relative percent differences, as large as 54.5 percent. However, this large difference is associated with samples with low concentrations of sulfate from Ottawa County Rural Water District Well 4. The sulfate concentrations were 4.0 mg/L in the environmental sample and 7.0 mg/L in the duplicate sample. Thus, although

Table 5. Physical properties and concentrations of major ions, nutrients, and trace elements in water used for preparing blank samples and equipment cleaning[Constituents and properties: $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter]

Constituents and properties	Concentration
Specific conductance ($\mu\text{S}/\text{cm}$ at 25°C)	<0.5
pH (standard units)	6.78
Alkalinity (mg/L as CaCO_3)	<0.5
Calcium, dissolved (mg/L)	.06
Magnesium, dissolved (mg/L)	<0.01
Sodium, dissolved (mg/L)	<0.01
Potassium, dissolved (mg/L)	<0.01
Sulfate, dissolved (mg/L)	<0.01
Chloride, dissolved (mg/L)	<0.01
Fluoride, dissolved (mg/L)	.02
Bromide, dissolved (mg/L)	<0.01
Silica, dissolved (mg/L)	.04
Nitrite (mg/L as N)	<0.001
Nitrite plus nitrate (mg/L as N)	.015
Nitrogen, ammonia (mg/L as N)	.005
Phosphorus (mg/L)	.002
Orthophosphorus (mg/L)	<0.001
Aluminum, dissolved ($\mu\text{g}/\text{L}$)	<1.
Antimony, dissolved ($\mu\text{g}/\text{L}$)	<1.
Arsenic, dissolved ($\mu\text{g}/\text{L}$)	<1.
Barium, dissolved ($\mu\text{g}/\text{L}$)	<2.
Beryllium, dissolved ($\mu\text{g}/\text{L}$)	<0.5
Boron, dissolved ($\mu\text{g}/\text{L}$)	<10.
Cadmium, dissolved ($\mu\text{g}/\text{L}$)	<0.1
Chromium, dissolved ($\mu\text{g}/\text{L}$)	<0.5
Cobalt, dissolved ($\mu\text{g}/\text{L}$)	<0.5
Copper, dissolved ($\mu\text{g}/\text{L}$)	<0.5
Iron, dissolved ($\mu\text{g}/\text{L}$)	<3.
Lead, dissolved ($\mu\text{g}/\text{L}$)	<0.5
Lithium, dissolved ($\mu\text{g}/\text{L}$)	<4.
Manganese, dissolved ($\mu\text{g}/\text{L}$)	<0.2
Mercury, dissolved ($\mu\text{g}/\text{L}$)	<0.01
Molybdenum, dissolved ($\mu\text{g}/\text{L}$)	<1.
Nickel, dissolved ($\mu\text{g}/\text{L}$)	<1.
Selenium, dissolved ($\mu\text{g}/\text{L}$)	<1.
Silver, dissolved ($\mu\text{g}/\text{L}$)	<1.
Strontium, dissolved ($\mu\text{g}/\text{L}$)	<0.5
Vanadium, dissolved ($\mu\text{g}/\text{L}$)	<1.
Zinc, dissolved ($\mu\text{g}/\text{L}$)	<0.5

Table 6. Relative percent difference between environmental and duplicate samples

[--, Concentration reported in environmental or duplicate sample less than laboratory minimum reporting level; no calculation of relative percent difference]

Owner	Date	Time	Calcium	Magnesium	Sulfate	Cadmium	Copper	Iron	Lead	Manganese	Nickel	Zinc
Cardin	09-22-1992	900	5.4	5.2	11.3	--	--	1.8	27.0	9.2	--	30.0
Cardin	12-14-1992	920	.6	1.9	.5	--	--	.0	--	12.8	--	10.9
Cardin	01-25-1993	920	3.6	2.3	.3	--	--	2.9	--	5.4	--	3.2
Commerce 1	08-17-1992	930	.7	.5	8.2	--	--	20.3	--	--	--	41.0
Commerce 2	10-21-1992	1030	.3	1.4	30.1	--	23.0	4.0	57.1	.0	7.0	.0
Commerce 3	01-26-1993	1400	.9	.4	.7	--	--	.5	--	11.3	--	1.2
Commerce 4	11-17-1992	1550	.3	.7	15.4	--	--	36.5	13.3	13.3	--	73.5
Grand Lake Shores	01-27-1993	1430	1.6	.0	.0	--	--	19.2	--	--	--	18.8
RWD 4 Well 4	11-16-1992	1050	1.8	2.1	54.5	--	--	12.9	148.5	--	--	21.8
Picher 2	10-20-1992	940	2.4	.4	11.8	--	--	.4	30.0	7.9	68.1	3.4
Picher 3	08-17-1992	1610	.7	1.1	7.3	--	--	7.5	--	--	--	10.0
Picher 4	09-23-1992	910	3.8	3.3	5.3	--	.0	4.1	52.6	.0	4.3	5.6
Picher 4	12-15-1992	1010	.9	1.4	.3	--	--	5.1	--	.0	--	2.3

the relative percent difference is large, the conclusion that this well is producing water with low sulfate concentration is valid. The three duplicate samples with the largest relative percent difference are all associated with low sulfate concentrations, indicating the larger relative percent difference is not indicative of a problem with sampling or analytical procedures. The relative percent difference for zinc and iron range from 0 to 36.5 percent for iron and 0 to 73.5 percent for zinc, but the largest relative percent differences are associated with samples having low concentrations of these constituents.

Relative percent difference could not be calculated for most analyses of cadmium, copper, or nickel, because the environmental sample or the duplicate sample (or both) had concentrations below the laboratory minimum reporting level. Relative percent differences for lead were large, but all concentrations of lead were small and near the laboratory minimum reporting level. As discussed in the “Blank Samples” section of this report, lead concentrations in the environmental and duplicate samples may be affected by sampling contamination.

Results of the duplicate samples show that the constituent concentrations are reproducible in environmental samples. This is especially true of the larger concentrations associated with wells in the mining area.

Analysis of Environmental Data

To facilitate discussion of the water-quality data, descriptive statistics were calculated. To meet the objective of this investigation, hypothesis testing was used to compare: (1) current (1992-93) water quality in the Picher mining district wells to background wells, and (2) historic (1981-83) to current (1992-93) water quality in the Picher mining district wells.

Descriptive Statistics

Descriptive statistics, in the form of percentiles and maximum and minimum concentrations, were calculated for chemical analyses of water samples from wells in the Picher mining district (table 7) and background wells (table 8). These statistics are descriptive of the water samples collected during this investigation but are not necessarily a good description of the water quality in the Roubidoux aquifer, for several reasons:

1. The sampling points (in this case, the wells) are not randomly located.
2. Some of the wells in the mining area are very close to each other (less than 20 meters) and thus some parts of the aquifer are sampled more often than others.
3. The wells are not of uniform construction and do not necessarily produce water exclusively from the Roubidoux aquifer.

Thus, the descriptive statistics presented in tables 7 and 8 should not be considered as representative of the water in the Roubidoux aquifer.

The chemical analyses for many constituents include concentrations that are reported as less than a specified minimum-reporting level and are called censored data. If no censored data were present for a constituent, percentiles were calculated by standard methods. Percentiles below the largest minimum-reporting level can not be calculated accurately using standard methods. A procedure developed by Helsel and Cohn (1988) for calculating percentiles in data with one or more minimum-reporting levels was used to calculate percentiles for any constituent with censored data. The procedure used a statistical model to calculate percentiles that were less than the largest minimum-reporting level. Many percentiles calculated by the method of Helsel and Cohn are smaller than the smallest minimum-reporting level. No percentiles were calculated if more than 80 percent of the data for a constituent were censored.

Comparison of Picher Mining District to Background Water Quality

Water quality in wells in the Picher mining district and background wells were compared using the Mann-Whitney test (P-STAT, Inc., 1989). The Mann-Whitney test was used because it is a nonparametric test, which does not require assumptions about the population distributions. The Mann-Whitney test works on the ranks of the data instead of the actual constituent concentrations. Censored data all were assigned fictitious small concentrations and were treated as having the same rank by the Mann-Whitney test.

The null hypothesis was that the concentrations of chemical constituents in ground-water samples were the same in the Picher mining district and background wells. The alternative hypothesis was that the populations were different in the mining district and background wells. The null hypothesis was rejected if the p -value of the test was less than or equal to 0.05.

The Mann-Whitney tests used the data for the January 1993 sample-collection trip, the only month the background wells were sampled. The tests compared mining district and background well constituent concentrations for samples analyzed by the same laboratory to ensure maximum comparability. The results of the Mann-Whitney tests for all mine-water indicator constituents are shown in table 9. The results of the Mann-Whitney tests for each constituent are discussed in the order of properties (pH and alkalinity, in this case), major ions (cations and anions), and trace constituents. Within these categories, constituents are discussed alphabetically.

pH

The p -value calculated by the Mann-Whitney test was 0.0055, leading to the rejection of the null hypothesis and the conclusion that pH values were significantly different between Picher mining district and background wells. Because pH is

Table 7. Summary statistics of physical properties, major ions, and trace elements for water samples from wells in the Picher mining district

[Constituents or physical properties: $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter. Method:

1, no censored data, ordinary percentile calculation; 2, censored data present, 20 or more observations, less than 80 percent of observations censored, percentiles calculated using methods of Helsel and Cohn (1988); 3, no calculation, more than 80 percent of the data were censored; 4, no calculation, censored data present, fewer than 20 observations. Largest MRL: largest minimum reporting level (percentiles less than this value were estimated using the methods of Helsel and Cohn (1988), percentiles greater than this value are the same as ordinary percentile calculation); --, no censored data for this constituent. Percentiles: --, indicates no statistic was calculated]

Constituents or physical properties	Method	Sample size	Largest MRL	Minimum	Percentiles					Maximum
					5	25	50	75	95	
Specific conductance ($\mu\text{S}/\text{cm}$ at 25°C)	1	60	--	269	275.45	330.25	498.	753.5	884.8	893.
pH, field (standard units)	1	60	--	6.95	7.01	7.24	7.44	7.64	7.91	8.03
Water temperature (°C)	1	60	--	18.8	19.	19.2	19.7	20.07	20.79	20.9
Alkalinity, unfiltered, field (mg/L as CaCO_3)	1	60	--	116.	118.05	126.	138.	160.	183.8	190.
Calcium, filtered (mg/L)	1	60	--	27.7	29.33	34.4	52.5	81.4	111.	112.
Calcium, unfiltered (mg/L)	1	120	--	26.8	28.3	33.68	51.45	78.55	108.95	120.
Magnesium, filtered (mg/L)	1	60	--	13.2	14.3	15.6	23.7	33.47	43.68	45.4
Magnesium, unfiltered (mg/L)	1	120	--	12.7	13.3	15.05	23.	32.28	42.88	46.7
Sodium, filtered (mg/L)	1	60	--	5.96	7.57	13.5	17.1	21.33	53.43	58.
Sodium, unfiltered (mg/L)	1	120	--	5.31	7.3	13.13	15.35	20.28	51.29	61.1
Potassium, filtered (mg/L)	2	60	<1.1	<45	.98	1.69	2.45	3.13	3.86	4.65
Potassium, unfiltered (mg/L)	2	120	<2.1	<45	1.13	1.71	2.51	3.09	3.99	4.67
Bicarbonate, field (mg/L)	1	60	--	141.	144.05	154.	168.	195.	223.9	231.
Sulfate, filtered (mg/L)	1	60	--	10.8	16.81	29.5	91.5	188.	291.95	301.
Sulfate, unfiltered (mg/L)	1	120	--	11.2	16.72	28.5	86.7	180.5	290.85	306.
Chloride, filtered (mg/L)	1	60	--	4.05	7.24	11.85	19.05	32.25	84.83	88.3
Chloride, unfiltered (mg/L)	1	80	--	4.55	7.52	11.00	19.35	28.83	79.73	87.20
Aluminum, filtered ($\mu\text{g}/\text{L}$)	3	60	<80.	<9.9	--	--	--	--	--	106.
Aluminum, unfiltered ($\mu\text{g}/\text{L}$)	3	120	<76.	6.0	--	--	--	--	--	200.
Antimony, unfiltered ($\mu\text{g}/\text{L}$)	3	60	<32.2	<16.9	--	--	--	--	--	33.3
Arsenic, filtered ($\mu\text{g}/\text{L}$)	3	60	<39.	<3.6	--	--	--	--	--	25.
Arsenic, unfiltered ($\mu\text{g}/\text{L}$)	3	120	<39.	<1.	--	--	--	--	--	24.

Table 7. Summary statistics of physical properties, major ions, and trace elements for water samples from wells in the Picher mining district—Continued

Constituents or physical properties	Method	Sample size	Largest MRL	Minimum	Percentiles					Maximum
					5	25	50	75	95	
Barium, filtered (µg/L)	1	60	--	8.8	10.07	37.32	54.55	67.6	87.18	96.6
Barium, unfiltered (µg/L)	1	120	--	8.2	9.65	36.35	52.7	67.72	85.49	96.8
Beryllium, filtered (µg/L)	2	60	<5.	<.1	.06	.09	.11	.15	.21	.30
Beryllium unfiltered (µg/L)	3	120	<5.	<.1	--	--	--	--	--	1.4
Boron, filtered (µg/L)	2	60	<52.	<9.4	5.91	15.05	28.82	66.45	108.8	133.
Boron, unfiltered (µg/L)	2	60	<52.	<9.4	6.29	16.06	30.8	65.23	108.8	188.
Cadmium, filtered (µg/L)	3	60	<2.6	<1.	--	--	--	--	--	3.1
Cadmium, unfiltered (µg/L)	3	120	<4.	<1.	--	--	--	--	--	5.1
Chromium, filtered (µg/L)	3	60	<6.	<.8	--	--	--	--	--	16.
Chromium, unfiltered (µg/L)	3	120	<8.	<.8	--	--	--	--	--	4.2
Cobalt, filtered (µg/L)	3	60	<8.2	<1.3	--	--	--	--	--	4.9
Cobalt, unfiltered (µg/L)	3	120	<14.	<1.7	--	--	--	--	--	4.8
Copper, filtered (µg/L)	3	60	<53.	<4.8	--	--	--	--	--	38.2
Copper, unfiltered (µg/L)	3	120	<51.	<2.6	--	--	--	--	--	50.9
Iron, filtered (µg/L)	2	60	<99.	<6.1	15.85	65.5	211.	461.25	1056.5	1110.
Iron, unfiltered (µg/L)	2	120	<94.	<6.1	33.24	125.5	310.5	461.25	996.9	1210.
Lead, filtered (µg/L)	3	60	<27.	<5.7	--	--	--	--	--	237.
Lead, unfiltered (µg/L)	2	120	<26.	<1.	.66	1.14	1.66	2.43	4.19	10.9
Lithium, filtered (µg/L)	1	60	--	7.2	12.28	22.03	30.9	39.6	52.48	56.2
Lithium, unfiltered (µg/L)	1	60	--	7.2	12.26	22.13	29.8	36.57	53.98	60.2
Manganese, filtered (µg/L)	2	60	<8.6	<2.3	1.44	3.09	5.26	9.67	16.76	19.3
Manganese, unfiltered (µg/L)	2	120	<8.6	<.8	.73	2.11	4.39	9.99	17.08	18.7
Mercury, unfiltered (µg/L)	3	60	<.2	<.1	--	--	--	--	--	2.9
Molybdenum, filtered (µg/L)	2	60	<4.2	<1.3	.51	1.17	2.09	4.48	8.38	8.7
Molybdenum unfiltered (µg/L)	2	60	<4.2	<1.3	.81	1.59	2.53	4.05	7.4	8.5
Nickel, filtered (µg/L)	2	60	<8.9	<2.6	.31	.95	2.08	4.57	15.13	21.9
Nickel, unfiltered (µg/L)	3	120	<14.5	<2.6	--	--	--	--	--	31.1
Selenium, filtered (µg/L)	3	60	<26.	<7.5	--	--	--	--	--	26.
Selenium, unfiltered (µg/L)	3	120	<26.	<.9	--	--	--	--	--	28.
Silver, filtered (µg/L)	3	60	<7.8	<1.7	--	--	--	--	--	8.2
Silver, unfiltered (µg/L)	3	120	<7.8	<1.8	--	--	--	--	--	10.8
Strontium, filtered (µg/L)	1	60	--	20.8	26.66	42.87	72.55	408.75	912.25	1290.
Strontium unfiltered (µg/L)	1	60	--	20.4	27.43	42.87	71.75	419.	913.85	1250.
Thallium, filtered (µg/L)	2	60	<24.	5.	2.48	5.	8.14	13.23	26.65	38.

Table 7. Summary statistics of physical properties, major ions, and trace elements for water samples from wells in the Picher mining district—Continued

Constituents or physical properties	Method	Sample size	Largest MRL	Minimum	Percentiles					Maximum
					5	25	50	75	95	
Thallium, unfiltered (µg/L)	3	120	<25.	<1.	--	--	--	--	--	30.
Titanium, filtered (µg/L)	2	60	<17.	<1.3	.48	1.26	2.45	4.77	12.47	12.3
Titanium, unfiltered (µg/L)	2	60	<17.	.6	.46	1.07	1.93	3.49	8.19	8.5
Vanadium, filtered (µg/L)	3	60	<24.	<2.3	--	--	--	--	--	<24.
Vanadium unfiltered (µg/L)	3	120	<24.	<2.8	--	--	--	--	--	10.9
Zinc, filtered (µg/L)	2	60	<40.	<1.3	.07	.83	4.58	25.39	135.	195.
Zinc, unfiltered (µg/L)	2	120	<40.	<1.3	.89	5.1	17.2	78.02	168.85	242.

Table 8. Summary statistics of physical properties, major ions, and trace elements for water samples from background wells

[Constituents or physical properties: µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter. Method: 1, no censored data, ordinary percentile calculation; 2, censored data present, 20 or more observations, less than 80 percent of observations censored, percentiles calculated using methods of Helsel and Cohn (1988); 3, no calculation, more than 80 percent of the data were censored; 4, no calculation, censored data present, fewer than 20 observations. Largest MRL: largest minimum reporting level (percentiles less than this value were estimated using the methods of Helsel and Cohn (1988), percentiles greater than this value are the same as ordinary percentile calculation); --, no censored data for this constituent. Percentiles: --, indicates no statistic was calculated]

Constituents or physical properties	Method	Sample size	Largest MRL	Minimum	Percentiles					Maximum
					5	25	50	75	95	
Specific conductance (µS/cm at 25°C)	1	9	--	271.	271.	363.	444.	541.	589.	589.
pH, field (standard units)	1	9	--	7.59	7.59	7.73	7.83	7.88	7.94	7.94
Water temperature (°C)	1	9	--	18.4	18.4	19.15	19.6	20.05	20.5	20.5
Alkalinity, unfiltered, field (mg/L as CaCO ₃)	1	9	--	116.	116.	119.	124.	131.	134.	134.
Calcium, filtered (mg/L)	1	9	--	28.9	28.9	29.7	30.7	32.7	33.7	33.7
Calcium, unfiltered (mg/L)	1	18	--	28.2	28.2	29.57	31.9	34.87	161.	161.
Magnesium, filtered (mg/L)	1	9	--	13.2	13.2	13.45	14.2	15.25	15.5	15.5
Magnesium, unfiltered (mg/L)	1	18	--	12.8	12.8	13.37	14.55	15.4	74.2	74.2
Sodium, filtered (mg/L)	1	9	--	4.51	4.51	22.5	51.8	61.55	66.7	66.7
Sodium, unfiltered (mg/L)	1	18	--	4.34	4.34	23.	50.95	59.52	155.	155.
Potassium, filtered (mg/L)	4	9	<44	<44	--	--	--	--	--	2.31
Potassium, unfiltered (mg/L)	4	18	<44	<44	--	--	--	--	--	13.8
Bicarbonate, unfiltered, field (mg/L)	1	9	--	141.	141.	145.	151.	159.5	163.	163.
Sulfate, filtered (mg/L)	1	9	--	10.6	10.6	11.25	12.1	12.8	13.2	13.2
Sulfate, unfiltered (mg/L)	1	18	--	10.9	10.9	12.57	13.3	14.87	147.	147.
Chloride, filtered (mg/L)	1	9	--	9.88	9.88	28.00	62.7	85.1	105.	105.
Chloride, unfiltered (mg/L)	1	18	--	9.76	9.76	28.12	61.55	83.3	111.	111.

Table 8. Summary statistics of physical properties, major ions, and trace elements for water samples from background wells—Continued

[Constituents or physical properties: $\mu\text{S/cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; $\mu\text{g/L}$, micrograms per liter. Method: 1, no censored data, ordinary percentile calculation; 2, censored data present, 20 or more observations, less than 80 percent of observations censored, percentiles calculated using methods of Helsel and Cohn (1988); 3, no calculation, more than 80 percent of the data were censored; 4, no calculation, censored data present, fewer than 20 observations. Largest MRL: largest minimum reporting level (percentiles less than this value were estimated using the methods of Helsel and Cohn (1988), percentiles greater than this value are the same as ordinary percentile calculation); --, no censored data for this constituent. Percentiles: --, indicates no statistic was calculated]

Constituents or physical properties	Method	Sample size	Largest MRL	Minimum	Percentiles					Maximum
					5	25	50	75	95	
Aluminum, filtered ($\mu\text{g/L}$)	4	9	<59.	<59.	--	--	--	--	--	73.
Aluminum, unfiltered ($\mu\text{g/L}$)	4	18	<59.	<30.8	--	--	--	--	--	148.
Antimony, unfiltered ($\mu\text{g/L}$)	4	9	<24.3	<24.3	--	--	--	--	--	66.5
Arsenic, filtered ($\mu\text{g/L}$)	4	9	<18.	<18.	--	--	--	--	--	<18.
Arsenic, unfiltered ($\mu\text{g/L}$)	4	18	<18.	<1.5	--	--	--	--	--	<18.
Barium, filtered ($\mu\text{g/L}$)	1	9	--	5.2	5.2	18.75	25.1	31.35	34.5	34.5
Barium, unfiltered ($\mu\text{g/L}$)	1	18	--	5.6	5.6	19.85	26.8	31.37	168.	168.
Beryllium, filtered ($\mu\text{g/L}$)	4	9	<5.	<.1	--	--	--	--	--	.2
Beryllium unfiltered ($\mu\text{g/L}$)	4	18	<5.	<.1	--	--	--	--	--	.1
Boron, filtered ($\mu\text{g/L}$)	4	9	<15.	<15.	--	--	--	--	--	159.
Boron, unfiltered ($\mu\text{g/L}$)	4	9	<15.	<15.	--	--	--	--	--	148.
Cadmium, filtered ($\mu\text{g/L}$)	4	9	<1.6	<1.6	--	--	--	--	--	2.6
Cadmium, unfiltered ($\mu\text{g/L}$)	4	18	<2.3	<1.6	--	--	--	--	--	2.9
Chromium, filtered ($\mu\text{g/L}$)	4	9	<2.3	<2.3	--	--	--	--	--	2.4
Chromium, unfiltered ($\mu\text{g/L}$)	4	18	<5.7	<2.3	--	--	--	--	--	5.8
Cobalt, filtered ($\mu\text{g/L}$)	4	9	<8.2	<8.2	--	--	--	--	--	<8.2
Cobalt, unfiltered ($\mu\text{g/L}$)	4	18	<10.6	<8.2	--	--	--	--	--	10.4
Copper, filtered ($\mu\text{g/L}$)	4	9	<38.	<38	--	--	--	--	--	<38.
Copper, unfiltered ($\mu\text{g/L}$)	4	18	<38.	<2.6	--	--	--	--	--	19.8
Iron, filtered ($\mu\text{g/L}$)	4	9	<11.	<11.	--	--	--	--	--	202.
Iron, unfiltered ($\mu\text{g/L}$)	4	18	<11.	<11.	--	--	--	--	--	1320.

Table 8. Summary statistics of physical properties, major ions, and trace elements for water samples from background wells—Continued

Constituents or physical properties	Method	Sample size	Largest MRL	Minimum	Percentiles					Maximum
					5	25	50	75	95	
Lead, filtered (µg/L)	4	9	<8.1	<8.1	--	--	--	--	--	<8.1
Lead, unfiltered (µg/L)	4	18	<8.1	<1.4	--	--	--	--	--	12.8
Lithium, filtered (µg/L)	4	9	<4.6	<4.6	--	--	--	--	--	70.9
Lithium, unfiltered (µg/L)	1	9	--	6.8	6.8	28.5	50.	61.55	71.4	71.4
Manganese, filtered (µg/L)	4	9	<2.3	<2.3	--	--	--	--	--	6.1
Manganese, unfiltered (µg/L)	4	18	<2.3	<1.7	--	--	--	--	--	36.5
Mercury, unfiltered (µg/L)	4	9	<.2	<.2	--	--	--	--	--	<.2
Molybdenum, filtered (µg/L)	4	9	<3.6	<3.6	--	--	--	--	--	<3.6
Molybdenum unfiltered (µg/L)	4	9	<3.6	<3.6	--	--	--	--	--	<3.6
Nickel, filtered (µg/L)	4	9	<2.6	.9	--	--	--	--	--	3.
Nickel, unfiltered (µg/L)	4	18	<8.8	<2.6	--	--	--	--	--	15.8
Selenium, filtered (µg/L)	4	9	<21.	<21.	--	--	--	--	--	<21.
Selenium, unfiltered (µg/L)	4	18	<21.	<.9	--	--	--	--	--	<21
Silver, filtered (µg/L)	4	9	<7.8	<7.8	--	--	--	--	--	<7.8
Silver, unfiltered (µg/L)	4	18	<7.8	<4	--	--	--	--	--	<7.8
Strontium, filtered (µg/L)	1	9	--	90.6	90.6	296.5	498.	612.5	657.	657.
Strontium unfiltered (µg/L)	1	9	--	88.3	88.3	296.	490.	607.	638.	638.
Thallium, filtered (µg/L)	4	9	<8.1	<8.	--	--	--	--	--	<8.1
Thallium, unfiltered (µg/L)	4	18	<8.1	<2.5	--	--	--	--	--	<8.1
Titanium, filtered (µg/L)	4	9	<2.	<1.3	--	--	--	--	--	<2.
Titanium, unfiltered (µg/L)	4	9	<2.	<1.3	--	--	--	--	--	2.7
Vanadium, filtered (µg/L)	4	9	<13.	<13.	--	--	--	--	--	13.
Vanadium unfiltered (µg/L)	4	18	<13.	<3.7	--	--	--	--	--	18.
Zinc, filtered (µg/L)	4	9	<3.2	<3.2	--	--	--	--	--	<3.2
Zinc, unfiltered (µg/L)	4	18	<3.6	<3.2	--	--	--	--	--	18.6

Table 9. *P*-values from Mann-Whitney tests comparing the concentrations of constituents from samples collected in January 1993 from wells in the Picher mining district and background wells

[Laboratory: CLP, U.S. Environmental Protection Agency contract laboratory program; RSK, Robert S. Kerr Environmental Research Laboratory; --, Unable to calculate *p*-value; numbers in bold type indicate constituent concentrations are different between wells in the Picher mining district and background wells]

Constituent	Laboratory		
	CLP	RSK	
	Unfiltered	Unfiltered	Filtered
pH ¹	0.0055	0.0055	0.0055
Alkalinity ¹	.0268	.0268	.0268
Calcium	.1208	.0090	.0143
Magnesium	.1416	.0089	.0079
Bicarbonate ¹	.0268	.0268	.0268
Sulfate	.0100	.0002	.0002
Cadmium	--	.4796	--
Copper	--	--	.3428
Iron	.0500	.0177	.0070
Lead	--	--	--
Manganese	.0070	.0476	.0300
Nickel	.6735	.2383	.1084
Zinc	.0074	.0478	.0178

¹Field measurements applied to samples from all laboratories

measured in the field, the same pH is assigned to all samples taken at a well at a specific time, regardless of the laboratory to which the sample is shipped or if the sample is unfiltered or filtered. The pH measured at all wells is shown in figure 6. pH in January 1993 at the background wells fell into a relatively narrow range between 7.59 and 7.94, with a median of 7.83. Seven of the ten wells in the mining district had pH less than 7.59 for the January sampling, including Cardin, Commerce 1 and 3, all three Picher wells, and Quapaw 2. Six of these seven wells had pH less than 7.59 for all six monthly samplings; Cardin had pH less than 7.59 for five of six monthly samplings.

Alkalinity

The *p*-value calculated by the Mann-Whitney test was 0.0268, leading to the rejection of the null hypothesis and the conclusion that alkalinities were significantly different between Picher mining district and background wells. Because alkalinity is measured in the field, the same alkalinity is assigned to all samples taken at a well at a specific time, regardless of the laboratory to which the sample is shipped or if the sample is unfiltered or filtered.

The alkalinity measured at all wells is shown in figure 7. The alkalinity in January 1993 at the background wells fell into

a relatively narrow range between 116 to 134, with a median of 124. Six of the ten wells in the mining district had an alkalinity greater than 134 for the January sampling, including Cardin, Commerce 3, all three Picher wells, and Quapaw 2. Commerce 1 had an alkalinity equal to 134. Five wells had alkalinities greater than 134 for all six monthly samplings, including Commerce 3, all Picher wells, and Quapaw 2. Cardin had an alkalinity greater than 134 for three of six monthly samplings and Commerce 1 had an alkalinity greater than 134 for four monthly samplings.

Calcium

The *p*-value calculated by the Mann-Whitney test was 0.1208 for unfiltered samples sent to the contract laboratories, 0.0090 for unfiltered samples sent to the Kerr Laboratory, and 0.0143 for filtered samples sent to the Kerr Laboratory. Using a significance level of 0.05, the null hypothesis would be rejected for the filtered and unfiltered Kerr Laboratory samples but accepted for the unfiltered contract lab samples. The reason for this apparent contradiction is thought to be caused by the introduction of particulate matter, probably scale on the casing or pump, in some samples from some wells. The presence of particulate matter several millimeters in diameter in the flow-

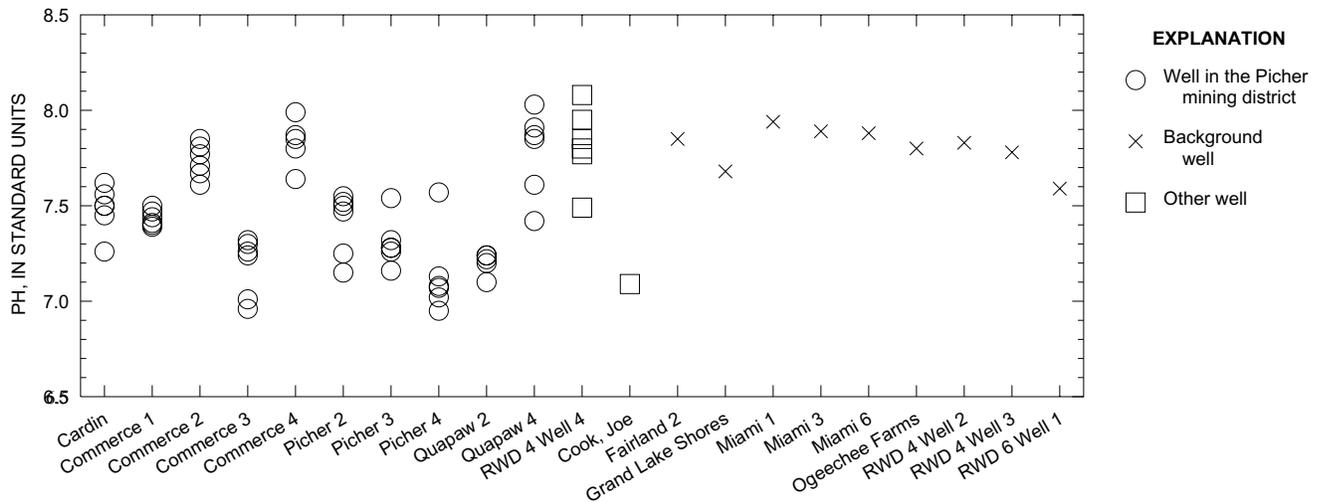


Figure 6. pH of water samples collected during the monthly sampling trips.

through cell was noted during the sampling of Miami 3, and some of the matter may have been analyzed with the water in the unfiltered sample. Calcium concentrations in background wells in filtered samples are in a narrow range of 28.9 to 33.7 mg/L, but in the unfiltered sample sent to the contract laboratory from Miami 3 the calcium concentration was 161 mg/L, the highest calcium concentration measured in any well during the six months of sampling. The calcium concentration in the filtered sample from Miami 3 was 29.5 mg/L and was 29 mg/L in the unfiltered sample sent to the Kerr Laboratory. As discussed later in this report, particulate matter altering the concentrations of constituents in water samples was not unique to calcium nor to the Miami 3 well. An inherent assumption of this investigation was that the water in samples was representative of the water produced by wells completed in the Roubidoux aquifer. Particulate matter introduced by the well is random in nature and makes the samples less representative of the produced water. Filtering the samples removes the particulate matter. Thus, the unfiltered samples are considered to be not suited to the statistical analysis of the wellhead sampling data, although the *p*-values for the Mann-Whitney tests for unfiltered samples are listed in this report. The results of the analyses of filtered samples are shown in figure 8 and unfiltered samples in figure 9.

Examining the data from filtered samples only, the *p*-value calculated by the Mann-Whitney test was 0.0143, leading to the

rejection of the null hypothesis and the conclusion that calcium concentrations were significantly different between Picher mining district and background wells. Calcium concentrations in January 1993 in the background wells fell into a relatively narrow range between 28.9 and 33.7 mg/L, with a median of 30.7 mg/L. Eight of the ten wells in the mining district had calcium concentrations greater than 33.7 mg/L for the January sampling, including Cardin, Commerce 1 and Commerce 3, all three Picher wells, and Quapaw 2 and Quapaw 4. Quapaw 4 exceeded a calcium concentration of 33.7 mg/L only in January 1993; the calcium concentrations were less than 33.7 mg/L for the other five monthly samplings trips. Seven of the mining district wells (Cardin, Commerce 1 and Commerce 3, all three Picher wells, and Quapaw 2) had calcium concentrations greater than 33.7 mg/L for all six monthly sample-collection trips.

Magnesium

The *p*-value calculated by the Mann-Whitney test was 0.1416 for unfiltered samples sent to the contract laboratories, 0.0089 for unfiltered samples sent to the Kerr Laboratory, and 0.0079 for filtered samples sent to the Kerr Laboratory. The analyses for magnesium have the same problem as those for cal-

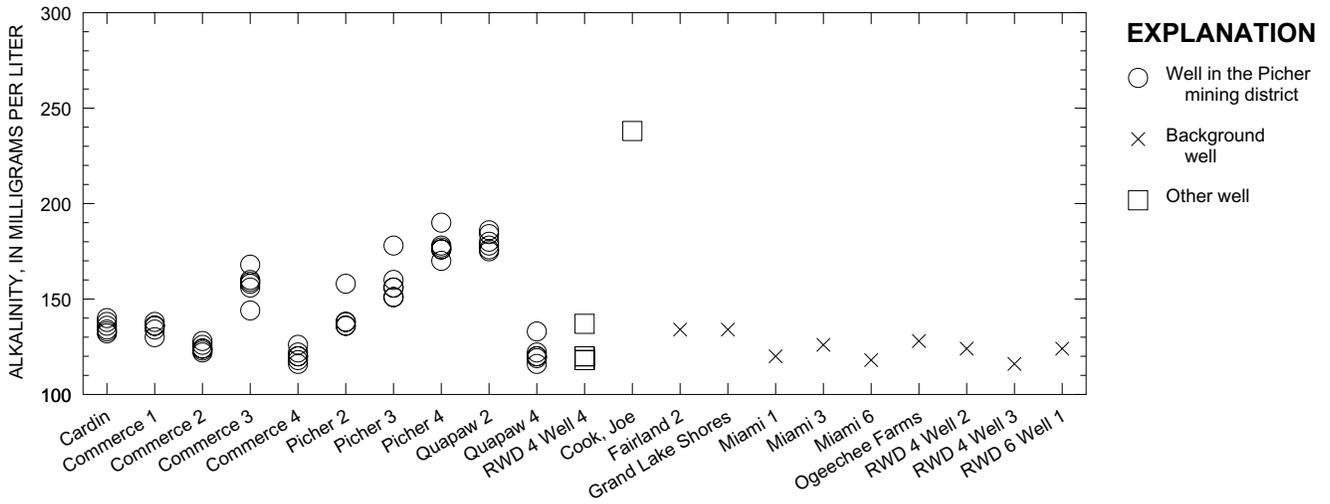


Figure 7. Alkalinity of water samples collected during the monthly sampling trips.

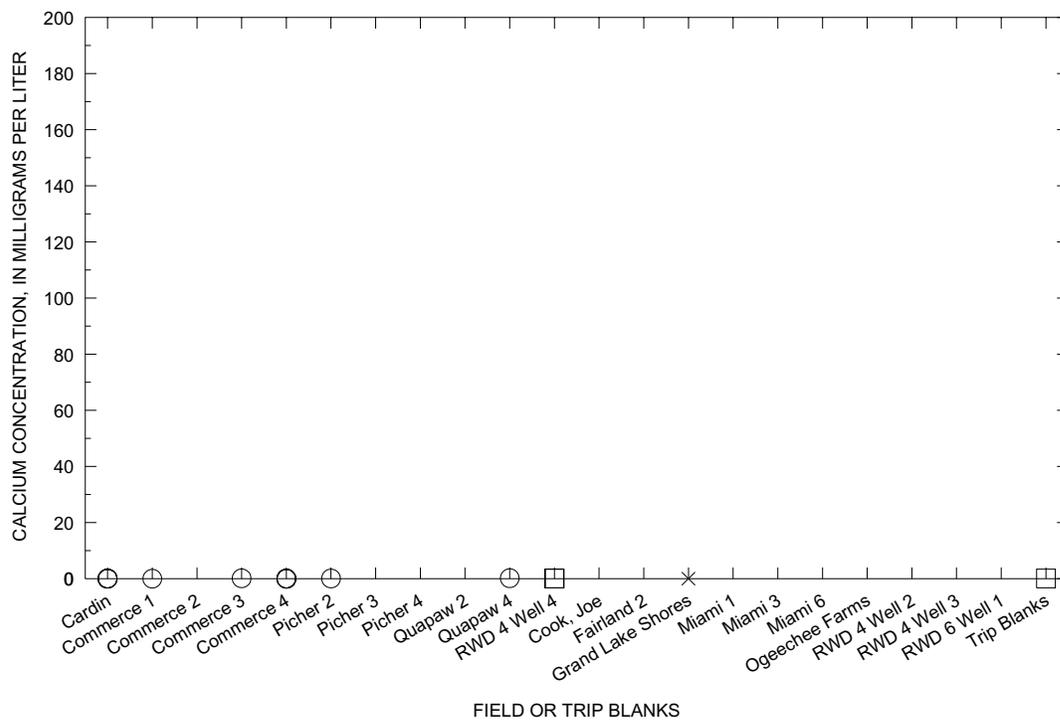
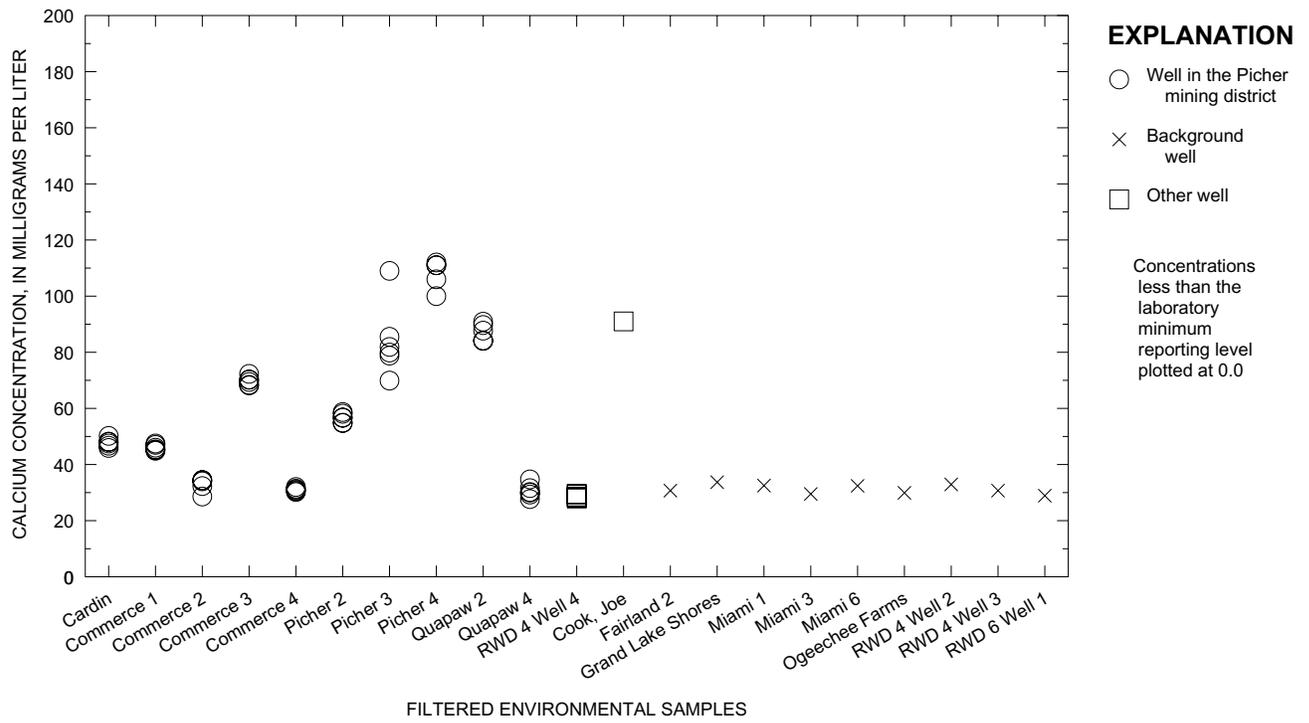


Figure 8. Calcium concentration in filtered environmental and blank samples collected during the monthly sampling trips.

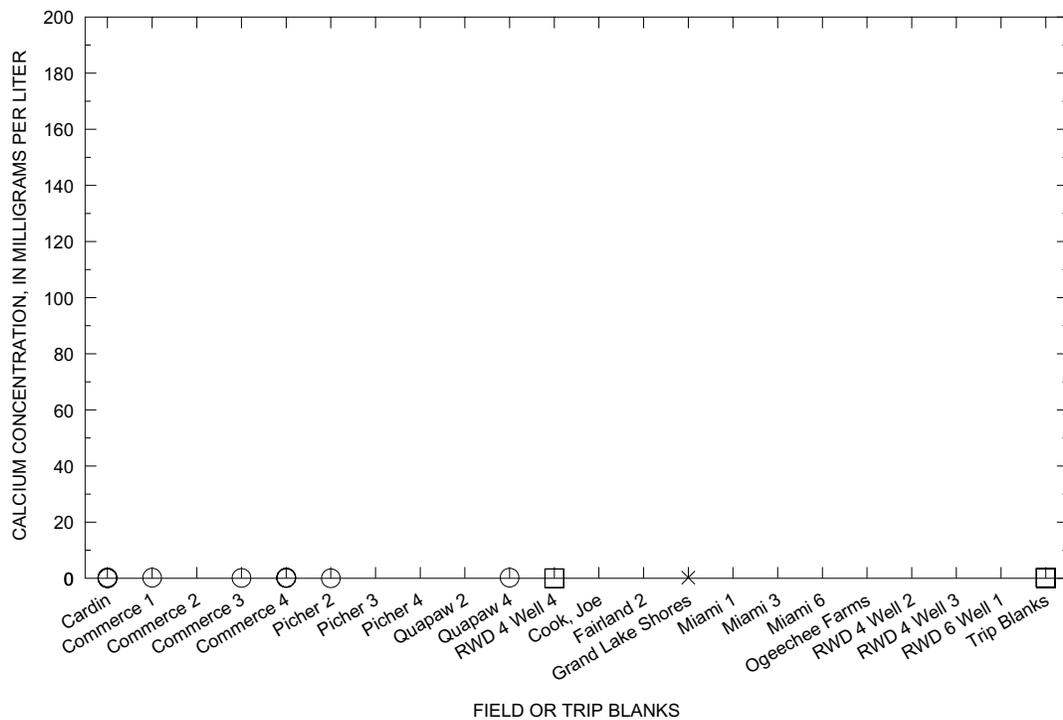
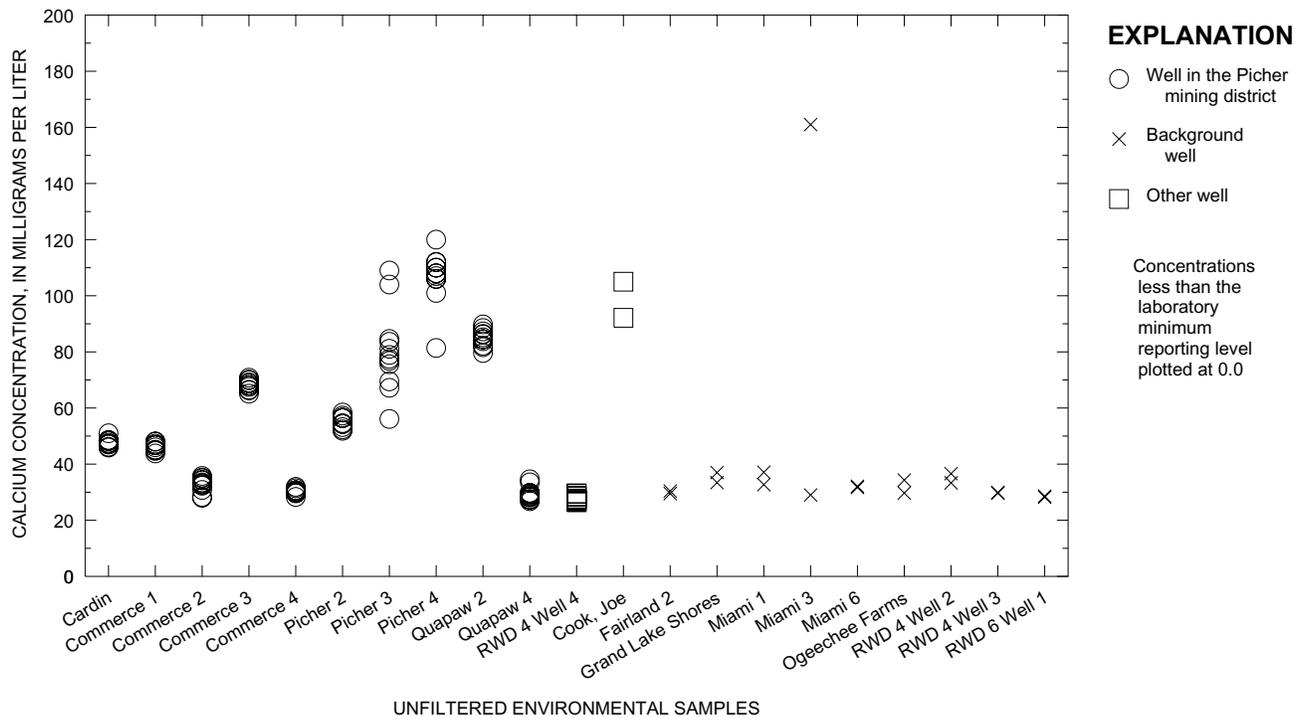


Figure 9. Calcium concentration in unfiltered environmental and blank samples collected during the monthly sampling trips.

cium, that of introduction of particulates from the well. The same unfiltered sample from Miami 3 that had the highest calcium concentration also had the highest magnesium concentration of any well, inside or outside the Picher mining district, for all monthly samplings. The magnesium concentrations for filtered samples are shown in figure 10 and for unfiltered samples in figure 11.

Examining the data from filtered samples only, the p -value calculated by the Mann-Whitney test was 0.0079, leading to the rejection of the null hypothesis and the conclusion that magnesium concentrations were significantly different between Picher mining district and background wells. Magnesium concentrations in January 1993 in the background wells fell into a relatively narrow range between 13.2 and 15.5 mg/L, with a median of 14.2 mg/L. Eight of the ten wells in the mining district had magnesium concentrations greater than 15.5 mg/L for the January sampling, including Cardin, Commerce 1 and Commerce 3, all three Picher wells, and Quapaw 2 and Quapaw 4. Quapaw 4 exceeded a magnesium concentration of 15.5 mg/L only in January 1993; the magnesium concentrations were less than 15.5 mg/L for the other five monthly samplings trips. Seven of the mining district wells (Cardin, Commerce 1 and Commerce 3, all three Picher wells, and Quapaw 2) had magnesium concentrations greater than 15.5 mg/L for all six monthly sample-collection trips.

Bicarbonate

The p -values calculated by the Mann-Whitney test for bicarbonate are identical in every respect to those calculated for alkalinity, because the alkalinity was assumed to be all due to bicarbonate. As with alkalinity, the p -value was 0.0268, leading to the rejection of the null hypothesis and the conclusion that the bicarbonate concentrations were significantly different between Picher mining district and background wells. The bicarbonate concentrations for all wells is shown in figure 12.

Sulfate

The p -value calculated by the Mann-Whitney test was 0.0100 for unfiltered samples sent to the contract laboratories, 0.0002 for unfiltered samples sent to the Kerr Laboratory, and 0.0002 for filtered samples sent to the Kerr Laboratory. All p -values were less than a significance level of 0.05, leading to the rejection of the null hypothesis and the conclusion that sulfate concentrations were significantly different between Picher mining district and background wells. Sulfate concentrations in unfiltered samples apparently were affected by particulate matter, as Miami 6 and Rural Water District 6 Well 1 show large differences between filtered and unfiltered samples. In spite of the problem with particulate matter, the null hypothesis still was rejected. The results of the analyses of filtered samples are shown in figure 13 and unfiltered samples in figure 14.

Examining the data from filtered samples only, sulfate concentrations in January 1993 in background wells fell into a

relatively narrow range between 10.6 and 13.2 mg/L (excluding the Cook well, which is not producing water exclusively from the Roubidoux aquifer), with a median of 12.1 mg/L. All ten wells in the mining district had sulfate concentration greater than 13.2 mg/L for the January sampling, and nine of the ten wells, excluding Quapaw 4, exceeded a sulfate concentration of 13.2 mg/L for all monthly samplings trips. Quapaw 4 exceeded 13.2 mg/L sulfate for five of six monthly sample-collection trips; the sulfate concentration for Quapaw 4 for the November 1993 sampling was 10.8 mg/L.

Cadmium

Many of the analyses for cadmium were censored and as a result, a p -value for a Mann-Whitney test could not be calculated for unfiltered samples sent to the contract laboratories. The quality-assurance data indicated a problem with filtered samples, so the Mann-Whitney test was calculated only for unfiltered samples sent to the Kerr Laboratory. The p -value calculated by the Mann-Whitney test was 0.4796 for unfiltered samples sent to the Kerr Laboratory. Using a significance level of 0.05, the null hypothesis was accepted, indicating that cadmium concentrations were not significantly different between Picher mining district and background wells. Although the Mann-Whitney calculated p -value was greater than 0.05, it is still possible that the cadmium concentrations in water produced by mining district wells are different from background wells. Many of the analyses for cadmium were censored and were treated as equal between mining district and background wells. Resolving the differences in cadmium concentrations between mining district and background wells requires a lower minimum reporting level. The results of the analyses of filtered samples are shown in figure 15 and unfiltered samples in figure 16. Censored data are plotted at a concentration of 0.0 on these figures.

Copper

The quality-assurance data indicated a problem with unfiltered samples, so the Mann-Whitney test was calculated only for filtered samples. The p -value calculated by the Mann-Whitney test was 0.3428 for filtered samples sent to the Kerr Laboratory. Using a significance level of 0.05, the null hypothesis was accepted, indicating that no differences exist in copper concentration between mining district and background wells. However, as with cadmium, most of the data (for both mining district and background wells) are censored, and it is possible that there are differences between the two groups. Lower laboratory reporting levels are required to determine if differences exist. The results of the analyses of filtered samples are shown in figure 17 and unfiltered samples in figure 18. Censored data are plotted at a concentration of 0.0 on these figures.

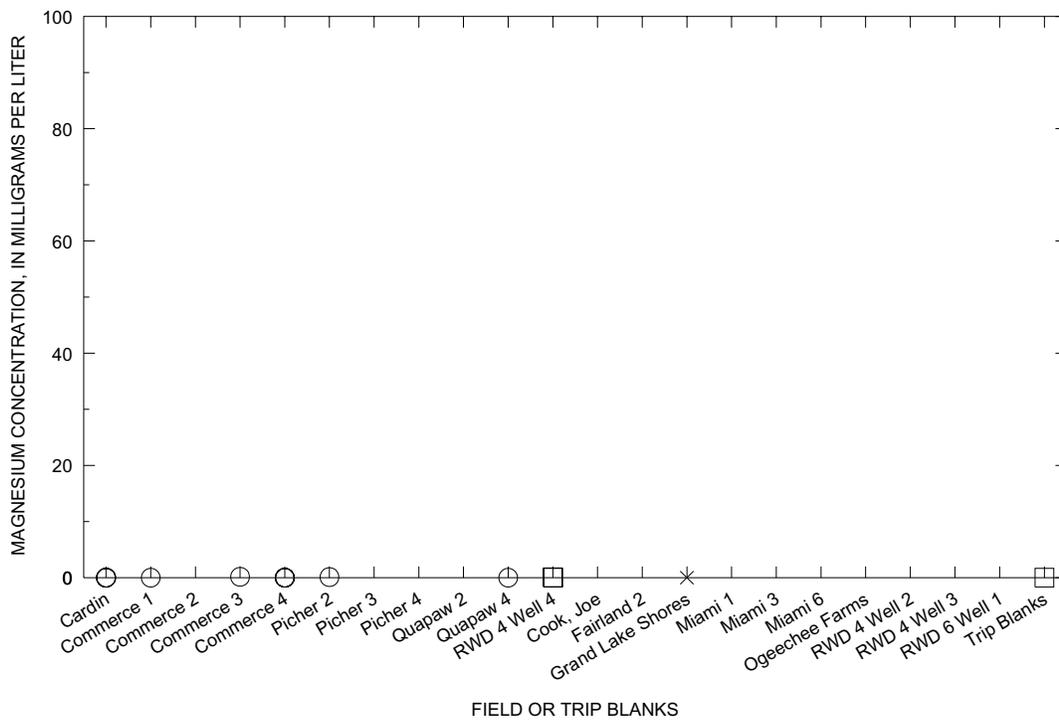
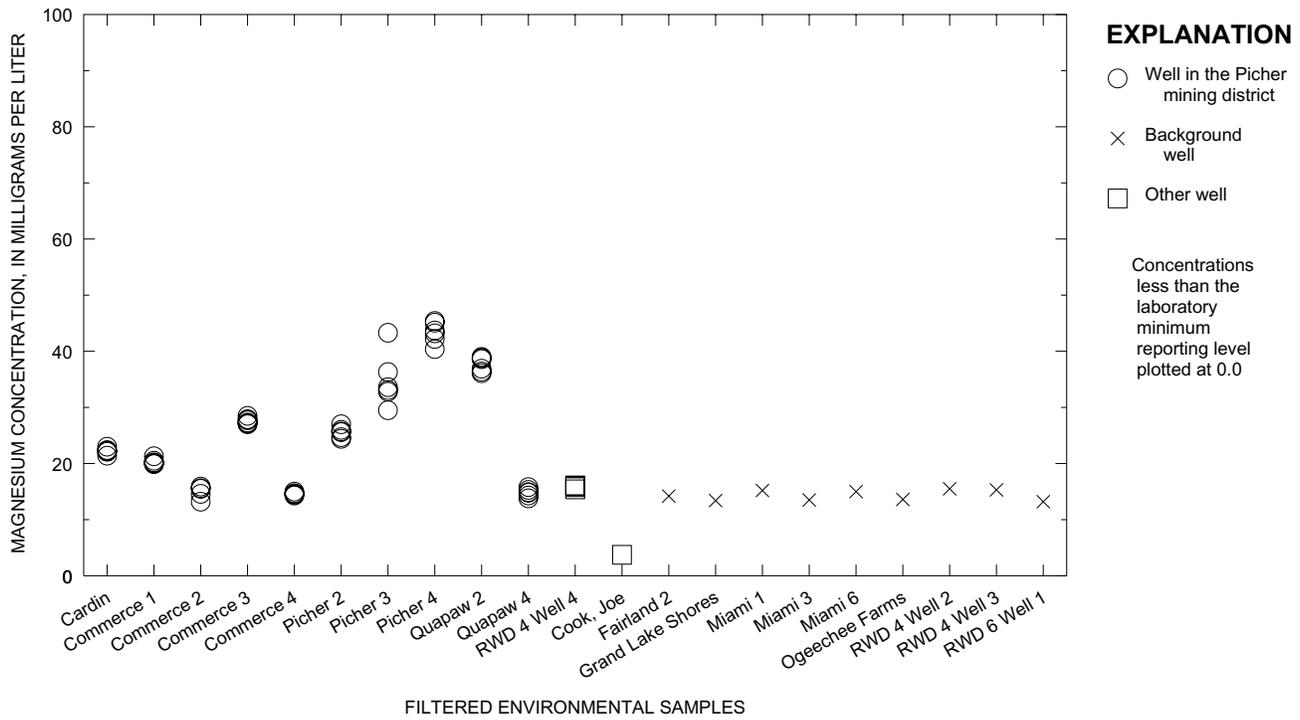


Figure 10. Magnesium concentration in filtered environmental and blank samples collected during the monthly sampling trips.

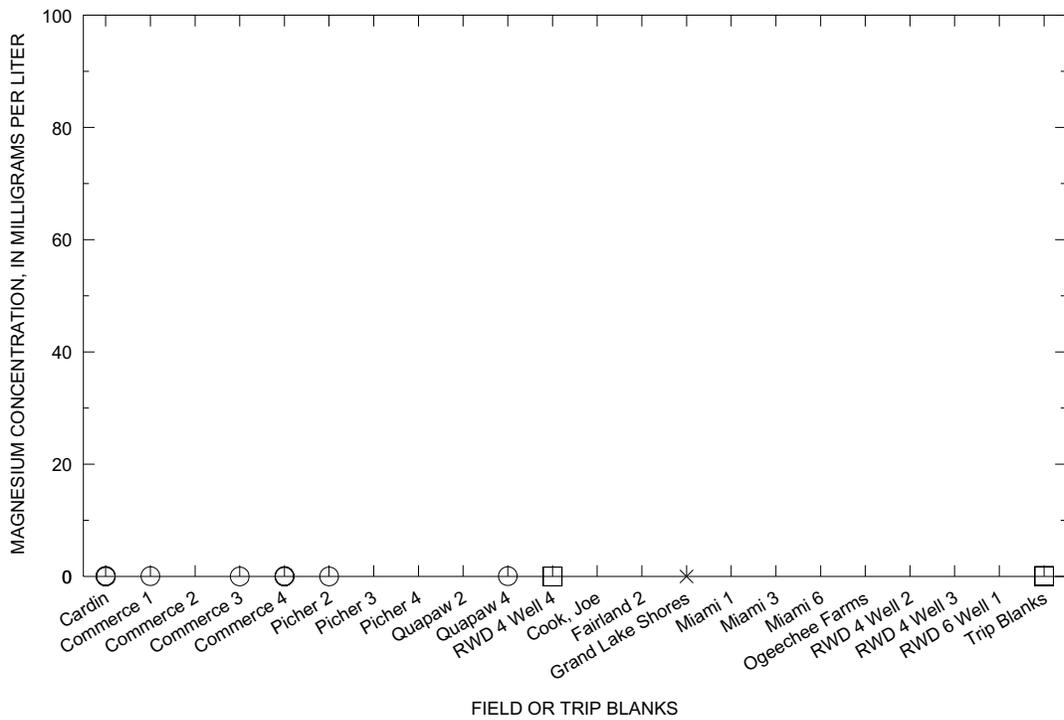
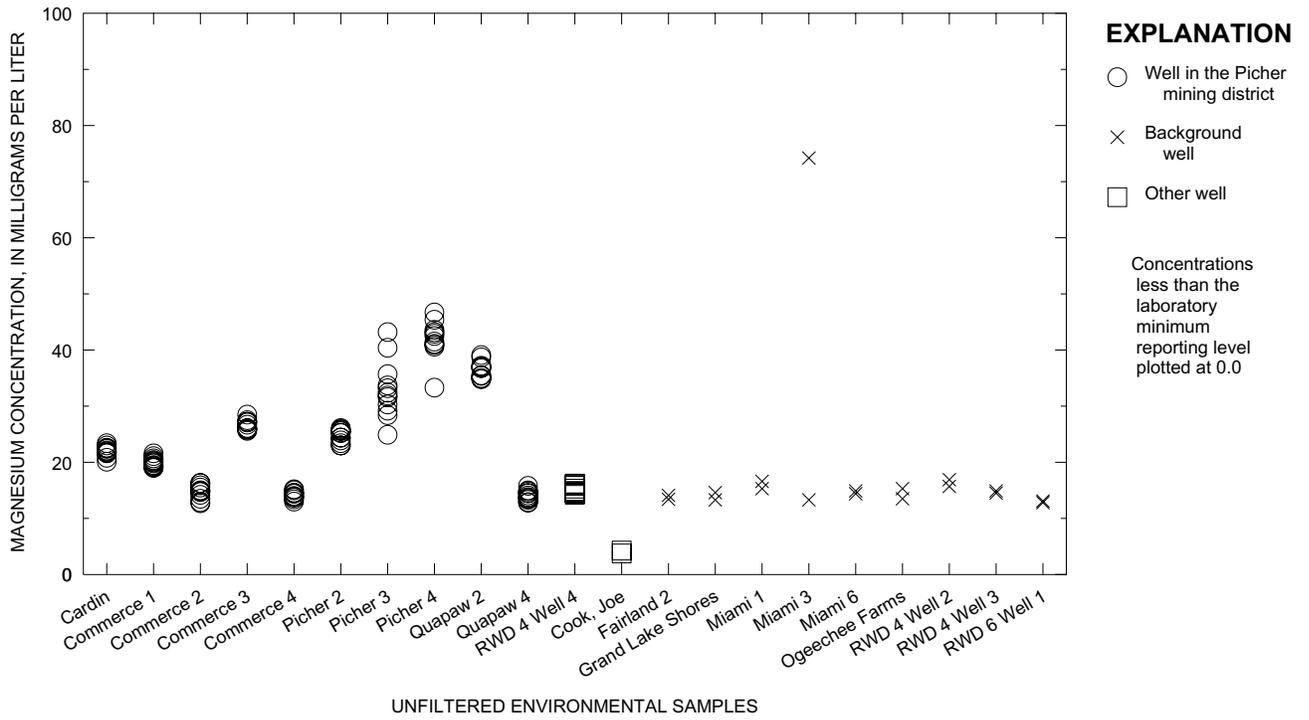


Figure 11. Magnesium concentration in unfiltered environmental and blank samples collected during the monthly sampling trips.

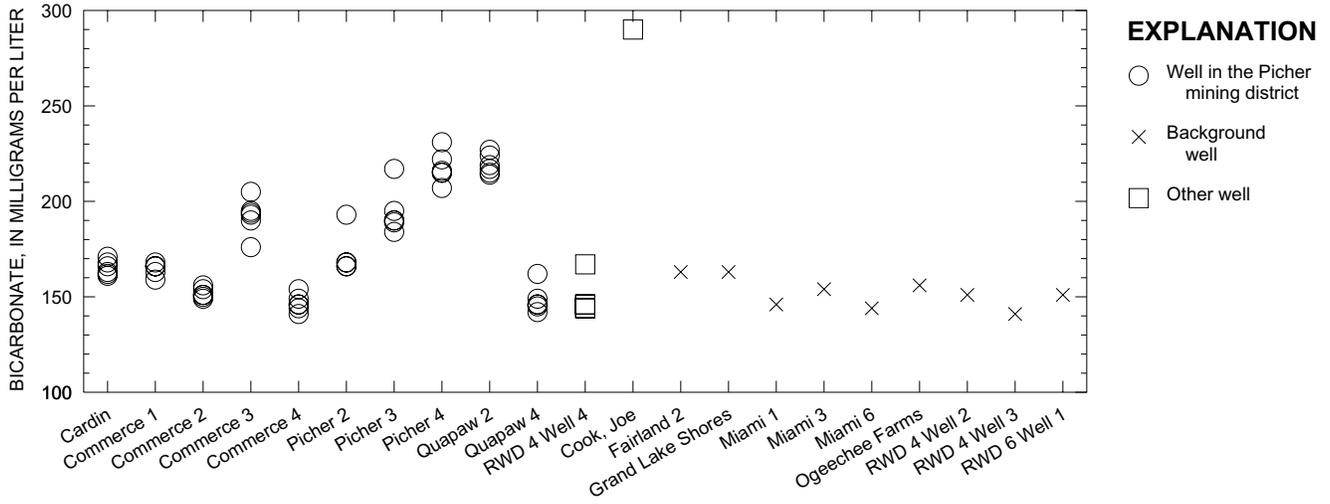


Figure 12. Bicarbonate concentration in water samples collected during the monthly sampling trips.

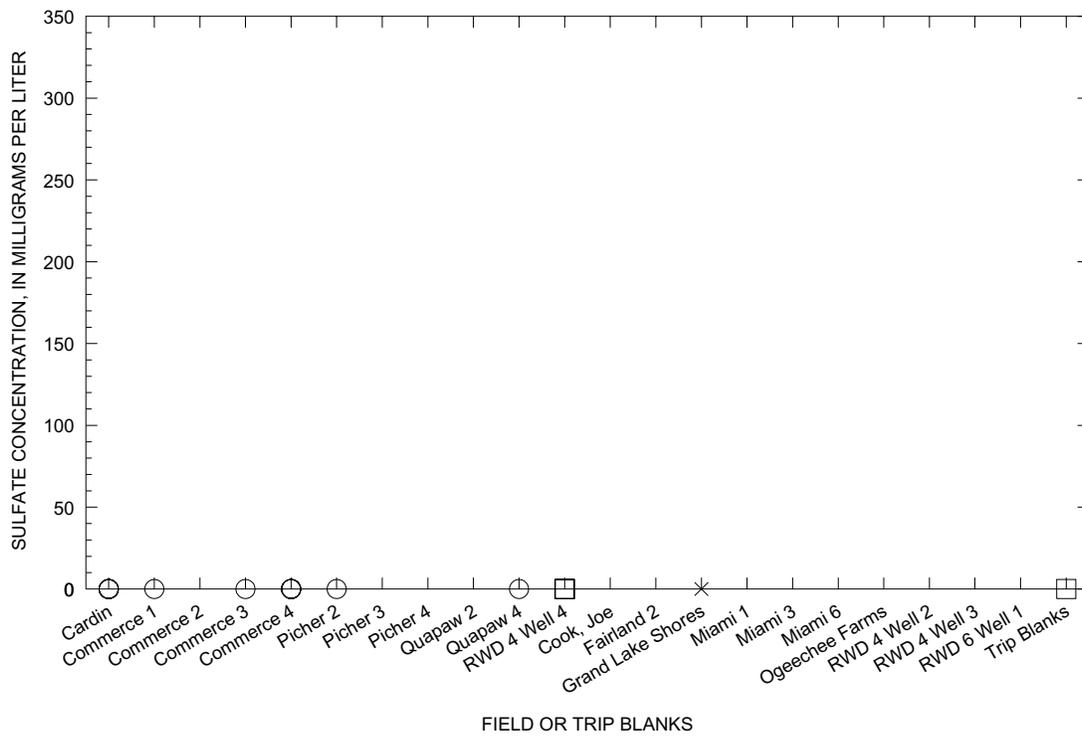
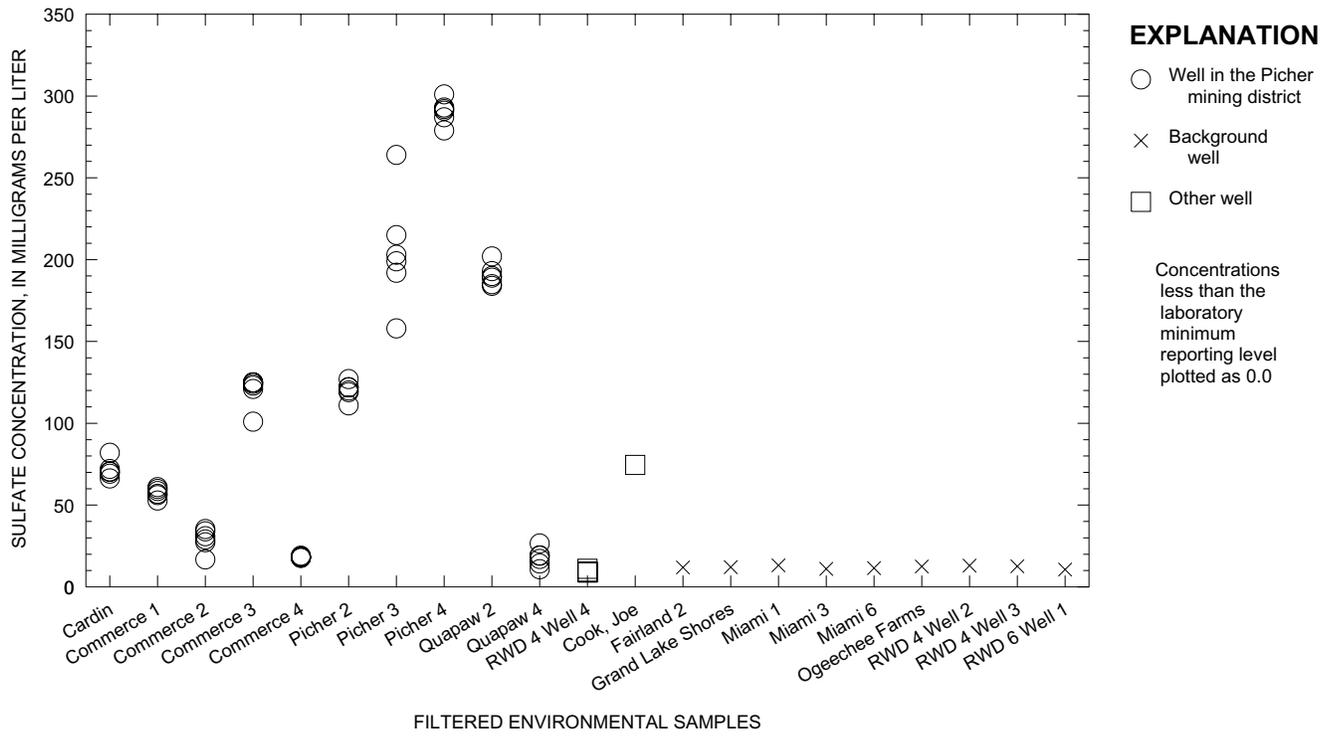


Figure 13. Sulfate concentration in filtered environmental and blank samples collected during the monthly sampling trips.

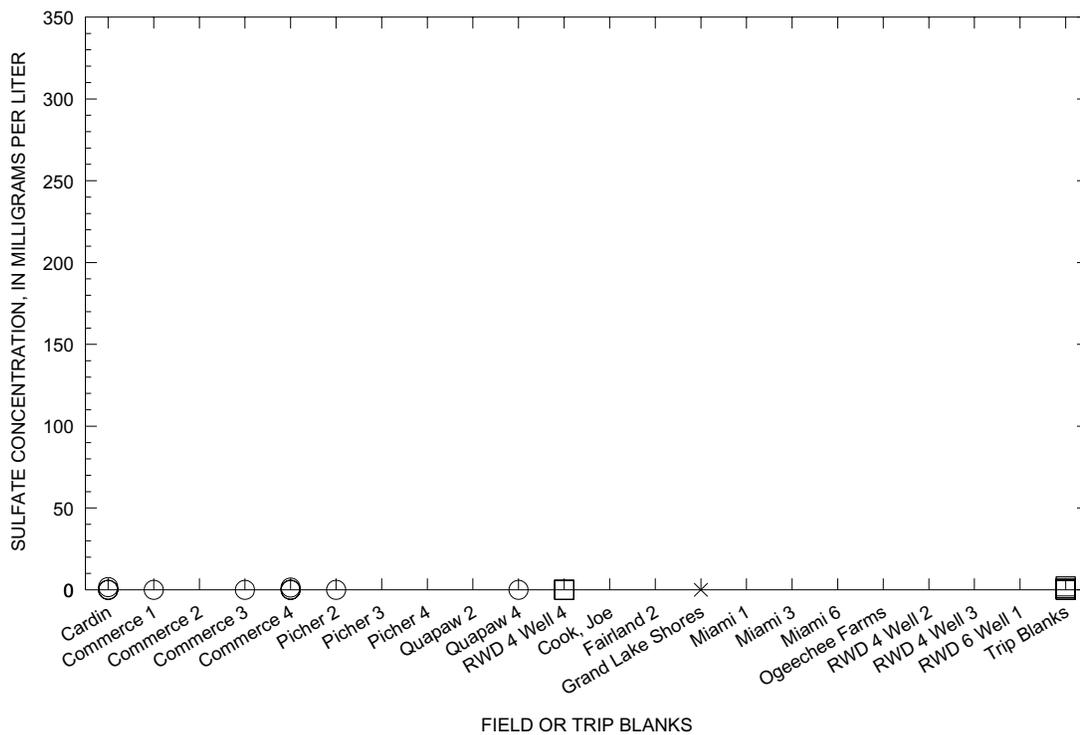
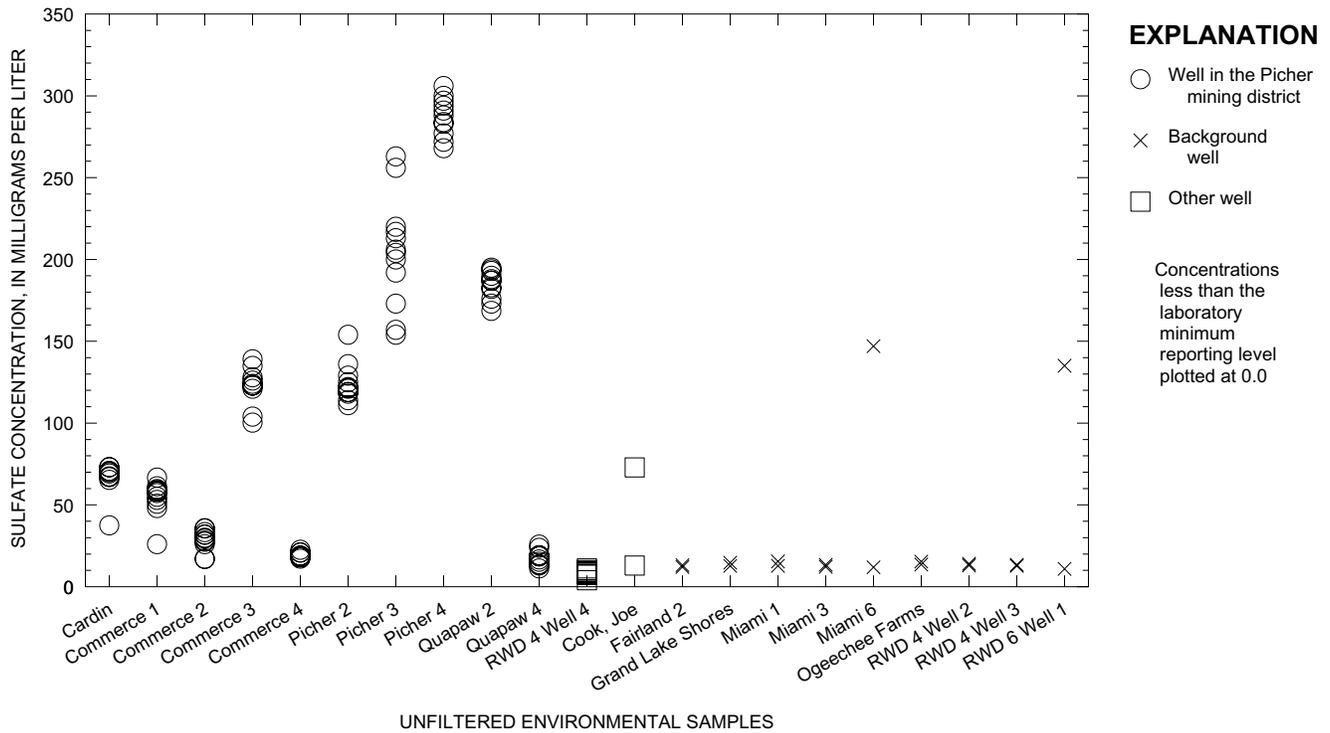


Figure 14. Sulfate concentration in unfiltered environmental and blank samples collected during the monthly sampling trips.

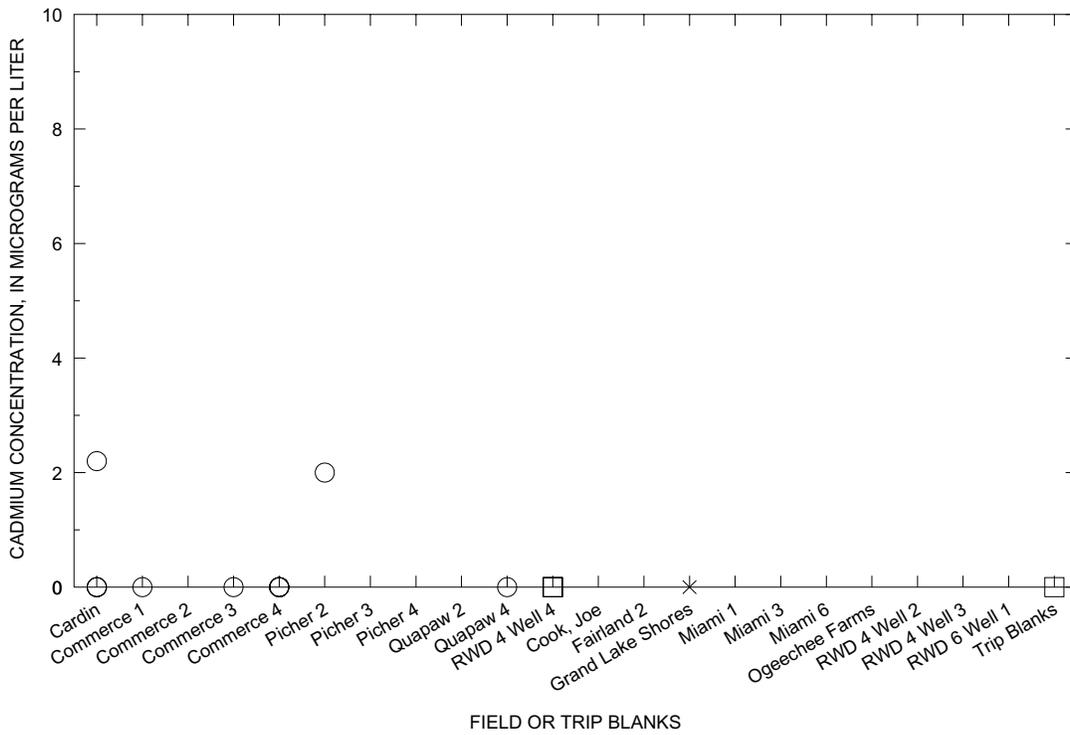
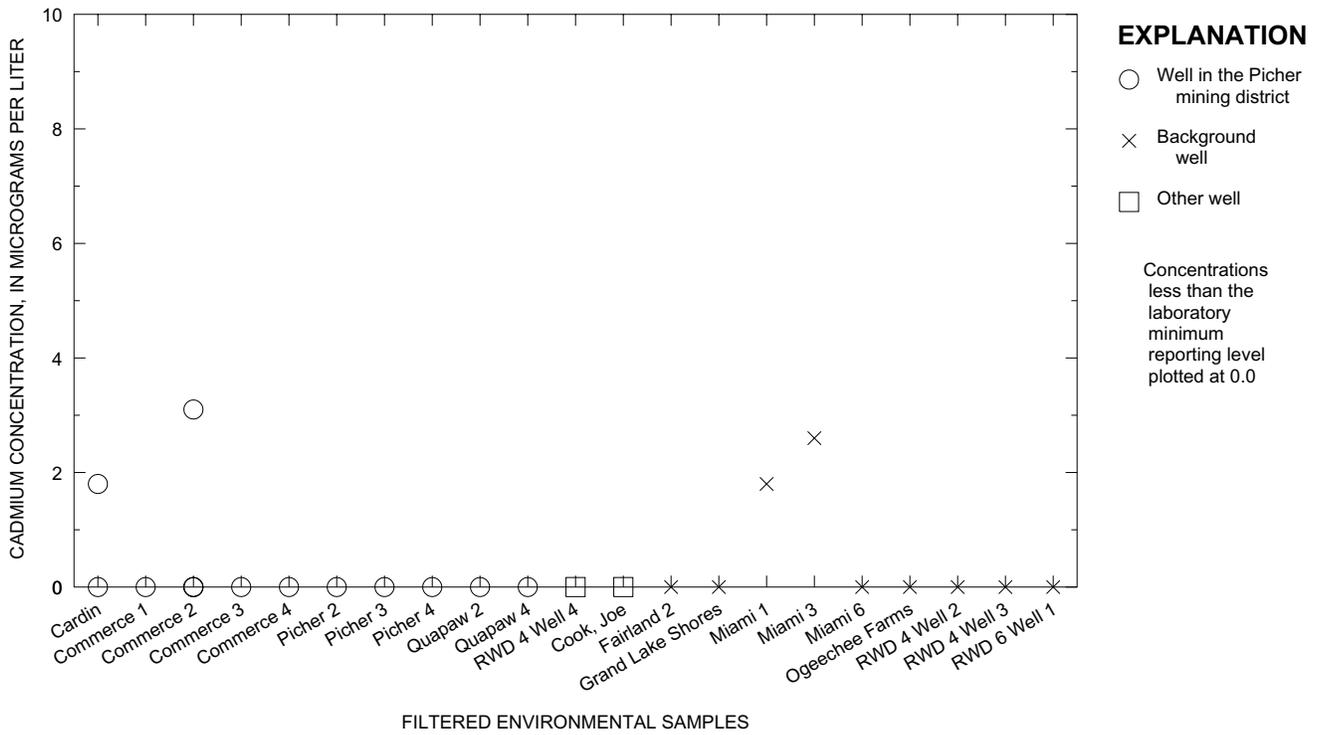


Figure 15. Cadmium concentration in filtered environmental and blank samples collected during the monthly sampling trips.

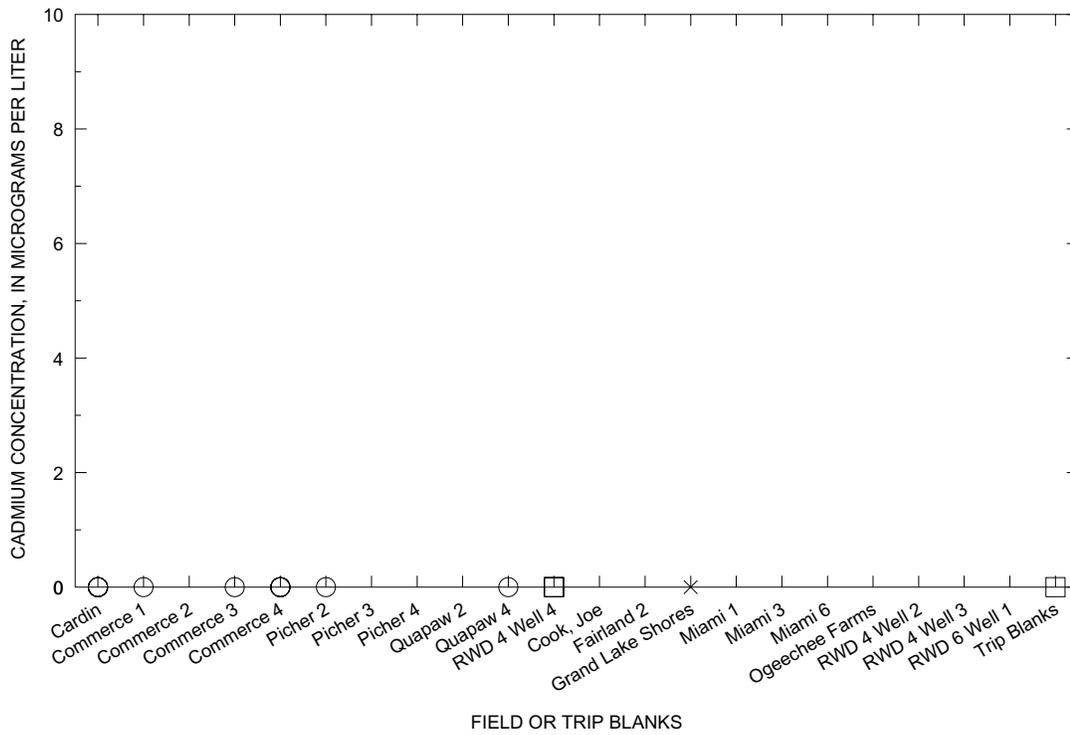
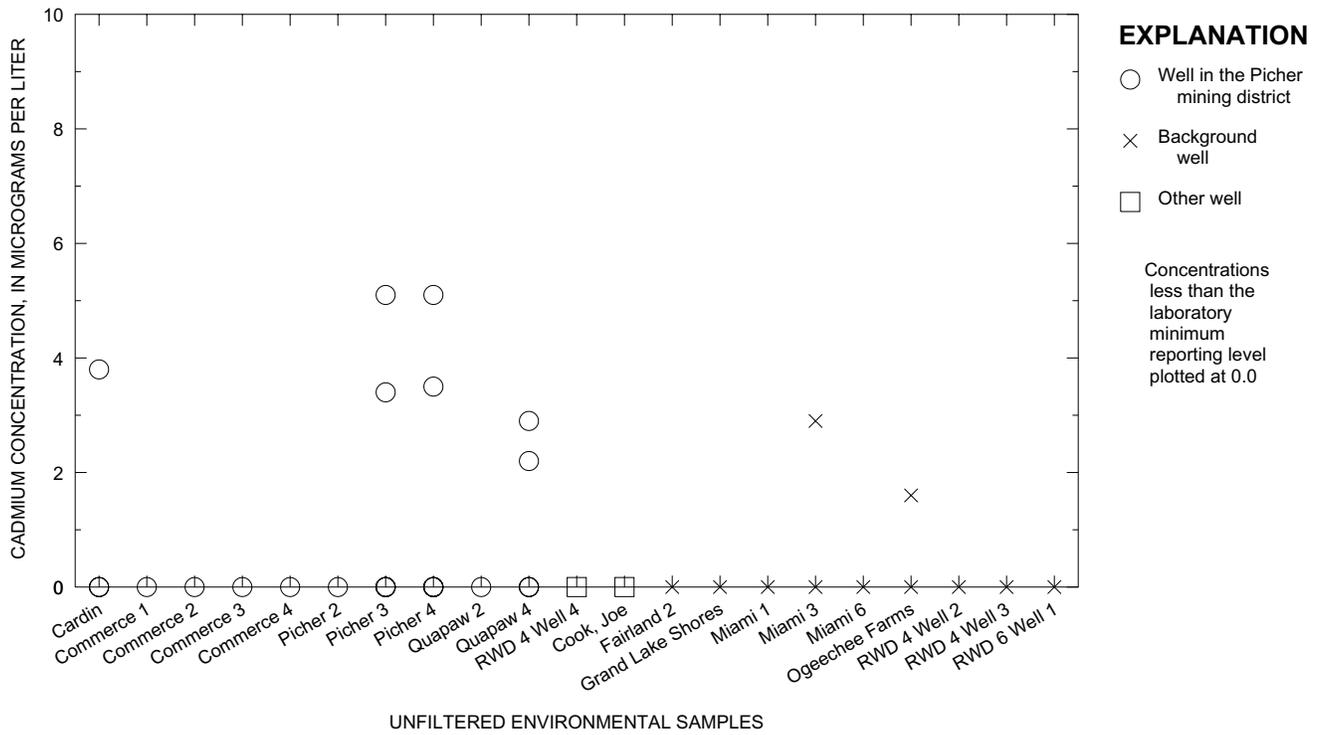


Figure 16. Cadmium concentration in unfiltered environmental and blank samples collected during the monthly sampling trips.

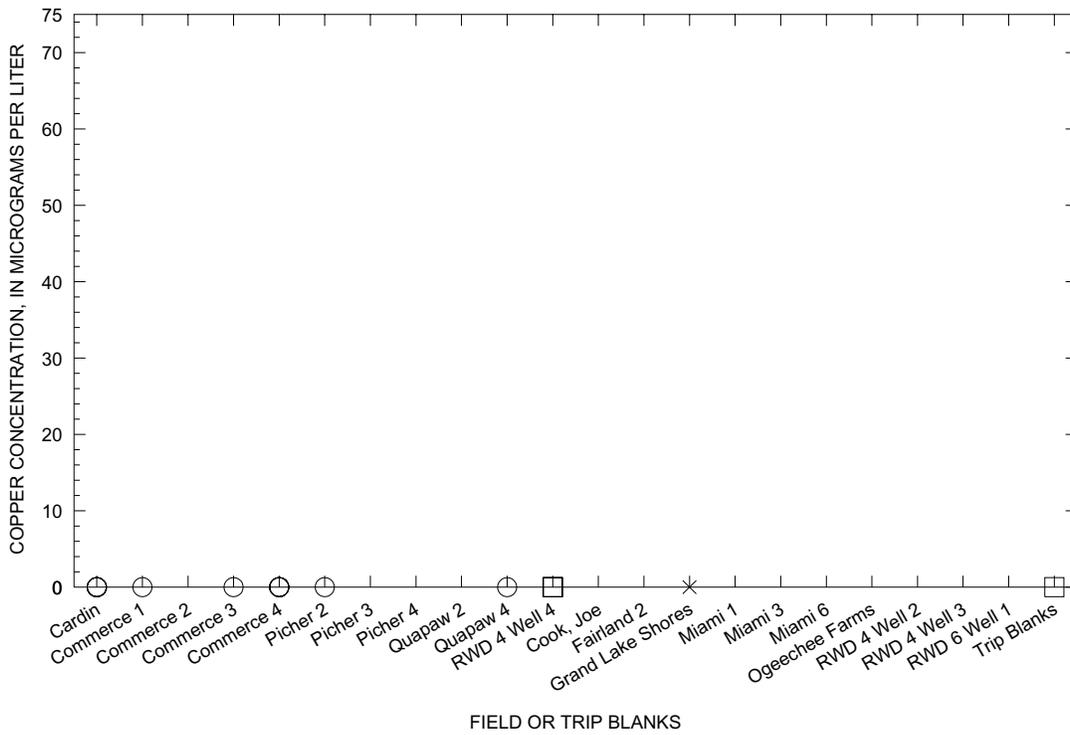
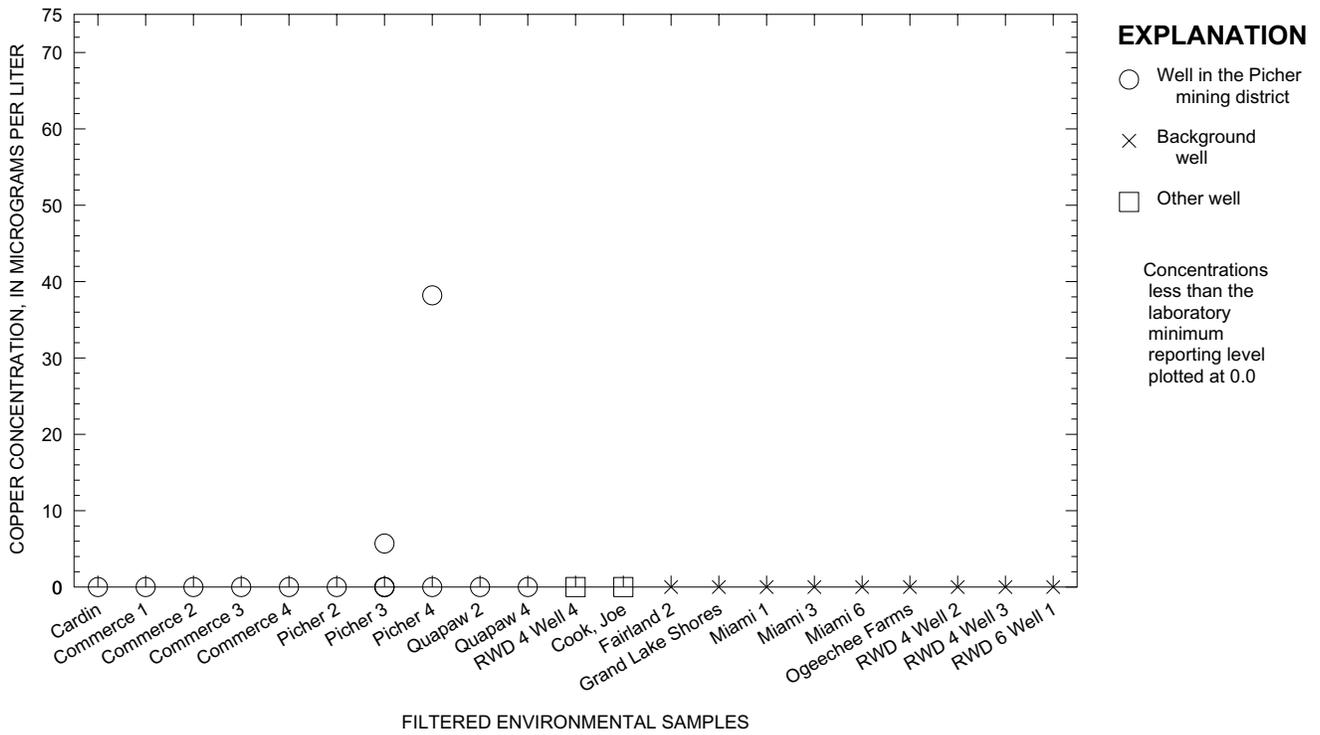


Figure 17. Copper concentration in filtered environmental and blank samples collected during the monthly sampling trips.

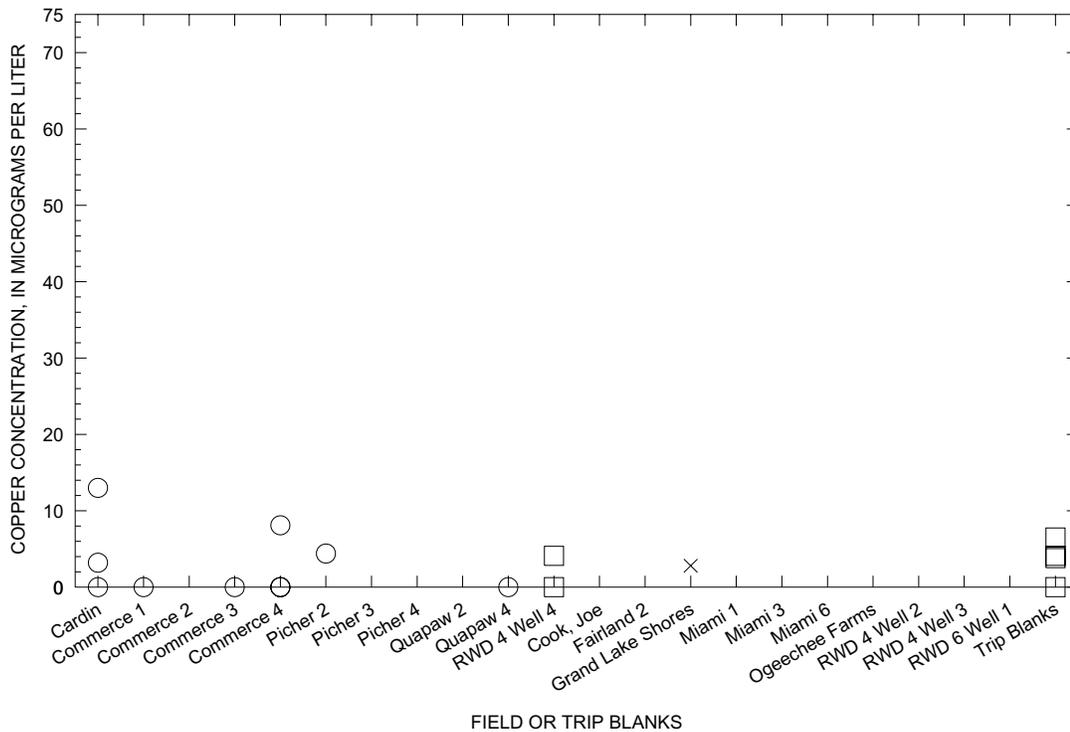
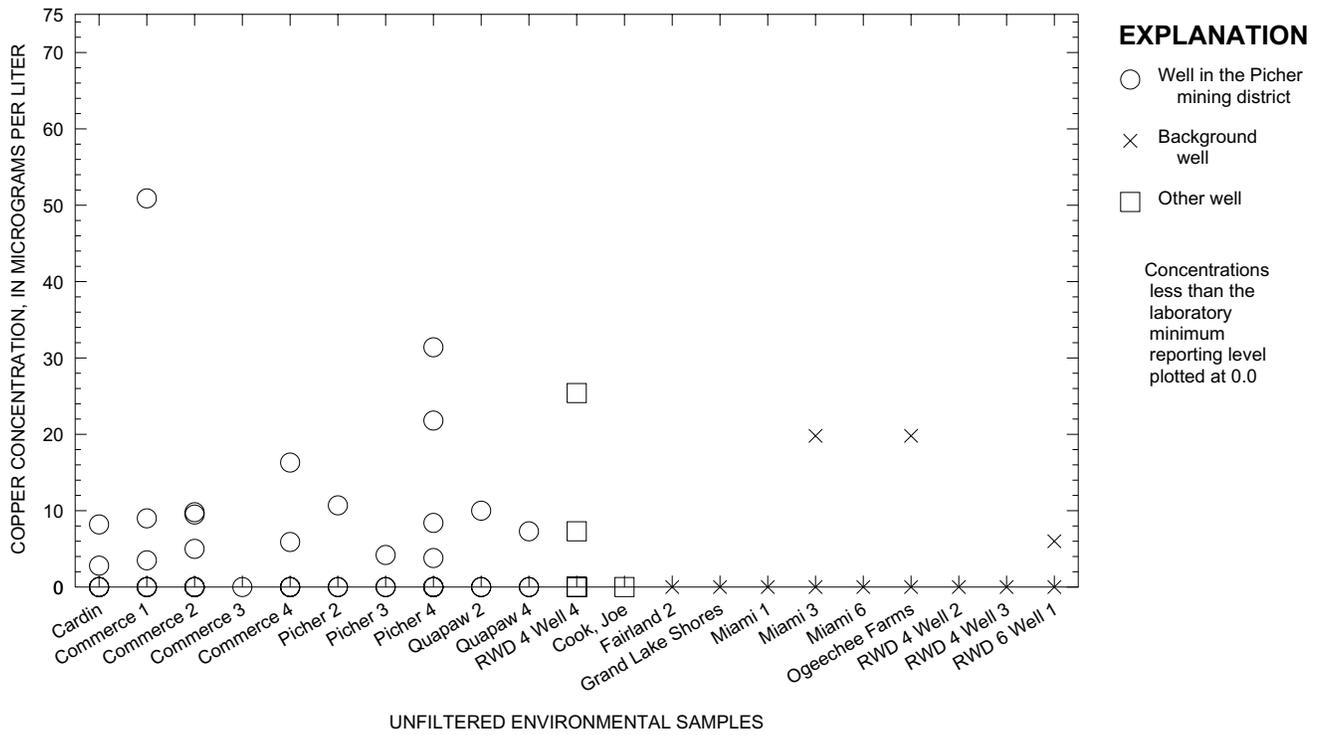


Figure 18. Copper concentration in unfiltered environmental and blank samples collected during the monthly sampling trips.

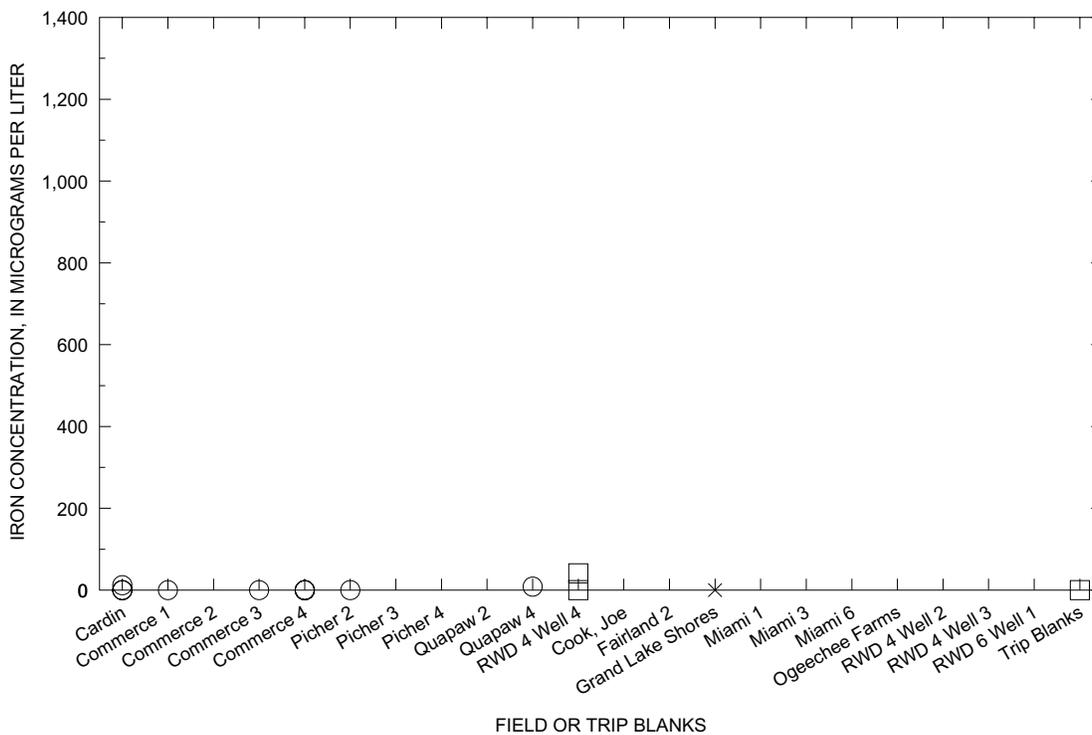
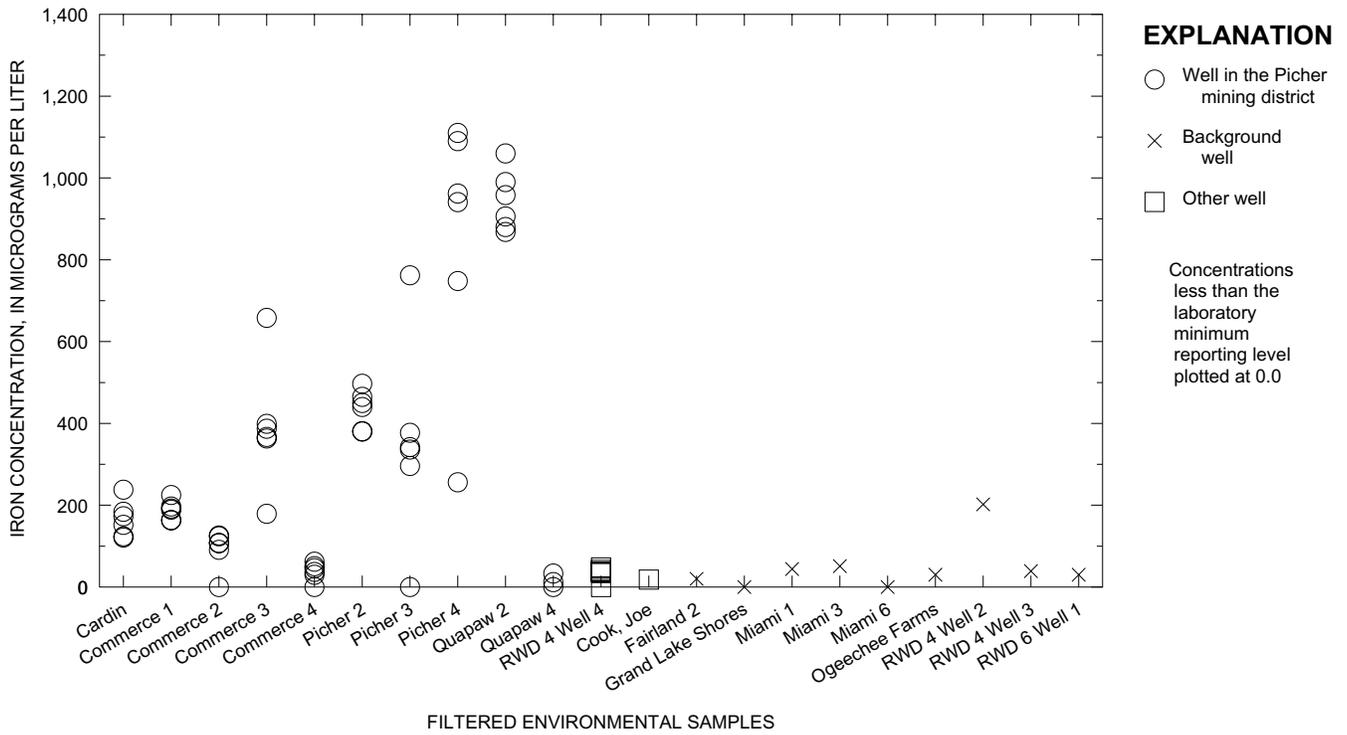


Figure 19. Iron concentration in filtered environmental and blank samples collected during the monthly sampling trips.

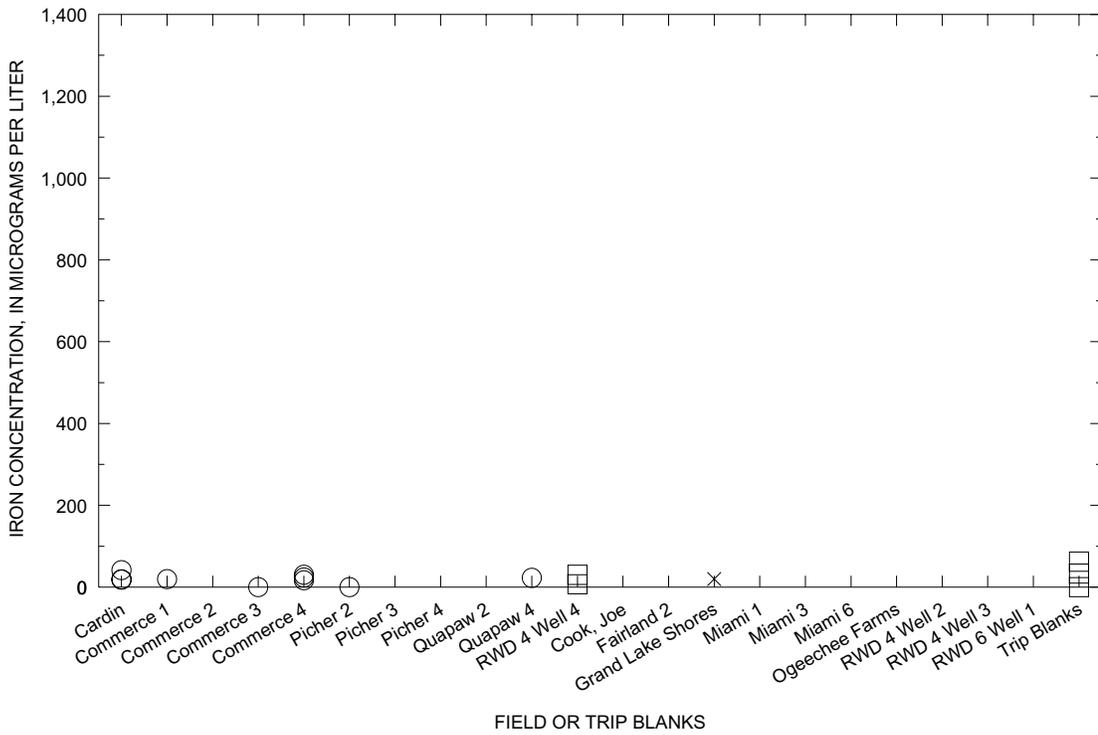
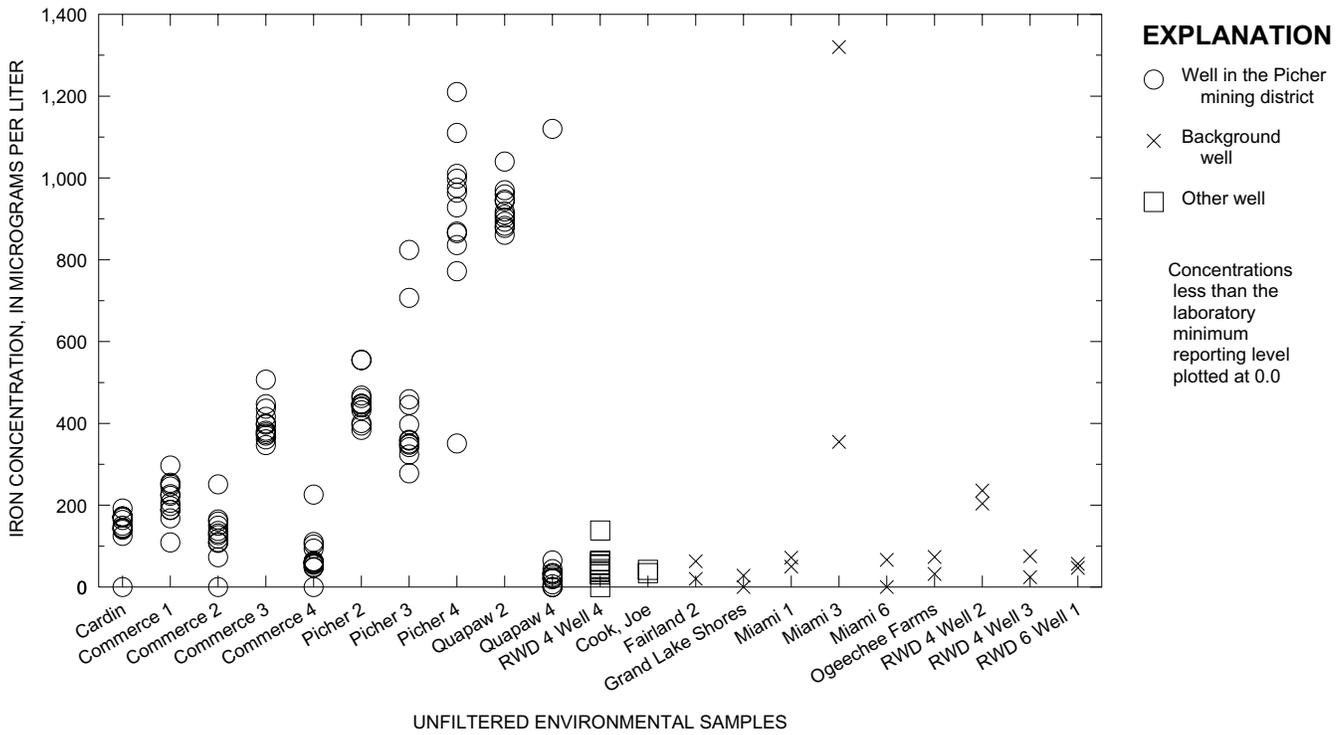


Figure 20. Iron concentration in unfiltered environmental and blank samples collected during the monthly sampling trips.

Iron

The p -value calculated by the Mann-Whitney test was 0.0500 for unfiltered samples sent to the contract laboratories, 0.0177 for unfiltered samples sent to the Kerr Laboratory, and 0.0070 for filtered samples sent to the Kerr Laboratory, leading to the rejection of the null hypothesis and the conclusion that iron concentrations were significantly different between Picher mining district and background wells. As with other constituents, iron concentrations in unfiltered samples are affected by particulate matter. The range in concentrations of iron in unfiltered sample sent to the contract laboratories were much greater than the range in concentrations for unfiltered or filtered samples sent to the Kerr Laboratory. In spite of the problem with particulate matter, the null hypothesis still was rejected. The results of the analyses of filtered samples are shown in figure 19 and unfiltered samples in figure 20. Censored data are plotted at a concentration of 0.0 on these figures.

Considering the data from filtered samples only, iron concentrations in January 1993 in the background wells ranged from $<11 \mu\text{g/L}$ to $202 \mu\text{g/L}$. The highest iron concentration of $202 \mu\text{g/L}$ in filtered samples from background wells was measured in RWD 4 Well 2, which is anomalously large for the background wells. The next highest iron concentration in a background well was $51 \mu\text{g/L}$. Even with the problem caused by particulate matter in unfiltered samples and the anomalously large iron concentration in RWD 4 Well 2, the scatter plots of iron concentrations in filtered (fig. 19) and unfiltered samples (fig. 20) show that iron concentrations in samples from wells in the Picher mining district are much greater than the iron concentrations in samples from background wells.

Lead

Mann-Whitney test statistics were not calculated for lead for any samples. Lead concentrations for filtered samples (fig. 21) were all censored, so the Mann-Whitney test statistics could not be calculated. Quality-assurance blank samples for lead showed sample contamination for lead at the same concentrations as measured in filtered and unfiltered environmental samples (fig. 22). One trip blank (not shown on figure 22) had a lead concentration of $17,800 \mu\text{g/L}$. Thus, the lead concentrations in environmental samples may have been caused by sample contamination. All the wells in the mining district are in the vicinity of abandoned mines and spoil piles, and sampling for lead at small concentrations proved to be difficult. Censored data are plotted at a concentration of 0.0 on these figures.

Manganese

The p -value calculated by the Mann-Whitney test was 0.0070 for unfiltered samples sent to the contract laboratories, 0.0476 for unfiltered samples sent to the Kerr Laboratory, and 0.0300 for filtered samples sent to the Kerr Laboratory, leading to the rejection of the null hypothesis and the conclusion that

manganese concentrations were significantly different between Picher mining district and background wells. As with other constituents, manganese concentrations in unfiltered samples are affected by particulate matter. The concentrations of manganese in the two unfiltered samples generally were greater than the corresponding unfiltered sample. In spite of the problem with particulate matter, the null hypothesis still was rejected. The results of the analyses of filtered samples are shown in figure 23 and unfiltered samples in figure 24. Censored data are plotted at a concentration of 0.0 on these figures.

Examining the data from filtered samples only, manganese concentrations in January 1993 were below the laboratory minimum reporting level of $2.3 \mu\text{g/L}$ in all background wells except Miami 3, where the manganese concentration was $6.1 \mu\text{g/L}$. Manganese concentrations were above the minimum reporting level for all wells in the mining district for the majority of the monthly sample-collection trips, except for Quapaw 4, where the manganese concentration exceeded the minimum reporting level during one monthly sampling; Commerce 2, where the minimum reporting level was exceeded during two monthly samplings; and Commerce 4, where the minimum reporting level was exceeded during three monthly samplings.

Nickel

The p -value calculated by the Mann-Whitney test was 0.6735 for unfiltered samples sent to the contract laboratories, 0.2383 for unfiltered samples sent to the Kerr Laboratory, and 0.1084 for filtered samples sent to the Kerr Laboratory. Using a significance level of 0.05, the null hypothesis was accepted for all samples, indicating that nickel concentrations were not significantly different between Picher mining district and background wells. The results of the analyses of filtered samples are shown in figure 25 and unfiltered samples in figure 26. Censored data are plotted at a concentration of 0.0 on these figures.

The results of nickel analyses require some qualification. Two field blank samples (one filtered and one unfiltered) prepared at the Cardin well showed contamination with nickel at about the same concentration as environmental samples. The Cardin well is located directly below the metal Cardin water tower, and the area immediately adjacent to the Cardin well is littered with many metal salvage items. It is possible the environment around this well resulted in contamination of some samples during collection.

The unfiltered samples analyzed for nickel appear to be affected by particulate matter. The unfiltered samples taken at Miami 3, where particulate matter was especially notable, have nickel concentrations much higher than the filtered sample taken at the same time.

Thus, although the Mann-Whitney calculated p -value was greater than 0.05 for all samples, it is still possible that the nickel concentrations in water produced by mining district wells are different from background wells. Many of the analyses for nickel were censored, regardless of which laboratory was used or if the samples were filtered. Resolving the differ-

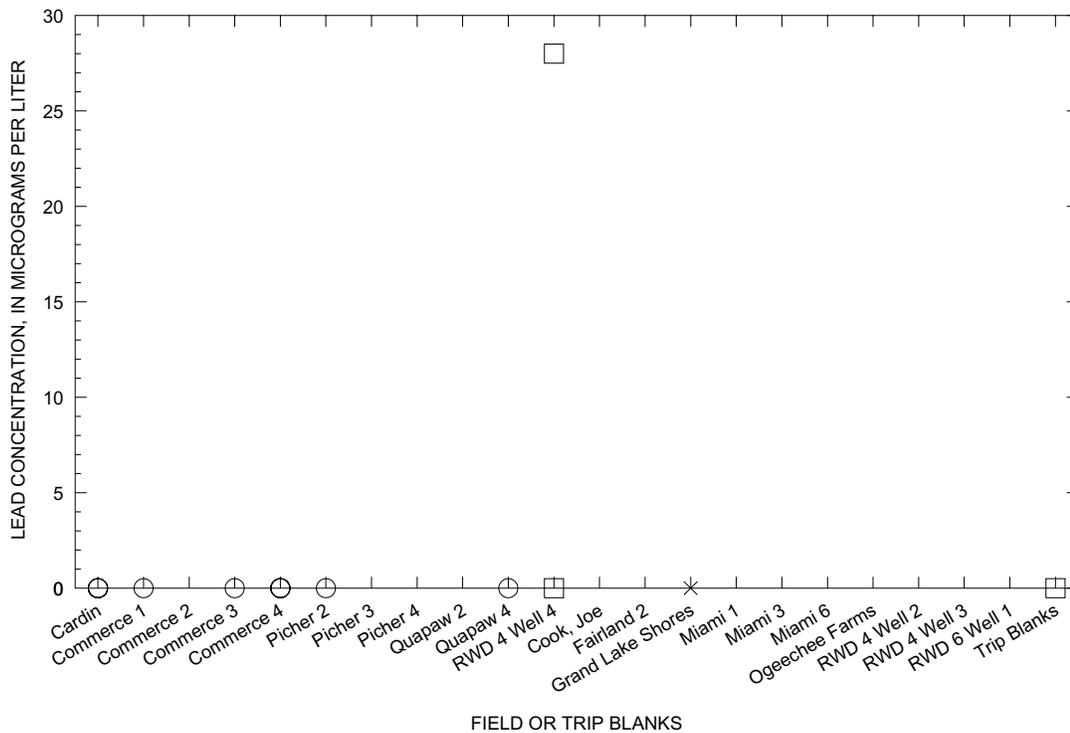
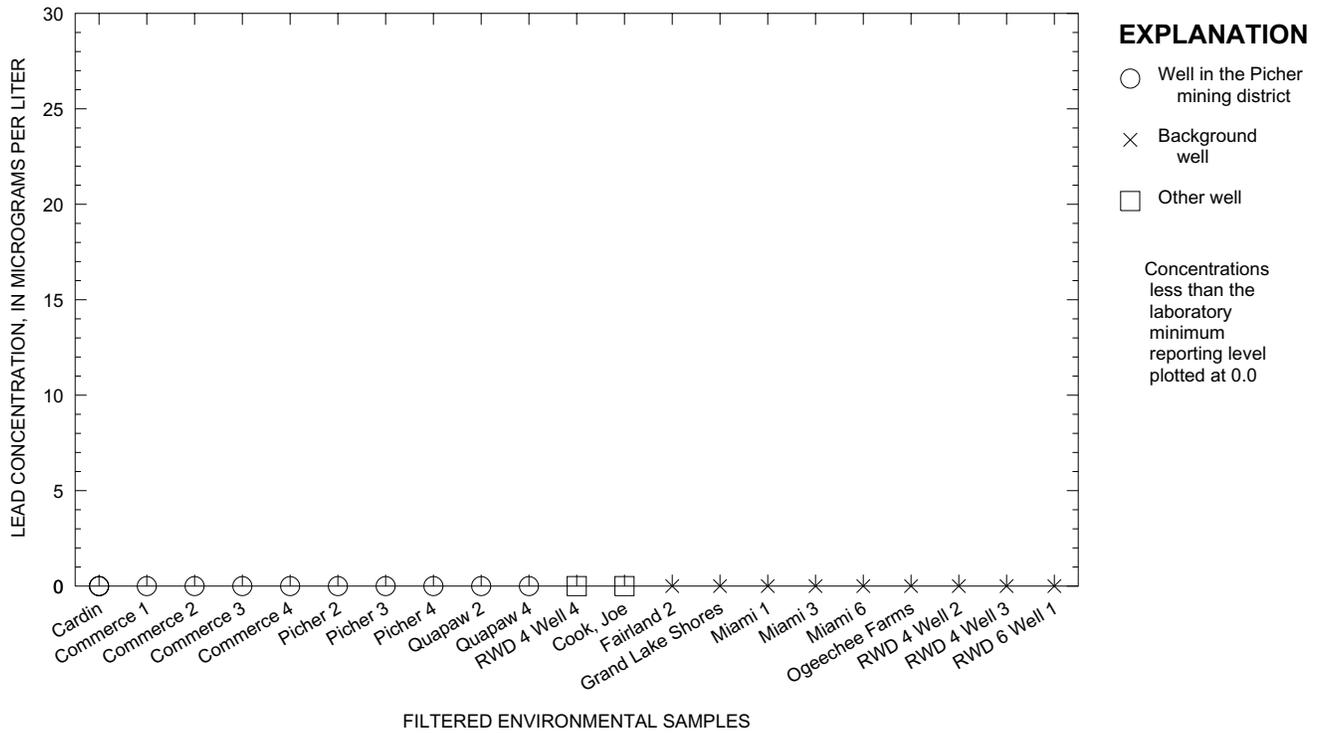


Figure 21. Lead concentration in filtered environmental and blank samples collected during the monthly sampling trips.

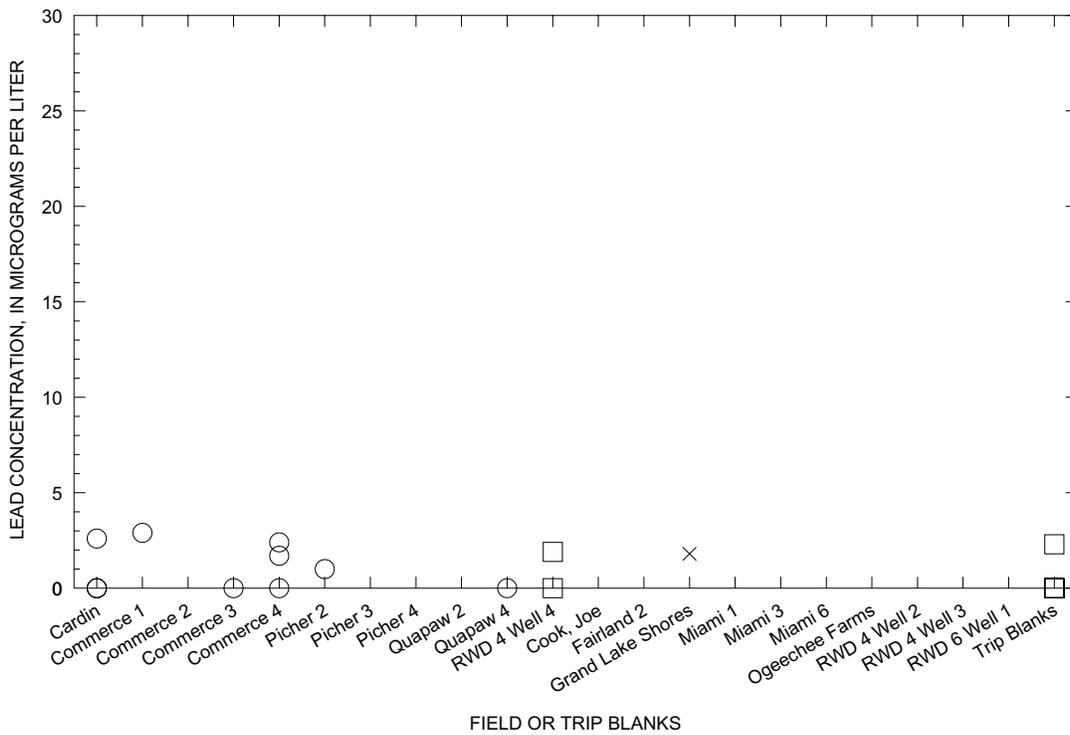
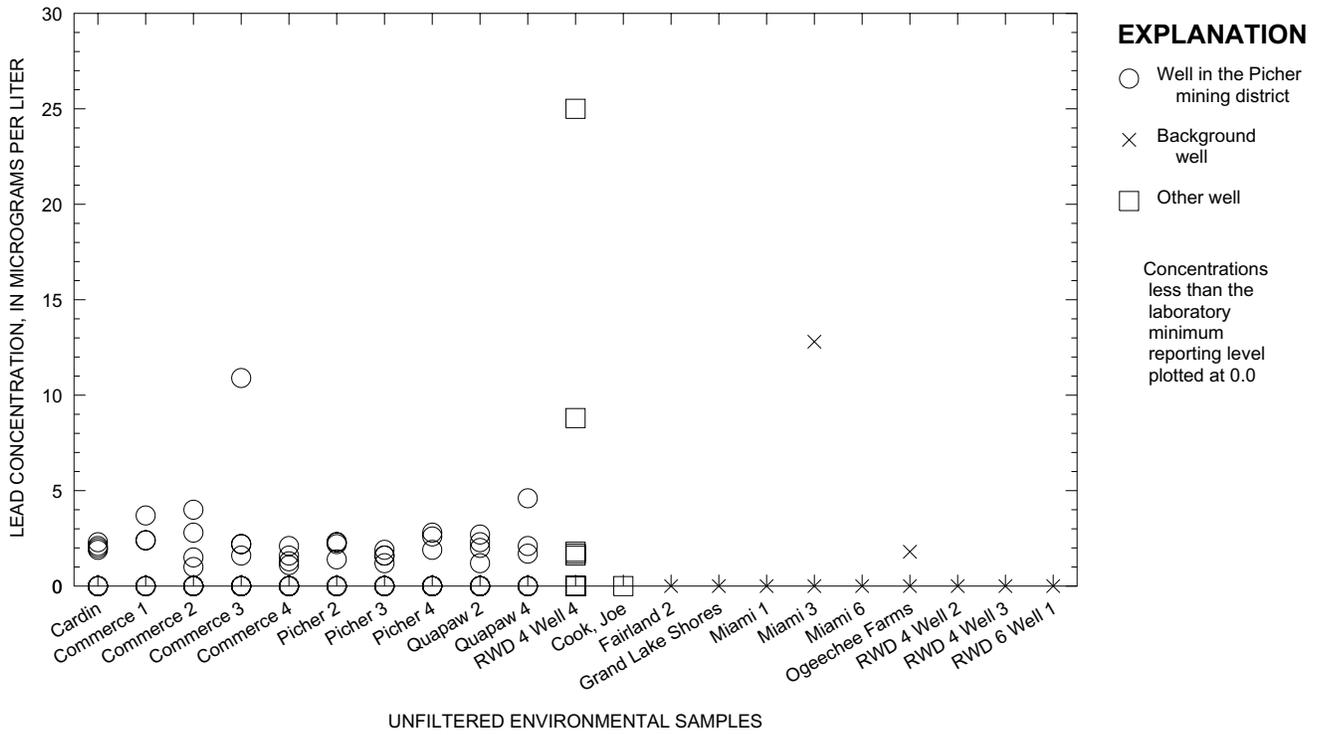


Figure 22. Lead concentration in unfiltered environmental and blank samples collected during the monthly sampling trips.

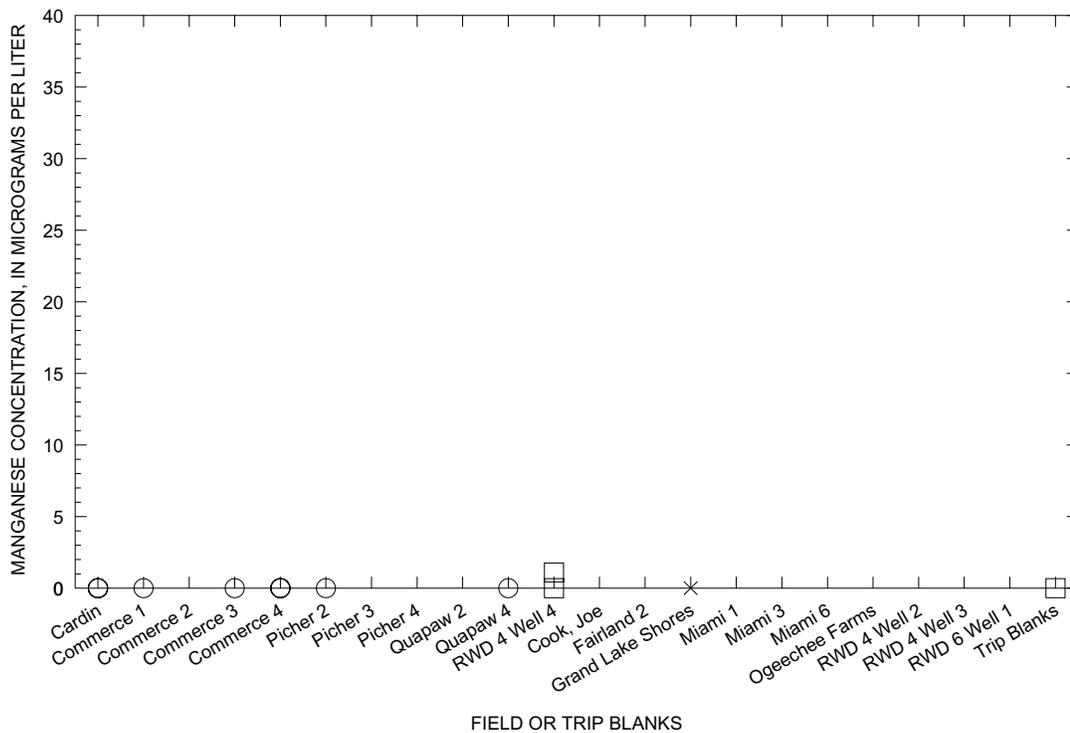
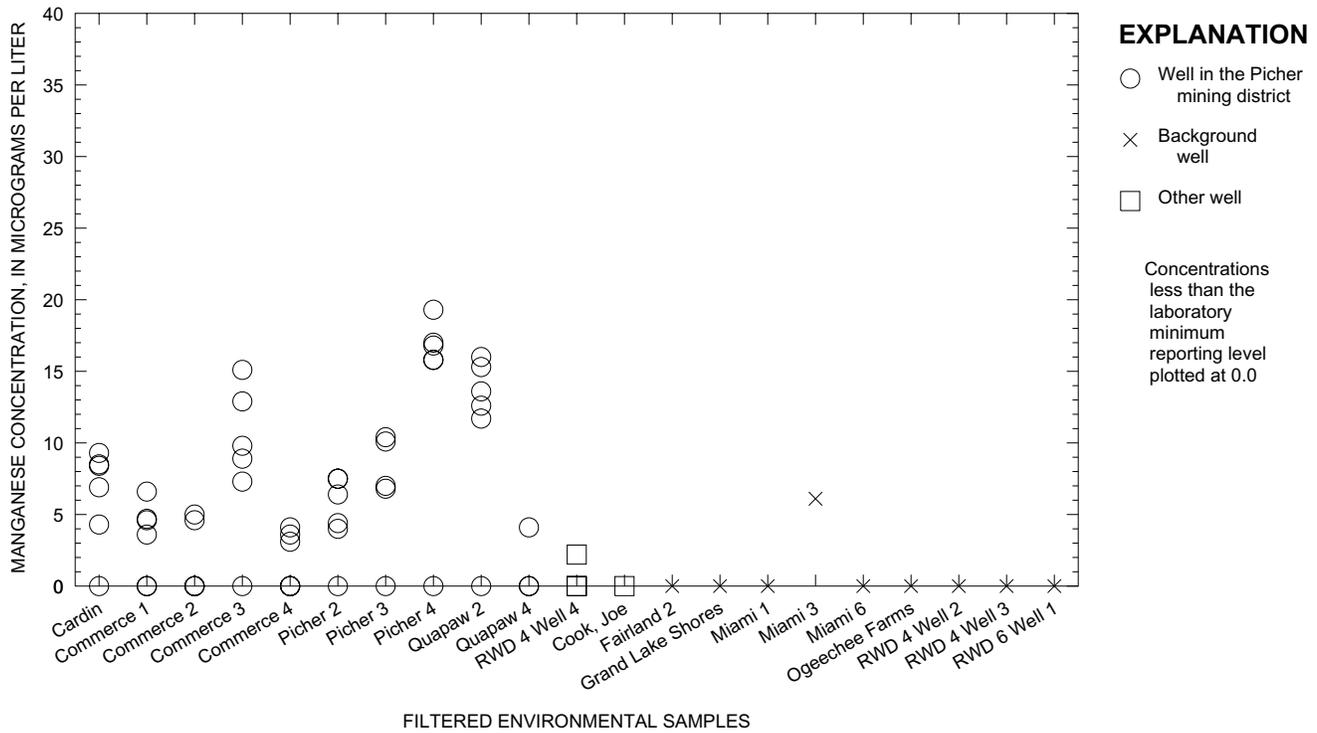


Figure 23. Manganese concentration in filtered environmental and blank samples collected during the monthly sampling trips.

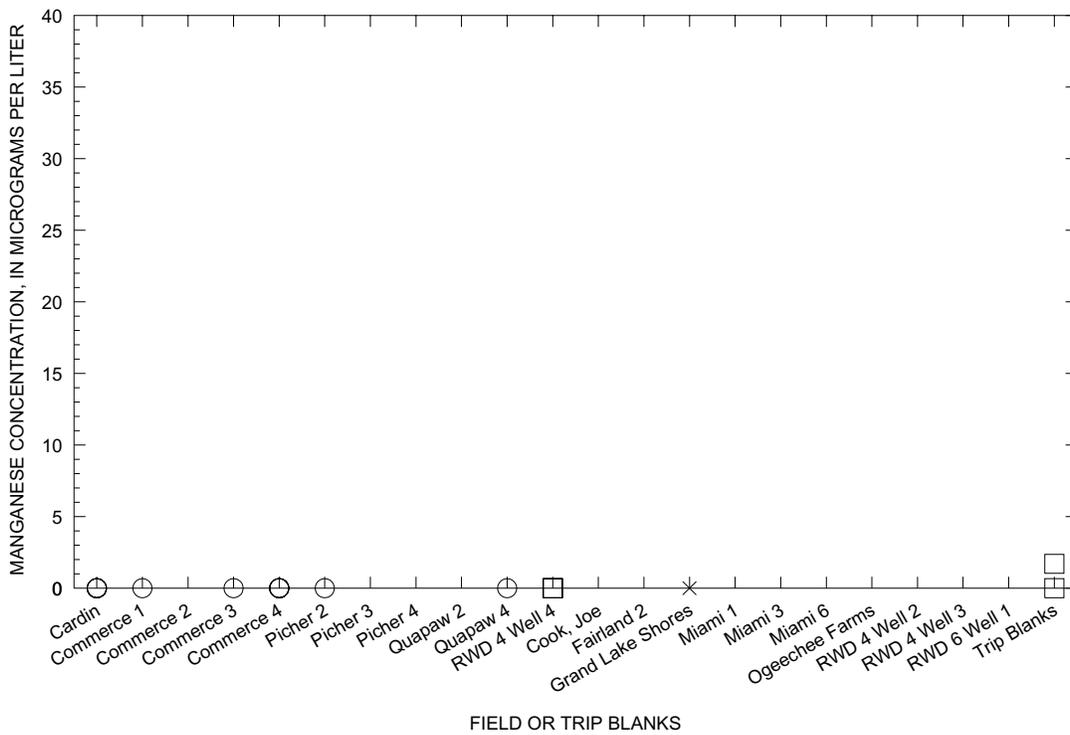
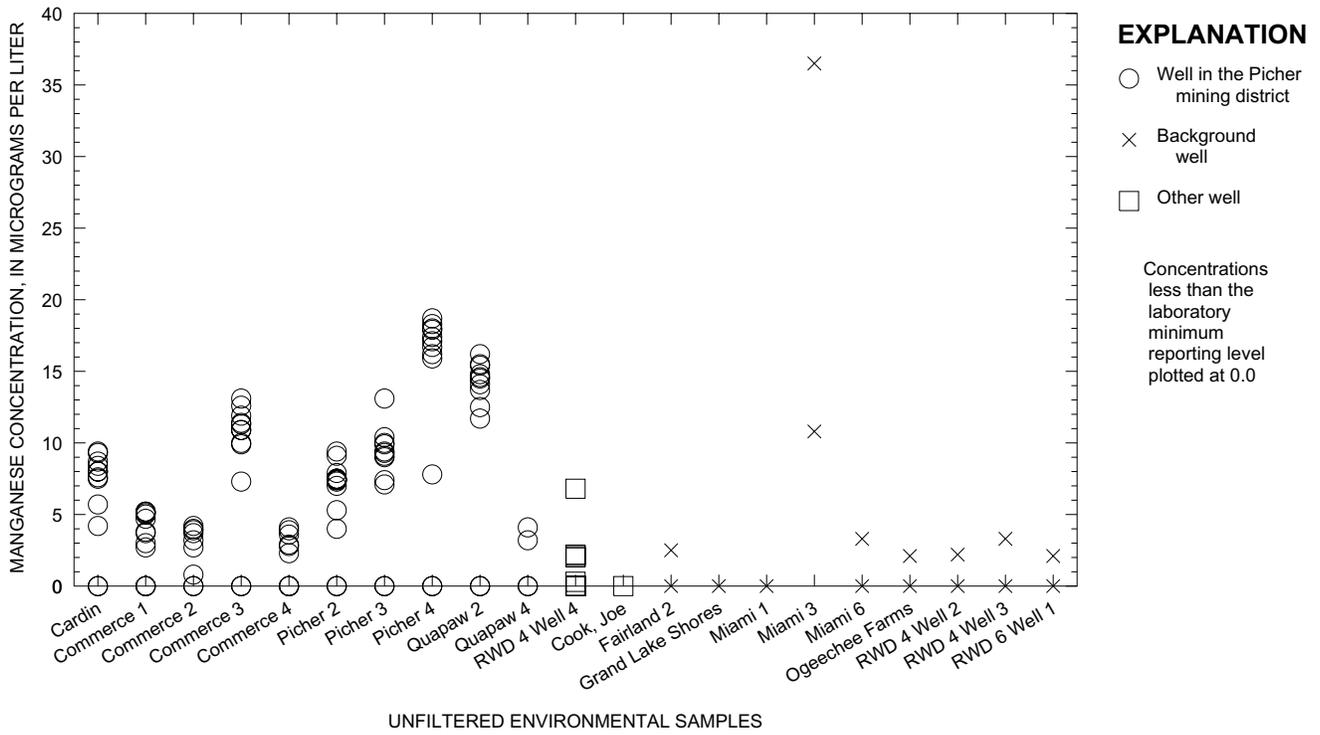


Figure 24. Manganese concentration in unfiltered environmental and blank samples collected during the monthly sampling trips.

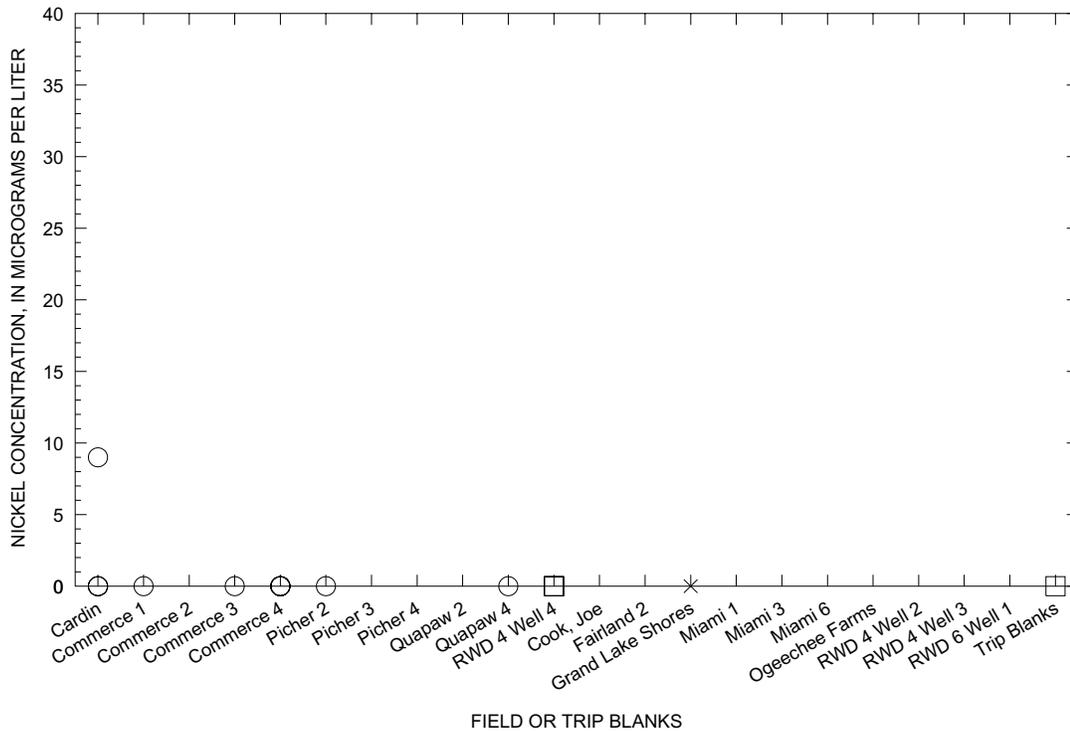
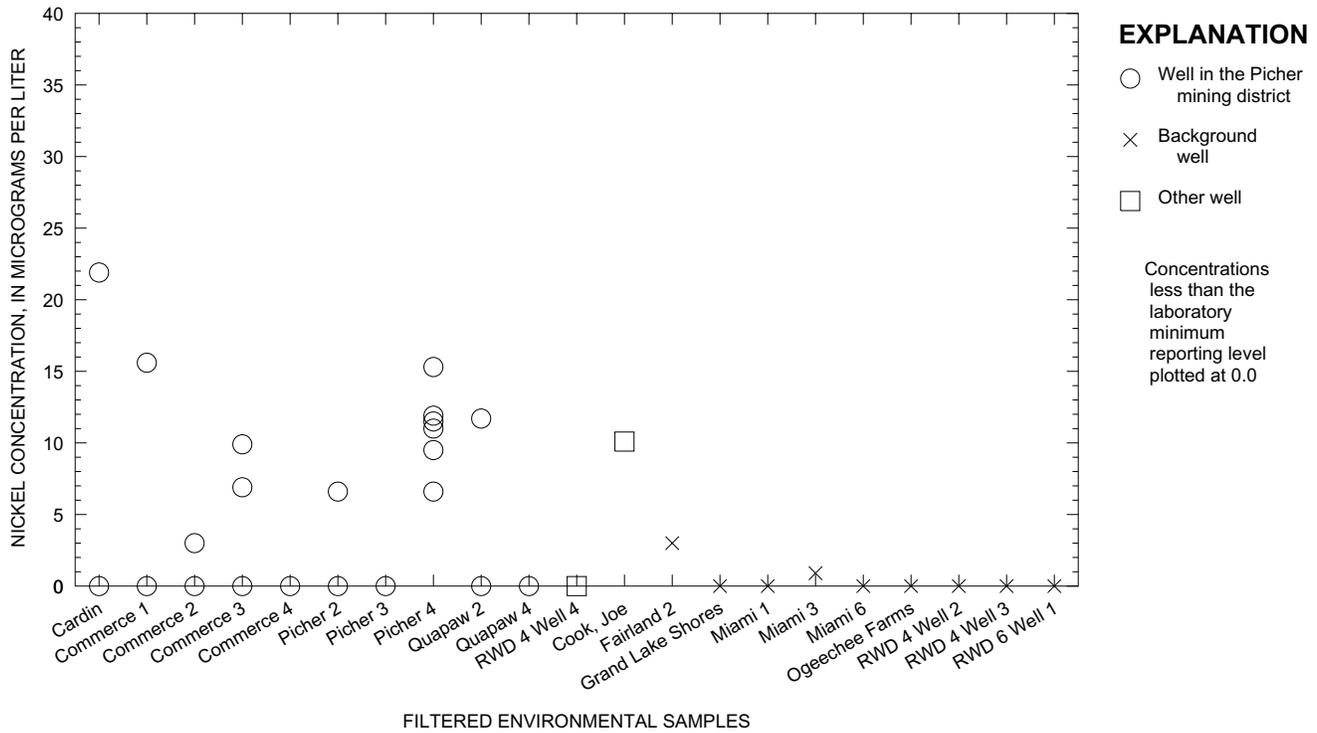


Figure 25. Nickel concentration in filtered environmental and blank samples collected during the monthly sampling trips.

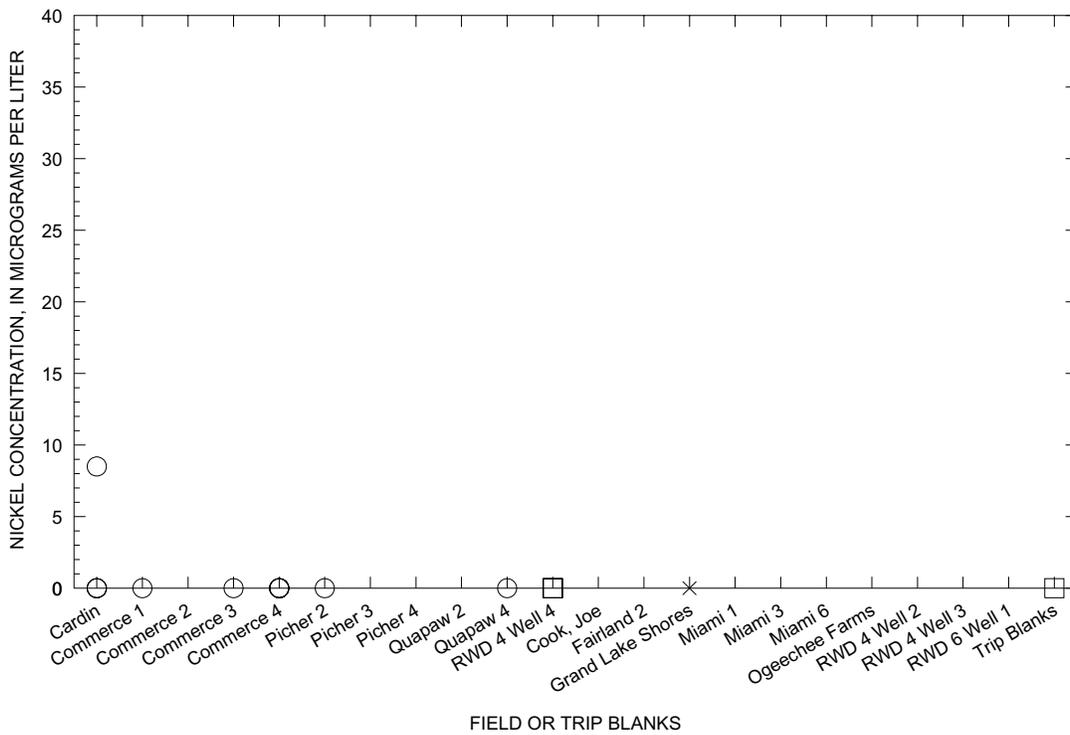
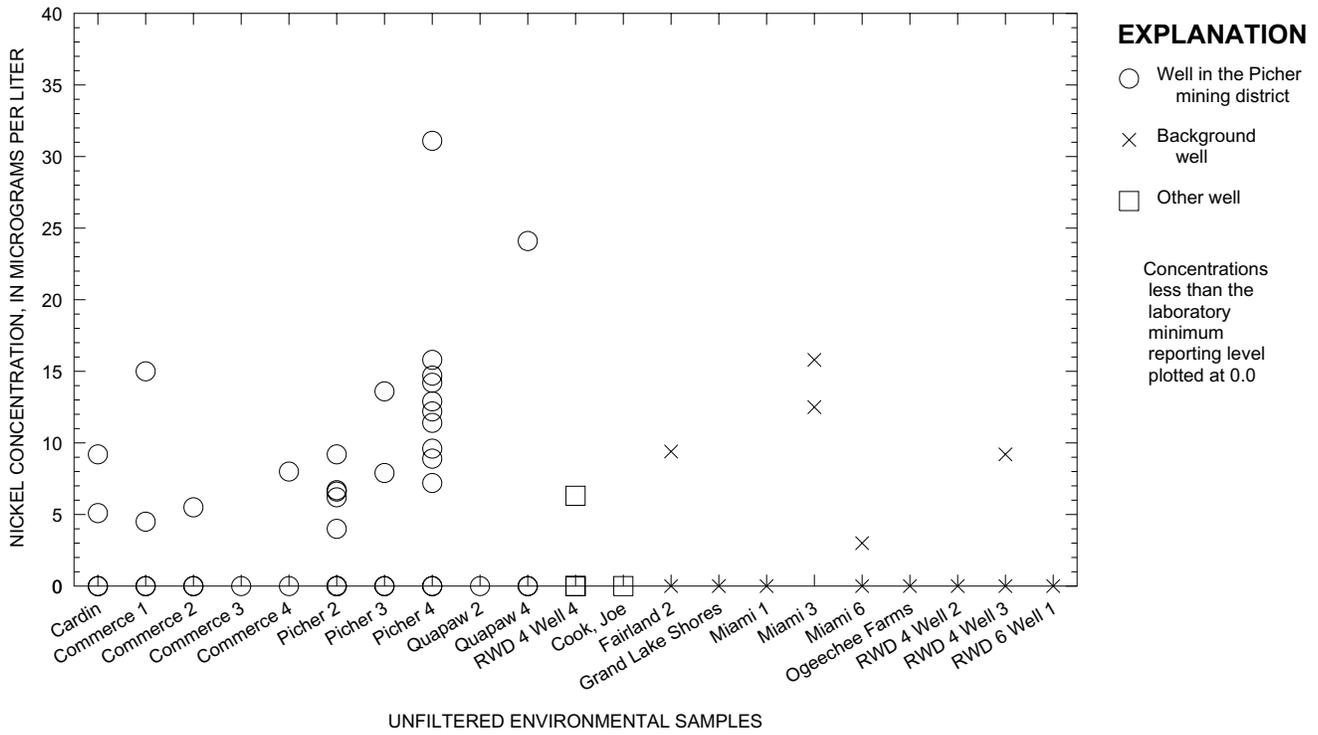


Figure 26. Nickel concentration in unfiltered environmental and blank samples collected during the monthly sampling trips.

ences in nickel concentrations between mining district and background wells requires a lower minimum reporting level. Visual examination of the scatter plots of nickel for filtered samples (fig. 25) shows that Picher 4, a well that consistently produced some of the highest concentrations of constituents considered to be indicators of mine-water contamination, produced water with nickel concentrations above the laboratory minimum reporting level for all monthly samplings.

Zinc

Sampling for zinc is difficult in many field situations, and especially in the Picher mining district. Zinc is used in many man-made compounds, including steel and rubber, which are found in abundance in the vicinity of many wells. Wells in the mining district are surrounded by abandoned mines and spoils piles, and zinc was the primary economic element in the mining operations. Blank samples frequently had measurable zinc concentrations, up to 29.5 µg/L.

The *p*-value calculated by the Mann-Whitney test was 0.0074 for unfiltered samples sent to the contract laboratories, 0.0478 for unfiltered samples sent to the Kerr Laboratory, and 0.0178 for filtered samples sent to the Kerr Laboratory. Using a significance level of 0.05, the null hypothesis was rejected for all samples and the alternate hypothesis accepted. In spite of the problems with sample contamination, zinc concentrations were significantly different between Picher mining district and background wells. The results of the analyses of filtered samples are shown in figure 27 and unfiltered samples in figure 28. These figures show that mining district wells consistently produce water with higher zinc concentrations than background wells. Censored data are plotted at a concentration of 0.0 on these figures.

Because of the zinc contamination of blank samples, might the higher concentrations in the mining district wells be caused by sample contamination? The wells that consistently produce the highest concentrations of constituents considered to be indicators of mine-water contamination (such as Picher 4) consistently produce water with the highest concentrations of zinc, and therefore sample contamination seems unlikely to have caused the higher concentrations in mining district wells. Thus, in spite of the zinc contamination of some blanks and the implied contamination of environmental samples, it seems likely that wells in the mining area are producing water with larger concentrations of zinc than background wells.

Comparison of Current to Historic Water Quality

Current (1992-93) and historic (1981-83) water quality in Picher mining district wells were compared using the Wilcoxon signed-rank test (P-STAT, Inc., 1989). The Wilcoxon signed-rank requires paired data between the two populations being compared. In this case, a current and historic chemical analysis from the same well was compared. The current water quality was considered to be the chemical analyses from the six

monthly sample-collection trips. The historic water quality was considered to be chemical analyses reported in Christenson, Parkhurst, and Fairchild (1994); these chemical analyses are referred to as the "historic data" in this report. These historic data consist of chemical analyses of a single water sample collected from wells between 1981 and 1983. Eight of the wells sampled as part of the current investigation were sampled during that time period (Cardin, all four Commerce wells, Picher 2 and 3, and Quapaw 2).

No best method exists to pair the six analyses of monthly samples from each well to the single historic analysis from the same well. The pairing was done by several different methods. Each monthly analysis of the current data was compared to the historic analysis at the same well, and the median concentration of the six analyses of monthly samples at each well was compared to the historic analysis at the same well. As it turned out, the conclusions reached from the Wilcoxon signed-rank test are essentially the same regardless of the method of pairing the analyses.

The Wilcoxon signed-rank test was used because it is a nonparametric test, which does not require assumptions about the population distributions. The test works on matched pairs of data, in this case the single historic chemical analysis and a chemical analysis from one of the six monthly sample-collection trips. The test is used to determine if one group of data is larger or smaller than the other group. If the wells in the mining area are becoming contaminated by mine water, the current data should have concentrations of mine-water constituents that are greater than the historic data.

The null hypothesis was that the concentrations of chemical constituents in ground-water samples from wells in the Picher mining district were the same between current and historic data. The alternative hypothesis was that the concentrations of chemical constituents in the current data were larger or smaller than the historic data. The null hypothesis was rejected if the *p*-value of the test was less than or equal to 0.05.

Only chemical analyses of filtered samples in the current data were used, as the historic data (Christenson, Parkhurst, and Fairchild, 1994) were filtered samples. The results of the Wilcoxon signed-rank tests for all mine-water indicator constituents are shown in table 10. The results of the tests for each constituent are discussed in the order of properties (pH and alkalinity), major ions (cations and anions), and trace constituents. Within these categories, constituents are discussed alphabetically.

pH

The *p*-values calculated by the Wilcoxon signed-rank test for pH ranged from 0.0173 to 0.0929. Five of six *p*-values for the monthly sample-collection trips (the October 1992 sample-collection trip is the exception) and the *p*-value for the median pH were less than 0.05, leading to the rejection of the null hypothesis and the conclusion that the historic data are significantly different from the current data. As can be seen in

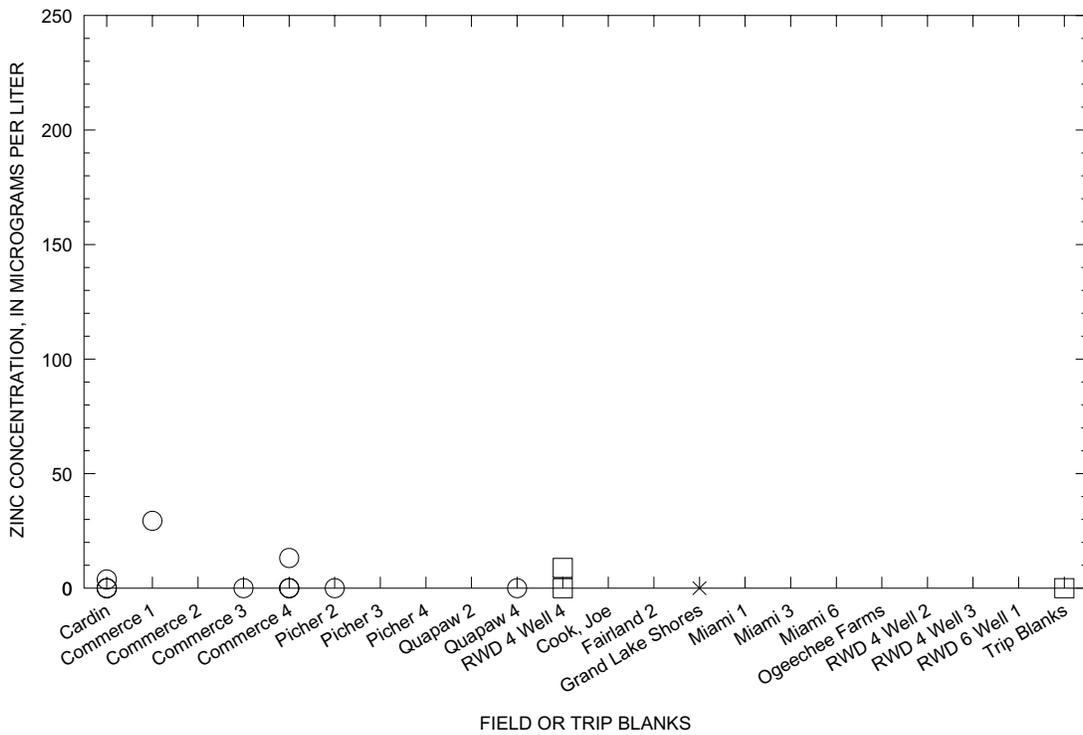
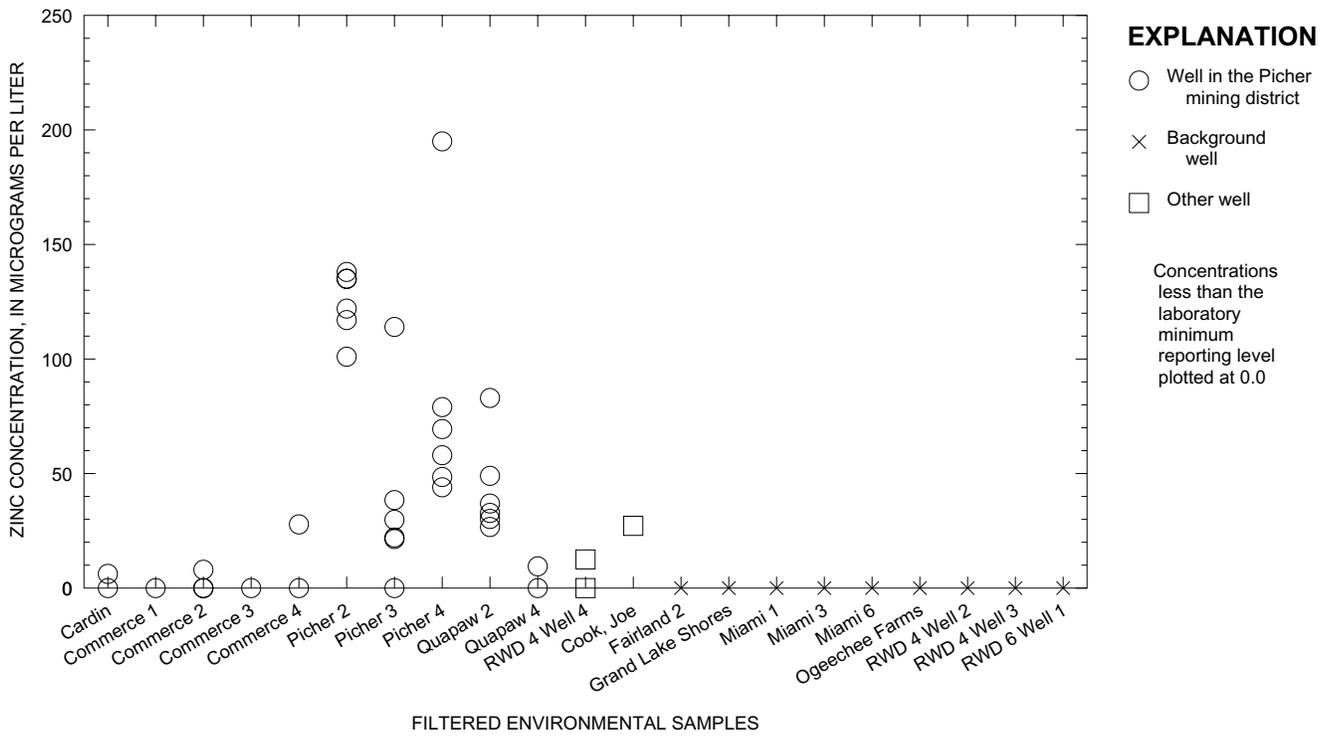


Figure 27. Zinc concentration in filtered environmental and blank samples collected during the monthly sampling trips.

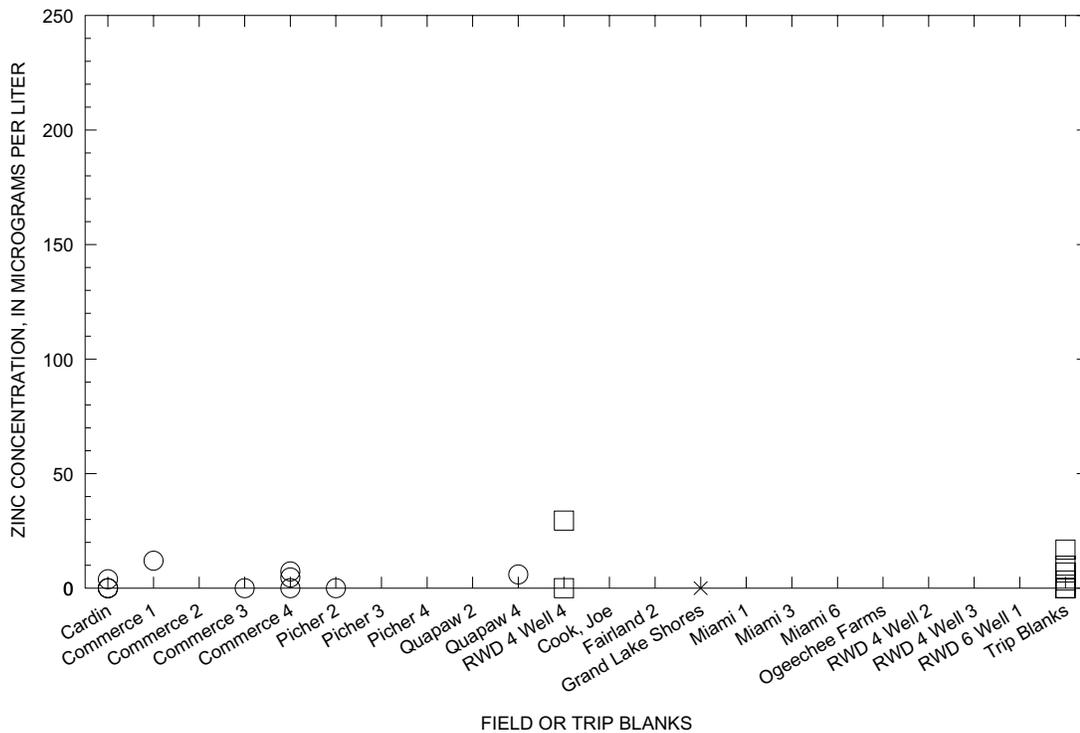
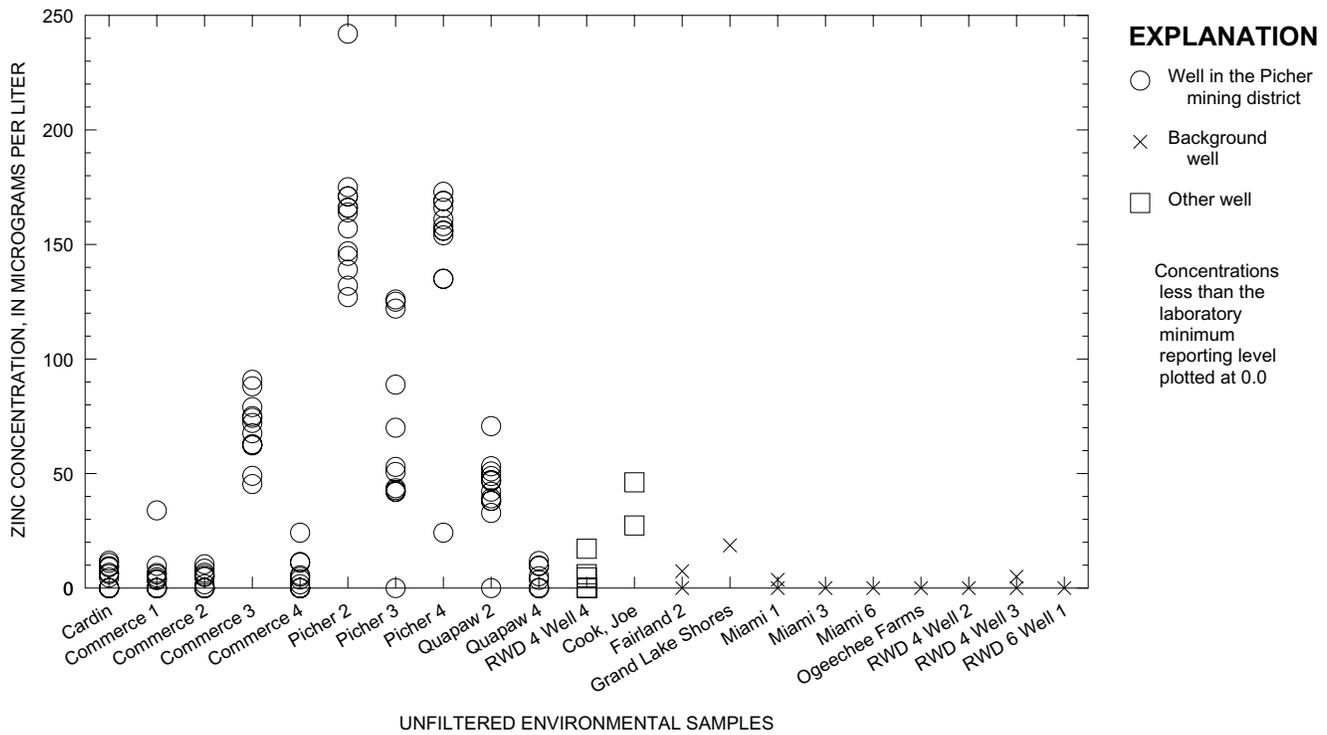


Figure 28. Zinc concentration in unfiltered environmental and blank samples collected during the monthly sampling trips.

Table 10. *P*-values from Wilcoxon signed-rank tests comparing constituent concentrations between current (1992-93) and historic data

[--, unable to calculate *p*-value; numbers in bold type indicate constituent concentrations are different between current and historic data]

Constituent	Sampling trip						Median concentration of the 6 monthly samples
	August 1992	September 1992	October 1992	November 1992	December 1992	January 1993	
pH	0.0251	0.0251	0.0929	0.0357	0.0357	0.0173	0.0251
Alkalinity	.0801	.1614	.0910	.0499	.0910	.0687	.0910
Calcium	.0173	.0173	.0173	.0173	.0173	.0357	.0173
Magnesium	.0173	.0173	.0173	.0173	--	.0173	.0173
Bicarbonate	.0801	.1614	.0910	.0499	.0910	.0687	.0910
Sulfate	.0173	.0173	.0173	.0173	.0173	.0357	.0173
Cadmium	--	--	--	--	--	--	--
Copper	--	--	--	--	--	--	--
Iron	.0499	.0357	--	--	--	--	--
Lead	--	--	--	--	--	--	--
Manganese	--	--	--	--	--	--	--
Nickel	--	--	--	--	--	--	--
Zinc	--	--	--	--	--	--	--

figure 29, pH for all six sample-collection trips in the current data were less than the historic data for seven of eight wells (Commerce 4 is the exception). Thus, pH has decreased in seven wells in the Picher mining district between the early 1980's and the early 1990's.

Alkalinity

The *p*-values calculated by the Wilcoxon signed-rank test for alkalinity ranged from 0.0499 to 0.1614. Five of six *p*-values for the monthly sample-collection trips (the November 1992 sample-collection trip is the exception) and the *p*-value for the median concentration were greater than 0.05, leading to the acceptance of the null hypothesis and the conclusion that the historic data are not significantly different from the current data. Consideration of the data for the individual wells is instructive. As can be seen in figure 30, alkalinities for all six sample-collection trips were greater than the historic data for six of eight wells. Alkalinity decreased over time at Commerce 2, and historical alkalinity at Commerce 4 is contained in the range of alkalinity for the current data. Thus, in six wells in the Picher mining district, alkalinity has increased over time.

Calcium

The *p*-values calculated by the Wilcoxon signed-rank test for calcium ranged from 0.0173 to 0.0357. All six *p*-values for all monthly sample-collection trips and median concentration were less than 0.05, leading to the rejection of the null hypothesis and the conclusion that the historic data are significantly different from the current data. As can be seen in figure 31, the calcium concentrations for all six sample-collection trips in the current data were greater than the historic calcium concentrations for six of eight wells. The calcium concentrations at Commerce 2 were larger in five of six sample-collection trips for the current data as compared to historic data, and at Commerce 4 the calcium concentrations were lower in all six current samples than in the single historic analysis. Thus, calcium concentrations generally have increased in seven wells in the Picher mining district between the early 1980's and the early 1990's.

Magnesium

The *p*-values calculated by the Wilcoxon signed-rank test for magnesium was 0.0173 for five of six sample-collection trips and for the median concentration; a *p*-value could not be calculated for the December 1992 sample-collection trip. All *p*-values that could be calculated for the monthly sample-collection trips were less than 0.05, leading to the rejection of the

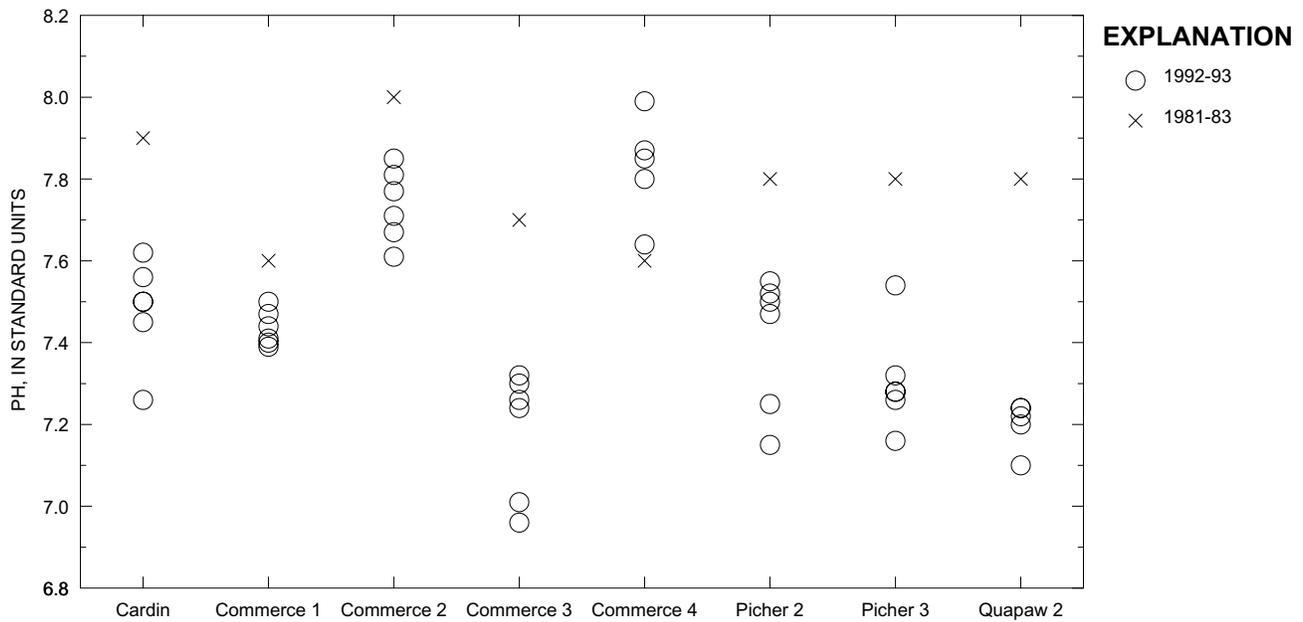


Figure 29. Comparison of historic (1981-83) to current (1992-93) pH in filtered environmental samples from wells in the Picher mining district.

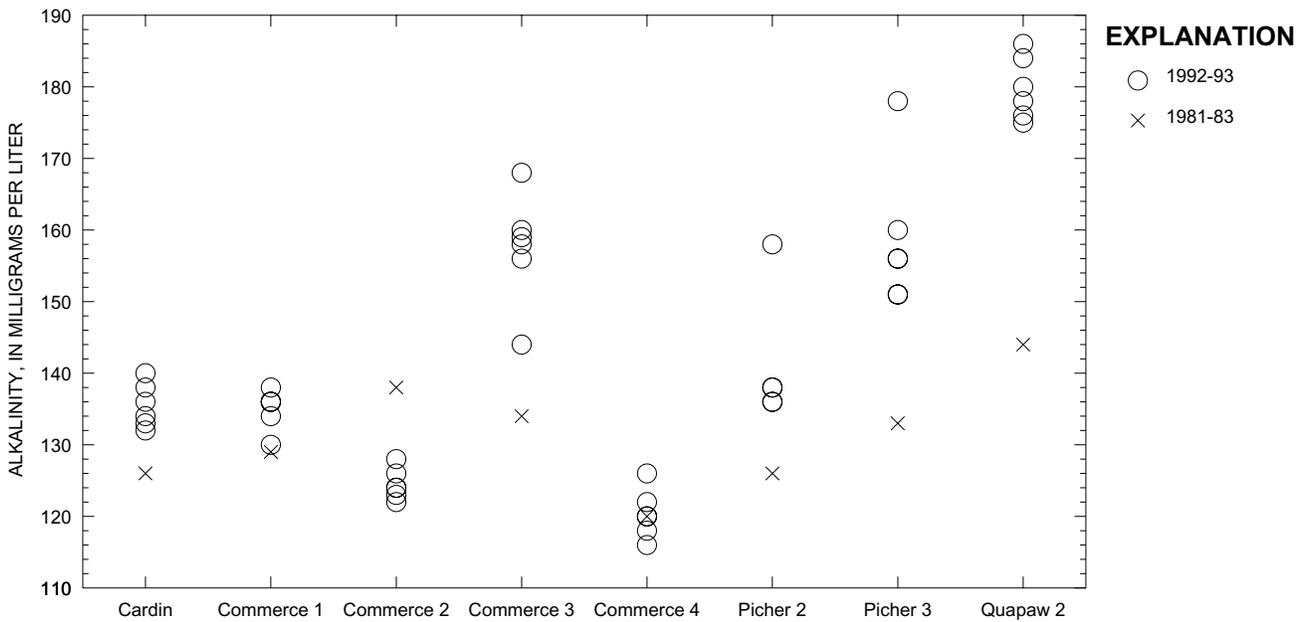


Figure 30. Comparison of historic (1981-83) to current (1992-93) alkalinity in filtered environmental samples from wells in the Picher mining district.

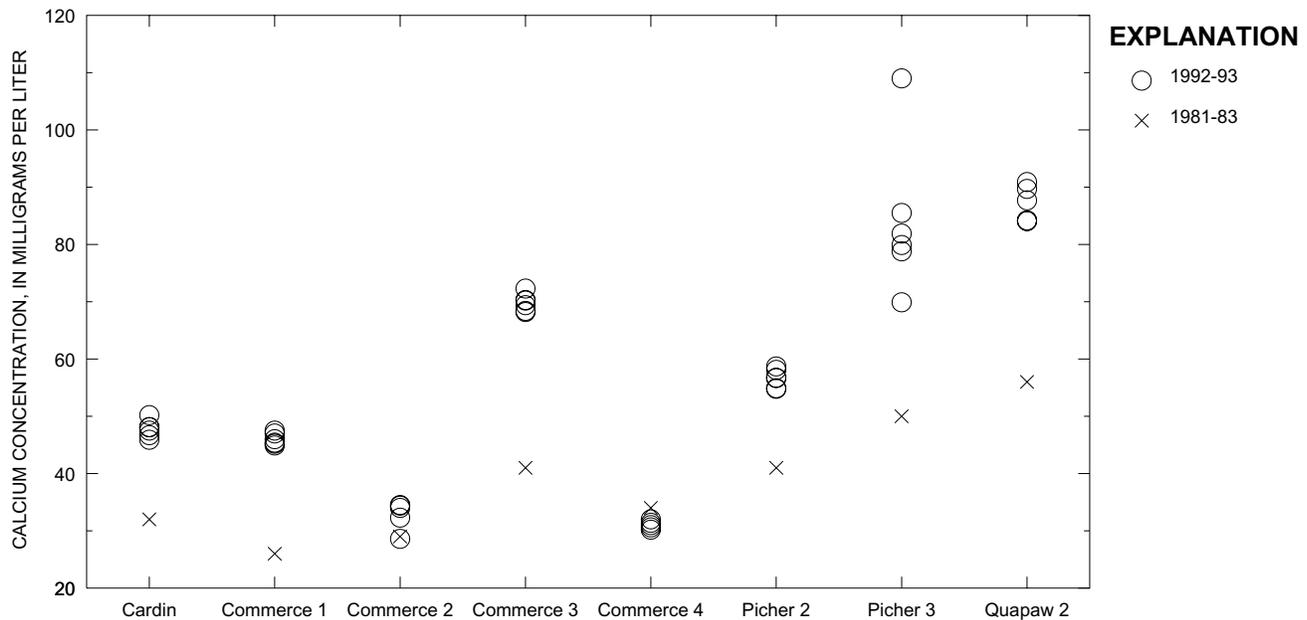


Figure 31. Comparison of historic (1981-83) to current (1992-93) calcium in filtered environmental samples from wells in the Picher mining district.

null hypothesis and the conclusion that the historic data are significantly different from the current data. As can be seen in figure 32, the magnesium concentrations for all six sample-collection trips in the current data were greater than the historic magnesium concentrations in seven wells. The historic magnesium concentration at Commerce 4 is contained within the range of magnesium concentrations for current data.

A p -value could not be calculated for the December 1992 sample-collection trip because all the current magnesium concentrations were greater or equal to the historic concentrations, a condition that precludes calculation of a p -value. Even though a p -value could not be calculated, the conclusion is the same: Magnesium concentrations generally have increased in seven wells in the Picher mining district between the early 1980's and the early 1990's.

Bicarbonate

The p -values calculated by the Wilcoxon signed-rank test for bicarbonate ranged from 0.0499 to 0.1614. Bicarbonate is assumed to be the source of alkalinity in water from the Roubidoux aquifer, so the p -values calculated for the Wilcoxon signed-rank for bicarbonate concentrations are identical to those for alkalinity. Five of six p -values for the monthly sample-collection trips (the November 1992 sample-collection trip is the exception) and the median concentration were greater

than 0.05, leading to the acceptance of the null hypothesis and the conclusion that the historic data are not significantly different from the current data. However, examination of the data at the individual wells is instructive. As can be seen in figure 33, bicarbonate concentrations for all six sample-collection trips in the current data were greater than the historic data for six of eight wells. Bicarbonate concentrations decreased over time at Commerce 2, and historical bicarbonate concentration at Commerce 4 is contained in the range of bicarbonate concentrations for the current data. Thus, in six wells in the Picher mining district, bicarbonate concentrations have increased over time.

Sulfate

The p -values calculated by the Wilcoxon signed-rank test for sulfate ranged from 0.0173 to 0.0357. All p -values for all monthly sample-collection trips and for the median concentration were less than 0.05, leading to the rejection of the null hypothesis and the conclusion that the historic data are significantly different from the current data. As can be seen in figure 34, the sulfate concentrations for all six sample-collection trips in the current data were greater than the historic sulfate concentrations for six of eight wells. The sulfate concentrations at Commerce 2 were larger in five of six sample-collection trips for the current data as compared to historic data (the historic and current sulfate concentrations were equal for

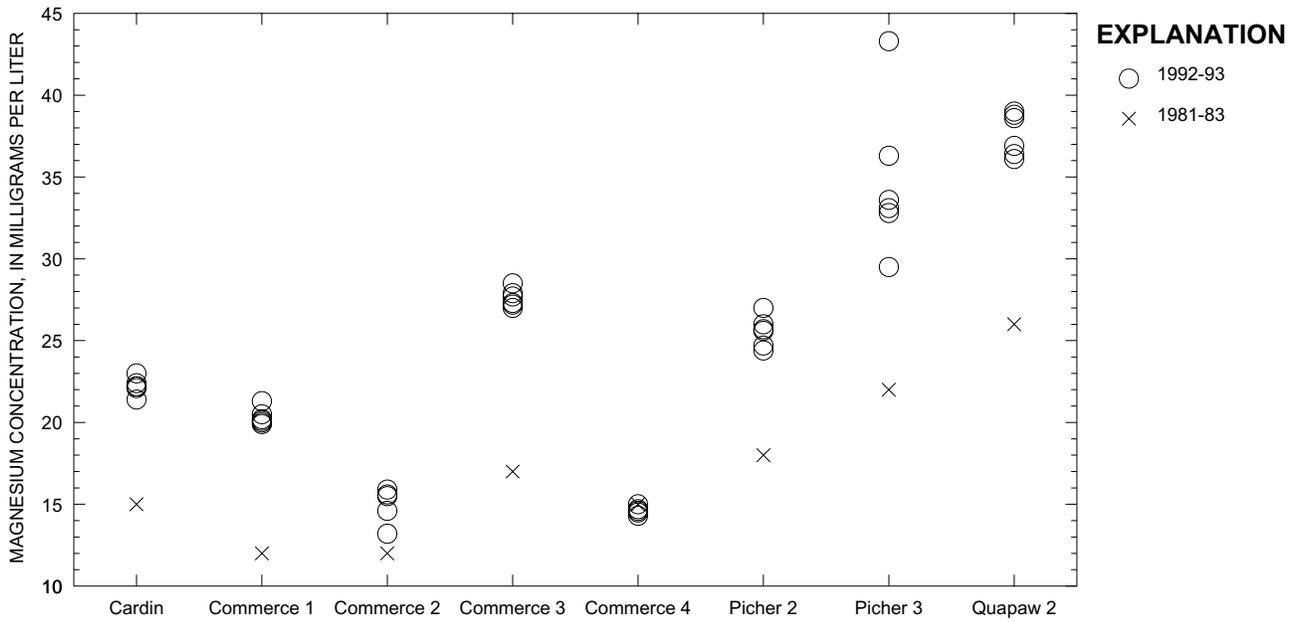


Figure 32. Comparison of historic (1981-83) to current (1992-93) magnesium in filtered environmental samples from wells in the Picher mining district.

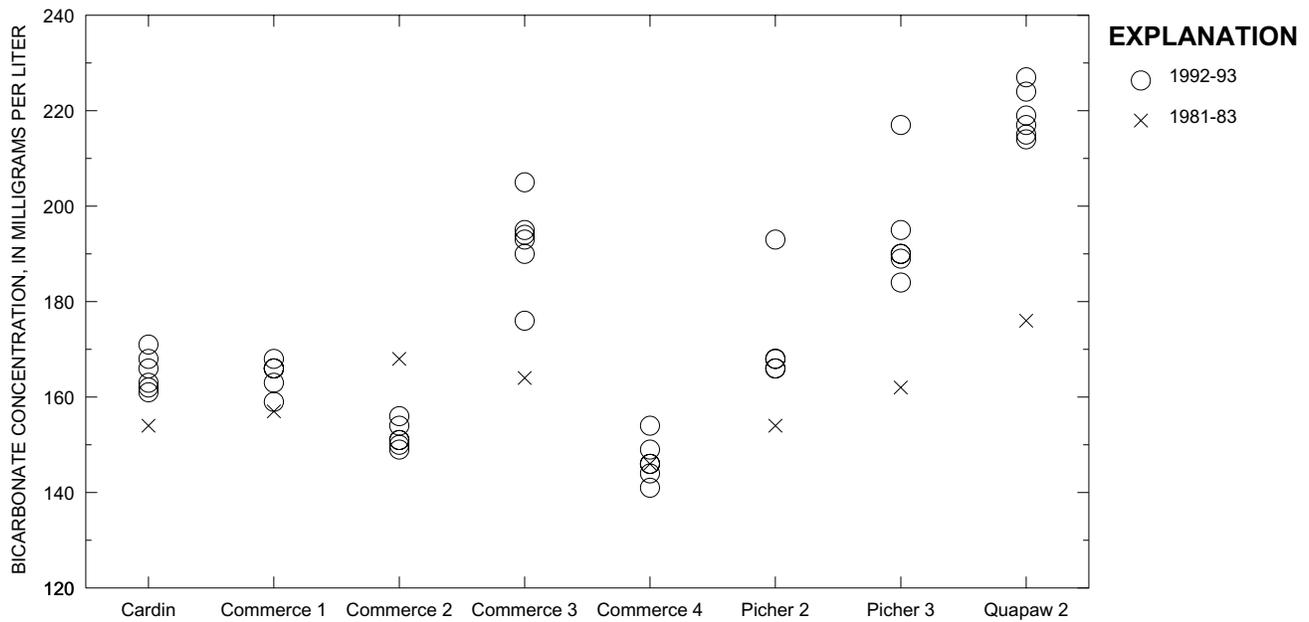


Figure 33. Comparison of historic (1981-83) to current (1992-93) bicarbonate in filtered environmental samples from wells in the Picher mining district.

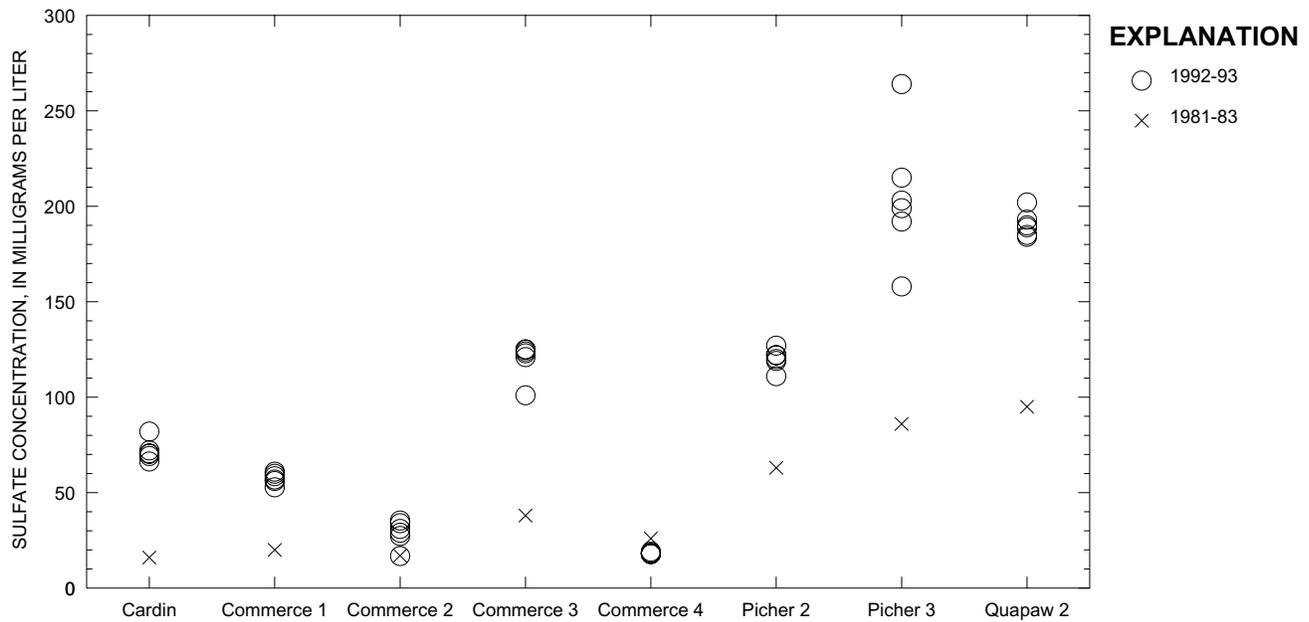


Figure 34. Comparison of historic (1981-83) to current (1992-93) sulfate in filtered environmental samples from wells in the Picher mining district.

the sixth sample-collection trip), and at Commerce 4 the sulfate concentrations were lower in all six current samples than in the single historic analysis. Thus, sulfate concentrations generally have increased in seven wells in the Picher mining district between the early 1980's and the early 1990's.

Cadmium

P-values could not be calculated for the Wilcoxon signed-rank test for cadmium because all of the historic and most of the current data are censored. Because so many of the water-quality data are censored (figure 15), no conclusion can be drawn regarding changes in cadmium concentrations between the early 1980's and the early 1990's.

Copper

P-values could not be calculated for the Wilcoxon signed-rank test for copper because all of the historic and most of the current data are censored. Because so many of the water-quality data are censored (figure 17), no conclusion can be drawn regarding changes in copper concentrations between the early 1980's and the early 1990's.

Iron

P-values could be calculated for the Wilcoxon signed-rank test for two of six sample-collection trips. The *p*-value was 0.0499 for the August 1992 sample-collection trip and 0.0357 for the September 1992 sample-collection trip. The *p*-values for these monthly sample-collection trips were less than 0.05, leading to the rejection of the null hypothesis and the conclusion that the historic data are significantly different from the current data. For the other four sample-collection trips, the *p*-values could not be calculated because the historic iron concentrations were all lower than all the current data, a condition that precludes calculation of a *p*-value. Although the *p*-value could not be calculated, the conclusion is the same as for those sample-collection trips with a calculated *p*-value, that iron concentrations have increased over time. As can be seen in figure 35, the iron concentrations in the current data are always larger than the historic concentrations at six of the eight wells. At Commerce 2 and 4, the historic concentrations fall within the range of the current concentrations. Censored data are plotted at a concentration of 0.0 on this figure.

Lead

P-values were not calculated for the Wilcoxon signed-rank test for lead because of the possible sample contamination prob-

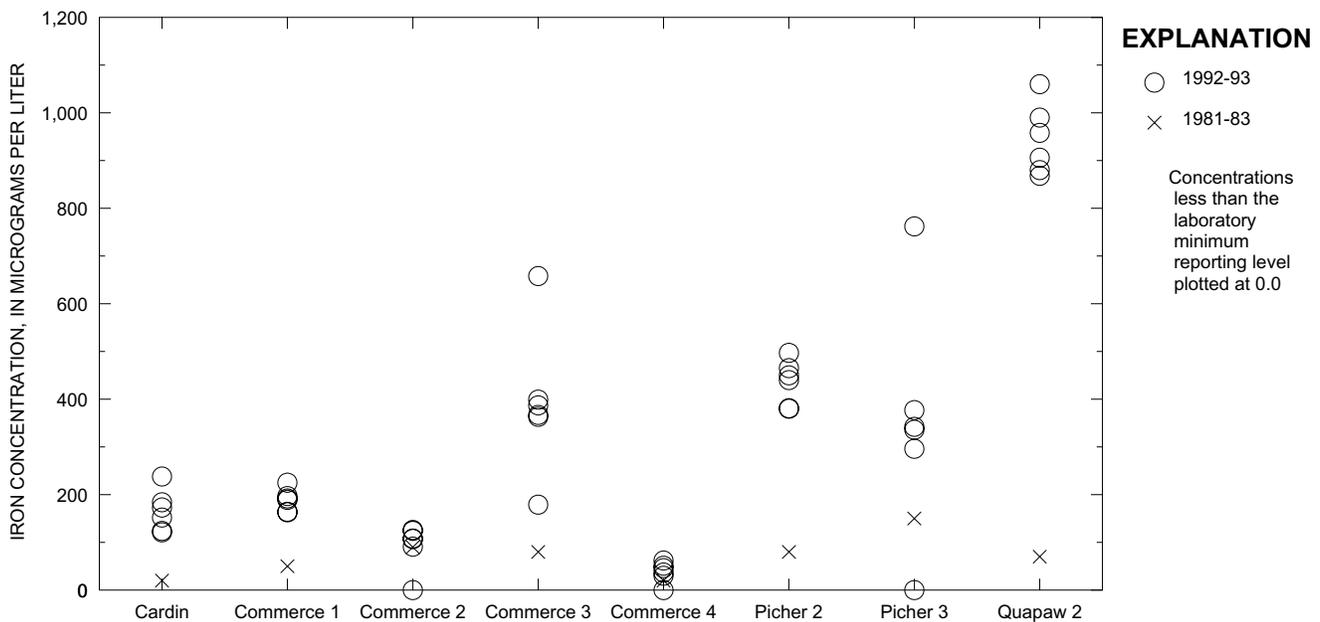


Figure 35. Comparison of historic (1981-83) to current (1992-93) iron in filtered environmental samples from wells in the Picher mining district.

lems associated with lead. (See the discussion in the “Quality-Assurance Data” section of this report). No conclusion can be drawn regarding changes in lead concentrations between the early 1980’s and the early 1990’s.

Manganese

P-values could not be calculated for the Wilcoxon signed-rank test for manganese because all of the historic manganese data are censored. In general, no conclusion can be drawn regarding changes in manganese concentrations between the early 1980’s and the early 1990’s because so many of the water-quality data are censored (figure 36). However, the historic data are censored at 10 µg/L, and in the current water-quality data Commerce 3 and Quapaw 2 produced water with concentrations of manganese greater than 10 µg/L. Thus it is possible that manganese concentrations in these two wells have increased between the early 1980’s and the early 1990’s.

Nickel

P-values could not be calculated for the Wilcoxon signed-rank test for nickel because all of the historic and most of the current data are censored. Because so many of the water-quality data are censored (fig. 25), no conclusion can be drawn regarding changes in nickel concentrations between the early 1980’s and the early 1990’s.

Zinc

P-values for the Wilcoxon signed-rank test were not calculated for zinc because the historic data for zinc are suspect. In the early 1980’s, the U.S. Geological Survey used plate filters with rubber gaskets to filter samples, and these rubber gaskets are suspected to have released zinc into the ground-water samples. No conclusion can be drawn regarding changes in zinc concentrations between the early 1980’s and the early 1990’s.

Tritium Concentration

Tritium is a radioactive isotope of hydrogen (³H) with a half-life of 12.43 years. Although some tritium is produced naturally by the interaction of cosmic rays with the atmosphere, tritium concentrations in the atmosphere were elevated dramatically after 1952 by atmospheric testing of hydrogen bombs. Precipitation occurring after 1952 is enriched in tritium as the tritium atoms are incorporated in the water molecules.

Tritium concentrations were measured in water samples from 10 wells to determine if water produced by wells in the Picher mining district contained some component of recent (post-1952) ground water. The results of the tritium sampling are shown in table 11.

Samples with measurable concentrations of tritium came from wells that were assumed to have a component of recent water. Water in the abandoned zinc and lead mines contains

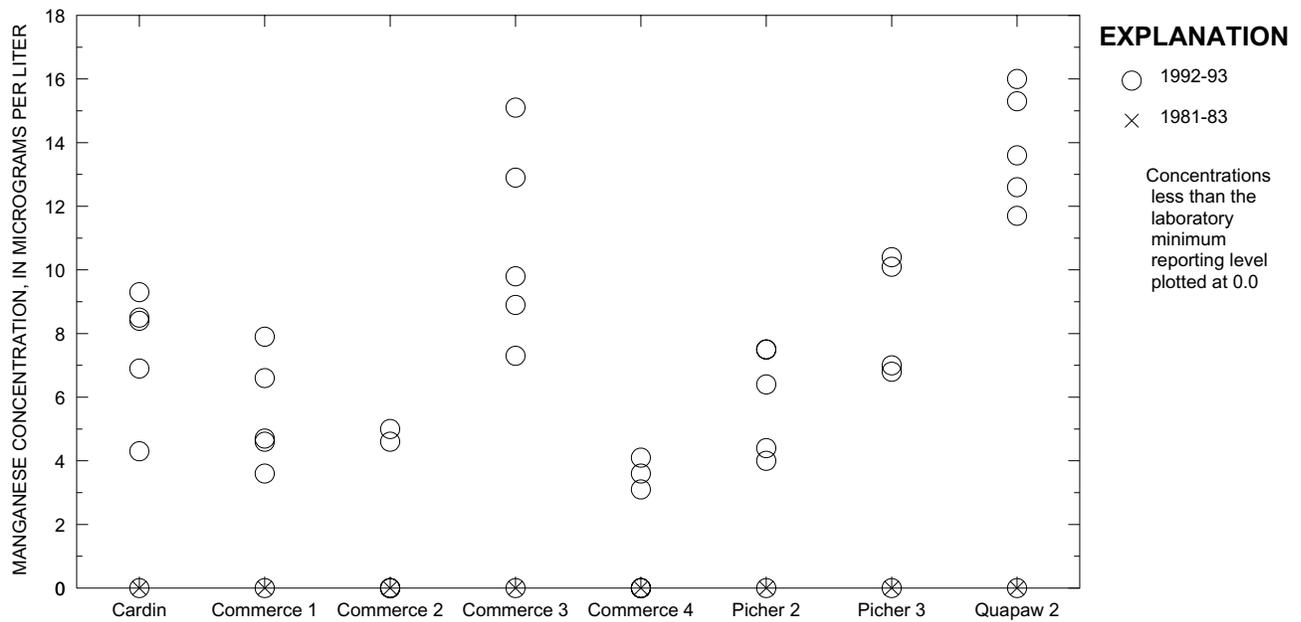


Figure 36. Comparison of historic (1981-83) to current (1992-93) manganese in filtered environmental samples from wells in the Picher mining district.

Table 11. Tritium concentration in water samples from wells in or near the Picher mining district
[pCi/L, picocuries per liter]

Well	Tritium (pCi/L)
Cardin	0.6
Commerce 1	0.5
Commerce 2	<0.3
Commerce 3	1.9
Commerce 4	<0.3
Ottawa County RWD 4 Well 4	<0.3
Picher 2	1.3
Picher 4	4.2
Quapaw 2	1.8
Quapaw 4	<0.3

measurable concentrations of tritium (Parkhurst, 1987) but water in the Roubidoux aquifer in northeast Oklahoma was assumed to have no measurable tritium because of the depth of the aquifer and the location of the recharge area hundreds of kilometers to the east. This assumption was tested by sampling Ottawa County RWD 4 Well 4, which is cased to the top of the Roubidoux Formation and appeared to have water quality very similar to the background wells. This well produced no measurable concentration of tritium, nor did Commerce 2, Commerce 4, and Quapaw 4.

Contamination of Wells by Mine Water

The chemical analyses of water samples collected for this investigation indicate that at least 7 of the 10 public supply wells in the Picher mining district are contaminated. The results of the Mann-Whitney tests generally indicate that the concentrations of some chemical constituents that are indicators of mine-water contamination are different in water samples from wells in the mining area as compared to wells outside the mining area. Concentrations of mine-water indicator constituents generally are higher in wells in the mining area than in background wells, except for pH, which is lower in wells in the mining area. A lower pH is consistent with mine-water contamination.

The results of Wilcoxon signed-rank tests generally indicate that pH and calcium, magnesium and sulfate concentrations are larger or smaller between historic (1981-83) and current (1992-93) data. Concentrations of these mine-water indicator constituents were higher in the current data than in the historic data, except for pH, which were lower in current than in historic data.

The Mann-Whitney and Wilcoxon signed-rank tests apply to groups of data. Examination of the chemical analyses from individual wells shows which wells are contaminated. A clear indicator of contamination is sulfate concentrations in filtered samples in the current data. Sulfate concentrations in filtered samples from background wells fell in a narrow range from 10.6 to 13.2 mg/L, with a median of 12.1 mg/L. The sulfate concentrations at Cardin, Commerce 1, Commerce 3, Picher 2, Picher 3, Picher 4, and Quapaw 2 were always greater than the concentrations in background wells for all six monthly sample-collection trips. Most other mine-water indicator constituents also show that the same wells are contaminated, although the indication of contamination may not be quite as clear because the range in constituent concentrations in background wells have a larger range than sulfate. Alkalinity, bicarbonate, calcium, magnesium, and iron concentrations in the same seven wells are elevated above concentrations in background wells. In the same seven wells, manganese and zinc concentrations also appear to be elevated above background concentrations, although the evidence is not as clear because of the presence of censored data. The pH in these seven wells tends to be lower

than in the background wells, which is consistent with these wells being contaminated by mine water.

The comparison of current to historic data also consistently show these same wells are contaminated, within the limits of the data (Picher 4 did not exist in the early 1980's, so no historic data are available). Chemical analyses of water samples from the same wells generally have shown increases in concentrations of some mine-water indicator constituents and decreases in pH.

Measurable concentrations of tritium were reported in six of these seven wells. Picher 3, the seventh well, was not sampled for tritium because funding was limited; this well is the same depth and within 20 meters of Picher 2, and was assumed to be producing the same water as Picher 2. The tritium data indicate a component of recent (post-1952) water is present in these same seven wells (assuming Picher 3 has a similar tritium concentration to Picher 2), which tends to corroborate that these seven wells are contaminated by mine water.

Commerce 2, Commerce 4, and Quapaw 4 also may be contaminated with mine water, but the indications are not as clear. Water from these three wells is slightly above the range in concentrations in background wells for some of the mine-water indicator constituents. For example, the range of sulfate concentrations for filtered samples was 16.8–35.4 mg/L at Commerce 2, 17.8–19.1 mg/L at Commerce 4, and 10.8–26.6 mg/L at Quapaw 4. However, these wells produced water with no measurable tritium. An explanation to account for slightly elevated concentrations of mine-water indicator constituents but no measurable tritium is that these three wells are producing water containing a small fraction of mine-water contamination. The fraction could be large enough to elevate some mine-water indicator parameters but not large enough to raise tritium concentrations above the laboratory minimum reporting level. In the case of Commerce 2 and 4, the presence of nearby wells (Commerce 1 and 3) that are contaminated lends credibility to this explanation.

Ottawa County Rural Water District 4 Well 4, does not appear to be contaminated. Mine-water indicator parameters measured at this well generally were within the range of background concentrations, and the well produced no measurable tritium.

Comparison of Produced Water to Water-Quality Standards

All of the wells in the Picher mining district and most of the wells outside the mining district sampled for this investigation are public-supply wells. The municipalities that produce water from these wells are governed by water-quality standards. These water-quality standards are the maximum contaminant levels (MCL's), promulgated to protect public health (U.S. Environmental Protection Agency, 1988a), and secondary maximum contaminant levels (SMCL's), promulgated for aesthetic reasons related to public acceptance of drinking water

(U.S. Environmental Protection Agency, 1988b). Although only filtered samples were used in the "Analysis of Data" section of this report, filtered and unfiltered samples are discussed in this section, as the population served by these wells drinks unfiltered water.

No samples, filtered or unfiltered, ever exceeded the Maximum Contaminant Levels for arsenic, barium, cadmium, chromium, or silver. No samples, filtered or unfiltered, ever exceeded the Secondary Maximum Contaminant Levels for chloride, copper, manganese, or zinc, and pH was between 6.5 and 8.5 for every sample.

The MCL for mercury was exceeded in the sample collected from Picher 3 in September 1992. The MCL for selenium was exceeded in samples collected in one month at Commerce 1, Commerce 2, Commerce 4, Picher 2, Picher 4, Quapaw 2, Ottawa County RWD 4 Well 4, and the Joe Cook well (which was sampled only once). The MCL for selenium was exceeded for two months at Cardin, Picher 3, and Quapaw 4.

The SMCL for iron was exceeded repeatedly at Commerce 3, Picher 2, Picher 3, Picher 4, and Quapaw 2. The SMCL for iron was exceeded once at Quapaw 4, but this was an unfiltered sample and was affected by particulate matter off the pump or casing, not reflective of the quality of the water produced from the Roubidoux aquifer. Similarly, the only time Miami 3 was sampled the unfiltered samples exceeded the iron SMCL but the filtered sample did not, again pointing to particulate matter and not the quality of the water produced from the Roubidoux aquifer. The sulfate SMCL was exceeded for filtered and unfiltered samples from Picher 3 collected in January 1993. The sulfate SMCL was exceeded for filtered and unfiltered samples from Picher 4 for all six monthly samplings.

Summary

The Roubidoux aquifer in northeastern Oklahoma is used extensively as a source of water for public supplies, commerce, industry, and rural water districts. Much of the water use from the aquifer in Oklahoma occurs in Ottawa County. The Roubidoux aquifer consists of the Cotter and Jefferson City Dolomites, the Roubidoux Formation, and the Gasconade Dolomite. The primary water-yielding geologic unit is the Roubidoux Formation, which is found at depths ranging from 230 to 320 meters below land surface in Ottawa County. Water in the Roubidoux aquifer in eastern Ottawa County has relatively low dissolved-solids concentrations (less than 200 mg/L) with calcium, magnesium, and bicarbonate as the major ions.

The Boone Formation is stratigraphically above the Roubidoux aquifer and crops out in eastern Ottawa County. The Boone Formation in Ottawa County is the host rock for zinc and lead sulfide ores, with the richest deposits located in the vicinity of the City of Picher. Mining in what became known as the Picher mining district began in the early the 1900's and continued until about 1970. The mines were dewatered during mining

operations but later filled with water when pumping ceased. The water in the abandoned zinc and lead mines contains high concentrations of calcium, magnesium, bicarbonate, sulfate, fluoride, cadmium, copper, iron, lead, manganese, nickel, and zinc.

Water began flowing from the abandoned mines in the late 1970's. When the U.S. Environmental Protection Agency created the Superfund Program in the early 1980's to clean up hazardous sites across the United States, the area in the vicinity of the Picher mining district was added to the list. The site generally is called the Tar Creek Superfund site because many of the mines discharge into the Tar Creek drainage basin.

Water from the abandoned mines is a potential source of contamination to the Roubidoux aquifer and to wells completed in the Roubidoux aquifer. In particular, the 10 public-supply wells for the cities of Cardin, Commerce, Picher, and Quapaw, which are located within the Picher mining district, are the wells most likely to be contaminated by the water from the abandoned mines. Water from the abandoned mines could be entering the wells in the Picher mining district by several possible paths: (1) discontinuities in the casing, (2) water migrating in the annular space between the casing and the well bore and entering the well at the foot of the casing, (3) water flowing downward through the geologic units below the abandoned mines and flowing laterally into the well, and (4) some combination of factors one through three.

The U.S. Geological Survey, in cooperation with the Oklahoma Water Resources Board, conducted an investigation to determine if these 10 wells are contaminated by water from the abandoned mines. Water samples were collected from these 10 wells; additional samples were collected from wells outside the mining district to establish background concentrations. Hypothesis testing was used to compare: (1) current (1992-93) water quality in the Picher mining district wells to background wells, and (2) current (1992-93) to historic (1981-83) water quality in the Picher mining district wells.

The sampling was conducted monthly between August 17, 1992, and January 28, 1993. At each well filtered and unfiltered samples were collected and analyzed for major ions and trace metals. The samples were sent to two different laboratories to quantify the analytical variance. At least three samples were collected at each well; one unfiltered sample was sent to a laboratory designated by the U.S. Environmental Protection Agency through their Contract Laboratory Program and two samples, one of unfiltered water and one of filtered water (for dissolved constituents), were sent to the U.S. Environmental Protection Agency's Robert S. Kerr Environmental Research Laboratory in Ada, Oklahoma. Comparison of the analyses of filtered and unfiltered samples showed that some unfiltered samples were affected by particulate matter in the well, probably scale from the casing or pump column, and were not suitable for statistical analysis.

Quality-assurance sampling was used to evaluate the precision and accuracy of the environmental samples. The quality-assurance samples included blank samples and duplicate samples. The results of the blank sample shows that some of the

constituents that are potential indicators of mine-water contamination are affected by sampling contamination. Cadmium in filtered samples, copper in unfiltered samples, and lead in filtered and unfiltered samples had sampling contamination problems because these constituents were found at concentrations greater than the minimum report level in at least one blank sample, and the concentrations in blank samples were in the same range as the concentrations in environmental samples. Because of these sampling contamination problems, these constituents were not used in any interpretation of the environmental data. Results of the duplicate samples show that the constituent concentrations are reproducible in environmental samples.

The chemical analyses of water samples collected for this investigation indicate that at least 7 of the 10 public supply wells in the Picher mining district are contaminated by mine water. Application of the Mann-Whitney test indicated that the concentrations of some chemical constituents that are indicators of mine-water contamination are different in water samples from wells in the mining area as compared to wells outside the mining area. Application of the Wilcoxon signed-rank test showed that the concentrations of some chemical constituents that are indicators of mine-water contamination were different in current (1992-93) data than in historic (1981-83) data. Comparison of historic (1981-83) and current (1992-93) data generally indicate that pH has decreased and calcium, magnesium and sulfate concentrations have increased over time.

Examination of the chemical analyses from individual wells shows which wells are contaminated. The sulfate concentrations at Cardin, Commerce 1, Commerce 3, Picher 2, Picher 3, Picher 4, and Quapaw 2 were always greater than the concentrations in background wells for all of the six monthly sampling trips. Most of the other mine-water indicator constituents, including alkalinity, bicarbonate, calcium, magnesium, and iron, also show that the same wells are contaminated. In the same seven wells, manganese and zinc concentrations also appear to be elevated above background concentrations, although the evidence is not as clear because of the presence of censored data. The pH in these seven wells tends to be lower than in the background wells, which is consistent with these wells being contaminated by mine water.

Measurable concentrations of tritium were reported in six of these seven wells. Picher 3, the seventh well, was not sampled for tritium because funding was limited and this well is within 20 meters of Picher 2, and was assumed to be producing the same water as Picher 2. The tritium data indicate a component of recent (post-1952) water is present in these same 7 wells (assuming Picher 3 has a similar tritium concentration as Picher 2), which tends to corroborate that these seven wells are contaminated by mine water.

Commerce 2, Commerce 4, and Quapaw 4 also may be contaminated with mine water, but the indications are not as clear. Concentrations of some of the mine-water indicator constituents from these three wells is slightly above the range in concentrations in background wells. However, these wells produced water with no measurable tritium. An explanation to account for slightly elevated concentrations of mine-water indi-

cator constituents but no measurable tritium is that these three wells are producing water containing a small fraction of mine-water contamination. The fraction could be large enough to elevate some mine-water indicator parameters but not large enough to raise tritium concentrations above the laboratory minimum reporting level. In the case of Commerce 2 and 4, the presence of nearby wells (Commerce 1 and 3) that are contaminated lends credibility to this explanation.

Ottawa County Rural Water District 4 Well 4 does not appear to be contaminated. Mine-water indicator parameters measured at this well generally were within the range of background concentrations, and the well produced no measurable tritium.

No samples, filtered or unfiltered, ever exceeded the Maximum Contaminant Levels for arsenic, barium, cadmium, chromium, or silver. No samples, filtered or unfiltered, ever exceeded the Secondary Maximum Contaminant Levels for chloride, copper, manganese, or zinc, and pH was between 6.5 and 8.5 for every sample. The MCL for mercury was exceeded in the sample collected from Picher 3 in September 1992. The MCL for selenium was exceeded in at least one sample collected at Cardin, Commerce 1, Commerce 2, Commerce 4, Picher 2, Picher 3, Picher 4, Quapaw 2, Quapaw 4, Ottawa County RWD 4 Well 4, and one background well. The SMCL for iron was exceeded repeatedly at Commerce 3, Picher 2, Picher 3, Picher 4, and Quapaw 2. The sulfate SMCL was exceeded for filtered and unfiltered samples from Picher 3 collected in January 1993. The sulfate SMCL was exceeded for filtered and unfiltered samples from Picher 4 for all six monthly samplings.

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Appendixes

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells

[Filter type: F, filtered; U, unfiltered. Sample type: Env, environmental sample; EnvD, environmental sample (duplicate). Agency analyzing: CLP, U. S. Environmental Protection Agency contract laboratory program; RSK, Robert S. Kerr Environmental Research Laboratory. $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25°C, mg/L, milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter]

Owner or well name	Date	Time	Filter type	Sample type	Agency analyzing	Specific conductance ($\mu\text{S}/\text{cm}$)	pH	Temperature (°C)	Alkalinity (mg/L as CaCO_3)	Calcium (mg/L)	Magnesium (mg/L)
Cardin	08-18-92	1050	U	Env	CLP	460	7.26	19.2	132	46.2	21.6
Cardin	08-18-92	1053	U	Env	RSK	460	7.26	19.2	132	51	23.4
Cardin	08-18-92	1054	F	Env	RSK	460	7.26	19.2	132	50.2	23
Cardin	09-22-92	0900	U	Env	CLP	456	7.56	19.2	140	47.2	21.7
Cardin	09-22-92	0901	U	EnvD	CLP	456	7.56	19.2	140	44.7	20.6
Cardin	09-22-92	0903	U	Env	RSK	456	7.56	19.2	140	48.3	22.6
Cardin	09-22-92	0904	F	Env	RSK	456	7.56	19.2	140	48.1	22.4
Cardin	10-21-92	0900	U	Env	CLP	437	7.62	19.1	136	45.9	20.1
Cardin	10-21-92	0903	U	Env	RSK	437	7.62	19.1	136	48.2	23
Cardin	10-21-92	0904	F	Env	RSK	437	7.62	19.1	136	46.7	22.2
Cardin	11-17-92	1050	U	Env	CLP	455	7.5	19.1	133	47.1	20.8
Cardin	11-17-92	1053	U	Env	RSK	455	7.5	19.1	133	48.3	22.4
Cardin	11-17-92	1054	F	Env	RSK	455	7.5	19.1	133	47.5	22.1
Cardin	12-14-92	0920	U	Env	CLP	469	7.45	19.1	134	47	21.7
Cardin	12-14-92	0921	U	EnvD	CLP	469	7.45	19.1	134	46.7	21.3
Cardin	12-14-92	0923	U	Env	RSK	469	7.45	19.1	134	47.6	21.9
Cardin	12-14-92	0924	F	Env	RSK	469	7.45	19.1	134	48.1	22.2
Cardin	01-25-93	0920	U	Env	CLP	461	7.5	19.1	138	48.5	22.1
Cardin	01-25-93	0921	U	EnvD	CLP	461	7.5	19.1	138	46.8	21.6
Cardin	01-25-93	0923	U	Env	RSK	461	7.5	19.1	138	48.6	22.5
Cardin	01-25-93	0924	F	Env	RSK	461	7.5	19.1	138	45.9	21.4
Commerce 1	08-17-92	0930	U	Env	CLP	480	7.4	19.7	136	45	19.8
Commerce 1	08-17-92	0931	U	EnvD	CLP	480	7.4	19.7	136	44.7	19.7
Commerce 1	08-17-92	0933	U	Env	RSK	480	7.4	19.7	136	48	21.1
Commerce 1	08-17-92	0934	F	Env	RSK	480	7.4	19.7	136	47	20.5

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)
Cardin	08-18-92	1050	12.7	2.23	161	67.2	--	<42	<32.2	<2.6	63.1	<1.6
Cardin	08-18-92	1053	14.6	2	161	70.6	20.8	<52	--	<39	68.2	.3
Cardin	08-18-92	1054	13.7	1.9	161	70.3	21.1	<52	--	<39	66.8	.1
Cardin	09-22-92	0900	13.1	2.12	171	69.2	--	<21.4	<16.9	<1.9	63.3	<.4
Cardin	09-22-92	0901	12.4	2.05	171	77.5	--	<21.4	<16.9	<1.9	59.8	<.4
Cardin	09-22-92	0903	14.7	1.9	171	70.8	21.7	<76	--	<5.9	68.6	<.9
Cardin	09-22-92	0904	13.7	2.1	171	70.6	21.4	<76	--	<5.9	68.8	<.9
Cardin	10-21-92	0900	12	1.4	166	37.51	--	<25	<32	1.1	62.1	<1
Cardin	10-21-92	0903	15.2	3.41	166	67.4	19.9	<37	--	<12	68.9	<.2
Cardin	10-21-92	0904	13.5	3.47	166	69.2	21.2	<37	--	<12	66.8	<.2
Cardin	11-17-92	1050	12.4	2.19	162	70	--	<61	<31	<4	66.1	<1
Cardin	11-17-92	1053	14.1	2.13	162	73.1	22.7	<26	--	<10	67.1	<.5
Cardin	11-17-92	1054	13	2.28	162	72.1	22.6	69	--	<10	66.1	<.5
Cardin	12-14-92	0920	13	2.45	163	73	23.3	<25	<32	<1	71.3	<1
Cardin	12-14-92	0921	12.8	2.57	163	72.6	23.1	<25	<32	<1	69.5	<1
Cardin	12-14-92	0923	12.6	3.27	163	73	23.3	<67	--	24	65.3	.2
Cardin	12-14-92	0924	12.8	2.82	163	82	37.9	<67	--	<23	65.6	<.2
Cardin	01-25-93	0920	12.7	2.62	168	65.3	20.4	<30.8	<24.3	<1.5	66.4	<1.7
Cardin	01-25-93	0921	13.3	2.42	168	65.5	20.4	<30.8	<24.3	<1.5	64.8	<1.7
Cardin	01-25-93	0923	13.6	1.25	168	67	21.2	6	--	<18	67.2	<.5
Cardin	01-25-93	0924	12.5	1.69	168	66.3	20.8	72	--	<18	63.8	.1
Commerce 1	08-17-92	0930	20.4	2.5	166	55	--	<42	<32.2	<2.6	46.7	<1.6
Commerce 1	08-17-92	0931	20.2	2.46	166	59.7	--	<42	<32.2	<2.6	46.4	<1.6
Commerce 1	08-17-92	0933	23	2.7	166	59.7	34.7	<52	--	<39	48.6	<.5
Commerce 1	08-17-92	0934	20.7	1.7	166	59.9	35.1	<52	--	<39	49.6	<.5

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Boron (µg/L)	Cad- mium (µg/L)	Chro- mium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/ L)	Lead (µg/L)	Lithium (µg/L)	Manga- nese (µg/L)	Mercury (µg/L)
Cardin	08-18-92	1050	--	<3.6	<4.1	<14	<2.7	173	<12	--	<.8	<.2
Cardin	08-18-92	1053	<15	<1.6	<1.9	<4.3	<50	192	<18	18.7	9.3	--
Cardin	08-18-92	1054	<14	<1.6	<1.9	<4.3	<50	184	<18	17.9	9.3	--
Cardin	09-22-92	0900	--	<1	<4.5	<2.7	<3.5	170	2.1	--	8	<.1
Cardin	09-22-92	0901	--	<1	<4.5	<2.7	<3.5	167	1.6	--	7.3	.16
Cardin	09-22-92	0903	<28	<2.3	<2.4	<3.5	<51	<94	<26	23.6	<7.9	--
Cardin	09-22-92	0904	<28	<2.3	<2.4	<3.5	<51	124	237	23.7	<7.9	--
Cardin	10-21-92	0900	--	<4	<3	<5	<4	145	1.9	--	8	<.2
Cardin	10-21-92	0903	37.5	<1.7	2.2	<1.8	<4.8	150	<22	33.4	8.4	--
Cardin	10-21-92	0904	41.4	<1.7	<.8	<1.8	<4.8	152	<22	34.3	8.4	--
Cardin	11-17-92	1050	--	<3	<8	<7	8.2	164	2.3	--	8.7	<.2
Cardin	11-17-92	1053	36.1	<2.1	2.1	<2.7	<20	170	<17	21.4	5.7	--
Cardin	11-17-92	1054	36.9	<2.1	16	<2.7	<20	238	<17	21.9	6.9	--
Cardin	12-14-92	0920	--	<4	<3	<5	<4	143	2	--	7.5	<.2
Cardin	12-14-92	0921	--	<4	<3	<5	<4	143	<1	--	6.6	<.2
Cardin	12-14-92	0923	<50	3.8	2.5	1.8	<15	125	<20	29.1	9.4	--
Cardin	12-14-92	0924	<50	<2.6	<1.4	<1.7	<15	121	<20	28.6	8.5	--
Cardin	01-25-93	0920	--	<2.3	<5.7	<10.6	2.8	172	<14	--	7.6	<.2
Cardin	01-25-93	0921	--	<2.3	<5.7	<10.6	<2.6	167	<14	--	7.2	<.2
Cardin	01-25-93	0923	28	<1.6	<2.3	<8.2	<38	140	<8.1	27.3	4.2	--
Cardin	01-25-93	0924	34	1.8	3.3	<8.2	<38	173	<8.1	30.4	4.3	--
Commerce 1	08-17-92	0930	--	<3.6	<4.1	<14	3.5	255	<1.2	--	<.8	<.2
Commerce 1	08-17-92	0931	--	<3.6	<4.1	<14	<2.7	208	<12	--	<.8	<.2
Commerce 1	08-17-92	0933	<12	<1.6	<1.9	<4.3	<50	109	<18	26.8	3.8	--
Commerce 1	08-17-92	0934	<14	<1.6	<1.9	<4.3	<50	225	<18	22.4	6.6	--

Appendix 1. Physical properties and concentrations of major ions and trace elements in samples from wells—Continued

Owner or well name	Date	Time	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Strontium (µg/L)	Thallium (µg/L)	Titanium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
Cardin	08-18-92	1050	--	<14.5	<1.6	<2	--	<1.2	--	<5	9.6
Cardin	08-18-92	1053	3.8	<5.6	11.1	<3.8	493	<24	<17	<14	<6.1
Cardin	08-18-92	1054	<2.3	<5.6	<7.5	<3.8	484	<24	<17	<14	6.2
Cardin	09-22-92	0900	--	<5.4	<2.9	2.6	--	<3.8	--	<2.8	11.9
Cardin	09-22-92	0901	--	<5.4	<2.9	<2.5	--	<3.8	--	<2.8	8.8
Cardin	09-22-92	0903	<2.2	<4.1	<10	<3.4	46	<19	<2.4	<8.6	<7.6
Cardin	09-22-92	0904	<2.2	<4.1	<10	<3.4	45.7	<19	6.4	<8.6	<7.6
Cardin	10-21-92	0900	--	<5	<1	<4	--	<1	--	<3	6.7
Cardin	10-21-92	0903	<2.7	<4.6	<26	<6.1	49.2	11	7.8	<13	<40
Cardin	10-21-92	0904	<2.7	<4.6	<26	<6.1	48	16	8.9	<13	<40
Cardin	11-17-92	1050	--	<7	<1	<5	--	<2	--	<6	11
Cardin	11-17-92	1053	<2.8	<8.1	<24	<6.4	45	<18	<1.9	<13	4.6
Cardin	11-17-92	1054	<2.8	<8.1	<24	<6.4	44.5	<18	4.4	<13	<3.6
Cardin	12-14-92	0920	--	<5	1.6	<4	--	<1	--	<3	6.1
Cardin	12-14-92	0921	--	<5	<1	<4	--	<1	--	<3	6.8
Cardin	12-14-92	0923	3	9.2	23.2	10.8	41.9	<15	6.9	<24	<1.5
Cardin	12-14-92	0924	<1.3	<8.9	<9.9	<7.4	42.5	<15	<5.6	<24	<1.5
Cardin	01-25-93	0920	--	<8.8	<.9	<4	--	<2.5	--	3.8	9.1
Cardin	01-25-93	0921	--	<8.8	<.9	<4	--	<2.5	--	<3.7	9.4
Cardin	01-25-93	0923	<3.6	5.1	<21	<7.8	490	<8.1	.6	<13	<3.2
Cardin	01-25-93	0924	<3.6	21.9	<21	<7.8	470	<8.1	4.7	<13	<3.2
Commerce 1	08-17-92	0930	--	<14.5	<1.6	<2	--	<1.2	--	<5	9.7
Commerce 1	08-17-92	0931	--	<14.5	<1.6	<2	--	<1.2	--	<5	6.4
Commerce 1	08-17-92	0933	<2.3	<5.6	<7.5	<3.8	484	<24	<17	<14	<6.1
Commerce 1	08-17-92	0934	2.8	<5.6	<7.5	<3.8	486	<24	<17	<14	<6.1

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Filter type	Sample type	Agency analyzing	Specific conductance ($\mu\text{S}/\text{cm}$)	pH	Temperature ($^{\circ}\text{C}$)	Alkalinity (mg/L as CaCO_3)	Calcium (mg/L)	Magnesium (mg/L)
Commerce 1	09-23-92	1050	U	Env	CLP	483	7.39	19.6	130	43.8	19
Commerce 1	09-23-92	1053	U	Env	RSK	483	7.39	19.6	130	46	20.2
Commerce 1	09-23-92	1054	F	Env	RSK	483	7.39	19.6	130	45.2	20
Commerce 1	10-21-92	1140	U	Env	CLP	480	7.47	19.7	136	46.7	19.3
Commerce 1	10-21-92	1143	U	Env	RSK	480	7.47	19.7	136	48.1	21.6
Commerce 1	10-21-92	1144	F	Env	RSK	480	7.47	19.7	136	47.5	21.3
Commerce 1	11-17-92	1200	U	Env	CLP	485	7.41	19.6	138	46.8	19.4
Commerce 1	11-17-92	1203	U	Env	RSK	485	7.41	19.6	138	47.3	20.7
Commerce 1	11-17-92	1204	F	Env	RSK	485	7.41	19.6	138	45.4	20.2
Commerce 1	12-14-92	1120	U	Env	CLP	477	7.44	19.5	136	44.7	19.1
Commerce 1	12-14-92	1123	U	Env	RSK	477	7.44	19.5	136	46.8	20.4
Commerce 1	12-14-92	1124	F	Env	RSK	477	7.44	19.5	136	46	20.1
Commerce 1	01-26-93	1050	U	Env	CLP	459	7.5	19.5	134	45	19.5
Commerce 1	01-26-93	1053	U	Env	RSK	459	7.5	19.5	134	45.1	20
Commerce 1	01-26-93	1054	F	Env	RSK	459	7.5	19.5	134	44.9	19.9
Commerce 2	08-17-92	1100	U	Env	CLP	342	7.61	19.9	128	34.2	15.5
Commerce 2	08-17-92	1103	U	Env	RSK	342	7.61	19.9	128	35.8	16.3
Commerce 2	08-17-92	1104	F	Env	RSK	342	7.61	19.9	128	34.5	15.6
Commerce 2	09-23-92	1150	U	Env	CLP	337	7.67	19.5	123	33.5	14.9
Commerce 2	09-23-92	1153	U	Env	RSK	337	7.67	19.5	123	35	15.9
Commerce 2	09-23-92	1154	F	Env	RSK	337	7.67	19.5	123	34.4	15.6
Commerce 2	10-21-92	1030	U	Env	CLP	329	7.71	19.7	124	34.4	14.7
Commerce 2	10-21-92	1031	U	EnvD	CLP	329	7.71	19.7	124	34.3	14.5
Commerce 2	10-21-92	1033	U	Env	RSK	329	7.71	19.7	124	35.2	16.3
Commerce 2	10-21-92	1034	F	Env	RSK	329	7.71	19.7	124	34.4	15.9

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)
Commerce 1	09-23-92	1050	20.2	2.52	159	66.7	--	<21.4	<16.9	<1.9	46.9	<.4
Commerce 1	09-23-92	1053	22.3	2.4	159	59	35.6	<76	--	<5.9	52.2	<.9
Commerce 1	09-23-92	1054	21.4	2.4	159	58.6	35.5	<76	--	<5.9	52.2	<.9
Commerce 1	10-21-92	1140	19.9	1.92	166	48.05	--	<25	<32	2	52.3	<1
Commerce 1	10-21-92	1143	25.4	4.07	166	58.4	35.3	<37	--	<12	56	<.2
Commerce 1	10-21-92	1144	24.3	3.85	166	56.1	35.3	<37	--	<12	56.3	<.2
Commerce 1	11-17-92	1200	19.9	2.62	168	26	--	<61	<31	<4	52.5	<1
Commerce 1	11-17-92	1203	21.7	2.76	168	61.4	35.3	<26	--	<10	50.3	<5
Commerce 1	11-17-92	1204	22.2	3	168	61	35.1	<32	--	<10	50.3	<.5
Commerce 1	12-14-92	1120	20.2	3.72	166	58.1	35.4	<25	<32	<1	52	<1
Commerce 1	12-14-92	1123	20.9	2.73	166	57.3	34.6	<67	--	<23	50.6	<.2
Commerce 1	12-14-92	1124	20.9	2.61	166	56.9	34.9	<67	--	<23	51.4	<.2
Commerce 1	01-26-93	1050	19.4	3.28	163	50.7	31	<30.8	24.6	<1.5	49.9	<1.7
Commerce 1	01-26-93	1053	21.1	1.69	163	53.1	32.8	<59	--	<18	49.6	.2
Commerce 1	01-26-93	1054	21	1.87	163	52.8	32.6	<59	--	<18	50.5	.1
Commerce 2	08-17-92	1100	11.9	1.98	156	35.8	--	<42	<32.2	<2.6	33.7	<1.6
Commerce 2	08-17-92	1103	13.6	1.7	156	33.4	12.9	<52	--	<39	36.3	<5
Commerce 2	08-17-92	1104	12.4	1.4	156	34	12.8	<52	--	<39	34.9	<5
Commerce 2	09-23-92	1150	12.3	1.95	150	31.9	--	<21.4	<16.9	<1.9	34	<.4
Commerce 2	09-23-92	1153	14.1	1.4	150	31.8	12.1	<76	--	<5.8	39.2	<.9
Commerce 2	09-23-92	1154	13.5	1.5	150	31	12.5	<76	--	<5.8	40.4	<.9
Commerce 2	10-21-92	1030	11.5	1.83	151	28.2	--	<25	<32	<1	36.5	<1
Commerce 2	10-21-92	1031	11.4	1.71	151	20.83	--	29.9	<32	<1	35.2	<1
Commerce 2	10-21-92	1033	14.3	3.28	151	35.6	11.4	<37	--	<12	38.8	<.2
Commerce 2	10-21-92	1034	11.6	3.07	151	35.4	7.82	<37	--	18	39.2	<.2

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Boron (µg/L)	Cad- mium (µg/L)	Chro- mium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)	Manga- nese (µg/L)	Mercury (µg/L)
Commerce 1	09-23-92	1050	--	<1	<4.5	<2.7	<3.5	251	3.7	--	4.7	.31
Commerce 1	09-23-92	1053	<25	<2.3	<2.4	<3.5	<51	188	<26	30.5	<7.9	--
Commerce 1	09-23-92	1054	<25	<2.3	<2.4	4.2	<51	189	<26	30.6	<7.9	--
Commerce 1	10-21-92	1140	--	<4	<3	<5	<4	206	2.4	--	5	<.2
Commerce 1	10-21-92	1143	79.8	<1.7	1.2	<1.8	<4.8	223	<22	43.3	2.7	--
Commerce 1	10-21-92	1144	80.3	<1.7	<.8	<1.8	<4.8	197	<22	40.4	3.6	--
Commerce 1	11-17-92	1200	--	<3	<8	<7	9	297	2.4	--	5.2	<.2
Commerce 1	11-17-92	1203	64.4	<2.1	<1.6	<2.7	<20	198	<17	30.8	3	--
Commerce 1	11-17-92	1204	77	<1.3	<2.9	<7.1	<26	192	<7.8	36.1	4.6	--
Commerce 1	12-14-92	1120	--	<4	<3	<5	50.9	227	<1	--	5.1	<.2
Commerce 1	12-14-92	1123	70	<2.6	<1.4	<1.7	<15	246	<20	34.9	3.7	--
Commerce 1	12-14-92	1124	73	<2.6	<1.4	<1.7	<15	164	<20	32.9	4.7	--
Commerce 1	01-26-93	1050	--	<2.3	<5.7	<10.6	<2.6	189	<1.4	--	5.2	<.2
Commerce 1	01-26-93	1053	58	<1.6	<2.3	<8.2	<38	168	<8.1	32.9	<2.3	--
Commerce 1	01-26-93	1054	66	<1.6	<2.3	<8.2	<38	163	<8.1	37.8	<2.3	--
Commerce 2	08-17-92	1100	--	<3.6	<4.1	<14	<2.7	131	<1.2	--	<.8	<.2
Commerce 2	08-17-92	1103	<12	<1.6	<1.9	<4.3	<50	150	<18	19.4	<3.7	--
Commerce 2	08-17-92	1104	<12	<1.6	<1.9	<4.3	<50	107	<18	17.3	<3.7	--
Commerce 2	09-23-92	1150	--	<1	<4.5	<2.7	<3.5	251	4	--	<4.7	.16
Commerce 2	09-23-92	1153	<20	<2.3	3.1	<3.5	<51	<94	<26	25.2	<7.8	--
Commerce 2	09-23-92	1154	<20	<2.3	<2.4	<3.5	<51	<94	<26	27.3	<7.8	--
Commerce 2	10-21-92	1030	--	<4	<3	<5	5	127	1	--	3.9	<.2
Commerce 2	10-21-92	1031	--	<4	<3	<5	6.3	122	1.8	--	3.9	<.2
Commerce 2	10-21-92	1033	67.3	<1.7	1.1	<1.8	<4.8	160	<22	35	2.7	--
Commerce 2	10-21-92	1034	71.9	<1.7	1.8	<1.8	<4.8	124	<22	33.7	4.6	--

Appendix 1. Physical properties and concentrations of major ions and trace elements in samples from wells—Continued

Owner or well name	Date	Time	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Strontium (µg/L)	Thallium (µg/L)	Titanium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
Commerce 1	09-23-92	1050	--	<5.4	<2.9	<2.5	--	<3.8	--	<2.8	6.6
Commerce 1	09-23-92	1053	<2.2	<4.1	<10	<3.4	46.1	<19	3.8	<8.6	<7.6
Commerce 1	09-23-92	1054	<2.2	<4.1	<10	<3.4	45.2	<19	9.3	<8.6	<7.6
Commerce 1	10-21-92	1140	--	<5	<1	<4	--	<1	--	<3	4.7
Commerce 1	10-21-92	1143	<2.7	<4.6	<26	<6.1	47.7	12	6.7	<13	<40
Commerce 1	10-21-92	1144	<2.7	<4.6	<26	<6.1	47.3	23	6.7	<13	<40
Commerce 1	11-17-92	1200	--	<7	<1	<5	--	<2	--	<6	33.9
Commerce 1	11-17-92	1203	3.5	<8.1	<24	<6.4	47.3	<18	2.1	<13	<3.6
Commerce 1	11-17-92	1204	<4.2	<8.1	<13	<1.8	47.3	5	<9	<4.7	<1.3
Commerce 1	12-14-92	1120	--	15	<1	<4	--	<1	--	<3	3.5
Commerce 1	12-14-92	1123	1.5	<8.9	<9.9	<7.4	45.7	<15	<5.6	<24	5.9
Commerce 1	12-14-92	1124	1.4	<8.9	10.9	<7.4	44.9	<15	<5.6	<24	<1.5
Commerce 1	01-26-93	1050	--	<8.8	<.9	<4	--	<2.5	--	5.7	3.9
Commerce 1	01-26-93	1053	<3.6	4.5	<21	<7.8	470	<8.1	<1.3	<13	<3.2
Commerce 1	01-26-93	1054	<3.6	15.6	<21	<7.8	467	8.5	<1.3	<13	<3.2
Commerce 2	08-17-92	1100	--	<14.5	<1.6	<2	--	<1.2	--	<5	5
Commerce 2	08-17-92	1103	2.3	<5.6	<7.5	<3.8	428	<24	<17	<14	<6.1
Commerce 2	08-17-92	1104	2.4	<5.6	<7.5	<3.8	414	<24	<17	<14	<6.1
Commerce 2	09-23-92	1150	--	<5.4	<2.9	<2.5	--	<3.8	--	<2.8	5.8
Commerce 2	09-23-92	1153	<2.2	<4.1	<10	<3.4	44.2	<19	<2.4	<8.6	<7.6
Commerce 2	09-23-92	1154	<2.2	<4.1	<10	<3.4	44.4	<19	3.1	<8.6	<7.6
Commerce 2	10-21-92	1030	--	5.5	<1	<4	--	<1	--	<3	10.4
Commerce 2	10-21-92	1031	--	5.9	<1	<4	--	<1	--	<3	10.4
Commerce 2	10-21-92	1033	<2.7	<4.6	<26	<6.1	42.3	19	4.4	<13	<40
Commerce 2	10-21-92	1034	<2.7	<4.6	<26	6.3	41.3	11	5.6	<13	<40

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Filter type	Sample type	Agency analyzing	Specific conductance (µS/cm)	pH	Temperature (°C)	Alkalinity (mg/L as CaCO ₃)	Calcium (mg/L)	Magnesium (mg/L)
Commerce 2	11-17-92	1250	U	Env	CLP	284	7.85	18.8	126	33.1	14.2
Commerce 2	11-17-92	1253	U	Env	RSK	284	7.85	18.8	126	32.3	15
Commerce 2	11-17-92	1254	F	Env	RSK	284	7.85	18.8	126	34	15.5
Commerce 2	12-14-92	1310	U	Env	CLP	321	7.81	19.6	122	30.8	13.5
Commerce 2	12-14-92	1313	U	Env	RSK	321	7.81	19.6	122	32.7	14.8
Commerce 2	12-14-92	1314	F	Env	RSK	321	7.81	19.6	122	32.3	14.6
Commerce 2	01-26-93	1130	U	Env	CLP	296	7.77	19.2	124	28.3	12.7
Commerce 2	01-26-93	1133	U	Env	RSK	296	7.77	19.2	124	28	12.9
Commerce 2	01-26-93	1134	F	Env	RSK	296	7.77	19.2	124	28.6	13.2
Commerce 3	08-17-92	1340	U	Env	CLP	796	6.96	20.9	156	65.1	26
Commerce 3	08-17-92	1343	U	Env	RSK	796	6.96	20.9	156	69.1	27.1
Commerce 3	08-17-92	1344	F	Env	RSK	796	6.96	20.9	156	72.3	28.5
Commerce 3	09-23-92	1350	U	Env	CLP	763	7.24	20.8	144	66.3	26.1
Commerce 3	09-23-92	1353	U	Env	RSK	763	7.24	20.8	144	68	27.2
Commerce 3	09-23-92	1354	F	Env	RSK	763	7.24	20.8	144	68.4	27.3
Commerce 3	10-21-92	1520	U	Env	CLP	841	7.32	20.9	168	68.9	25.9
Commerce 3	10-21-92	1523	U	Env	RSK	841	7.32	20.9	168	70.8	28.5
Commerce 3	10-21-92	1524	F	Env	RSK	841	7.32	20.9	168	69.4	27.9
Commerce 3	11-17-92	1440	U	Env	CLP	765	7.3	20.7	159	68.7	26
Commerce 3	11-17-92	1443	U	Env	RSK	765	7.3	20.7	159	67.5	26.7
Commerce 3	11-17-92	1444	F	Env	RSK	765	7.3	20.7	159	68.2	27
Commerce 3	12-14-92	1410	U	Env	CLP	760	7.26	20.7	160	68.1	25.6
Commerce 3	12-14-92	1413	U	Env	RSK	760	7.26	20.7	160	70.1	27.2
Commerce 3	12-14-92	1414	F	Env	RSK	760	7.26	20.7	160	70.3	27.2
Commerce 3	01-26-93	1400	U	Env	CLP	790	7.01	20.7	158	66.5	25.8
Commerce 3	01-26-93	1401	U	EnvD	CLP	790	7.01	20.7	158	67.1	25.9
Commerce 3	01-26-93	1403	U	Env	RSK	790	7.01	20.7	158	69.9	27.5
Commerce 3	01-26-93	1404	F	Env	RSK	790	7.01	20.7	158	70.2	27.7

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)
Commerce 2	11-17-92	1250	11.5	2.03	154	30	--	<61	<31	<4	36.8	<1
Commerce 2	11-17-92	1253	13.7	<2.1	154	29.4	11.3	<32	--	<10	37.3	<.5
Commerce 2	11-17-92	1254	12.9	1.9	154	29	13.3	<26	--	<10	37	<.5
Commerce 2	12-14-92	1310	12.2	2.58	149	27.5	13.5	27.3	<32	<1	39.7	<1
Commerce 2	12-14-92	1313	12.5	2.5	149	26	11.1	<67	--	<23	39.2	<.2
Commerce 2	12-14-92	1314	12.3	3.02	149	27.3	12.1	106	--	<23	39.7	.3
Commerce 2	01-26-93	1130	13.3	3.6	151	17.1	10.4	<30.8	<24.3	<1.5	45	<1.7
Commerce 2	01-26-93	1133	14	1.99	151	17	10	<59	--	<18	45.9	.1
Commerce 2	01-26-93	1134	14.7	1.91	151	16.8	10	<59	--	<18	47.8	.1
Commerce 3	08-17-92	1340	51.3	3.21	190	104	--	<42	<32.2	<2.6	54.8	<1.6
Commerce 3	08-17-92	1343	49.9	2.8	190	128	87.2	<52	--	<39	58.8	.1
Commerce 3	08-17-92	1344	57.2	3.7	190	125	85.3	<52	--	<39	59.3	.1
Commerce 3	09-23-92	1350	47.4	3.18	176	126	--	<21.4	<16.9	<1.9	57.4	<.4
Commerce 3	09-23-92	1353	52.4	2.8	176	123	71.2	<76	--	<5.9	56.1	<.9
Commerce 3	09-23-92	1354	52.1	2.9	176	101	85.1	<76	--	<5.9	56.8	<.9
Commerce 3	10-21-92	1520	53.1	3.25	205	100.3	--	<25	<32	1.6	57.4	<1
Commerce 3	10-21-92	1523	61.1	4.67	205	123	85.5	<37	--	<12	62.8	<.2
Commerce 3	10-21-92	1524	58	4.65	205	123	88.3	<37	--	25	62.2	<.2
Commerce 3	11-17-92	1440	46.8	3.37	194	121	--	<61	<31	<4	55.4	<1
Commerce 3	11-17-92	1443	47.4	3.56	194	124	72.6	<26	--	14	52.9	<.5
Commerce 3	11-17-92	1444	49.7	3.59	194	124	72.6	<26	--	17	54	<.5
Commerce 3	12-14-92	1410	51.1	3.48	195	139	82.7	<25	<32	<1	56.2	<1
Commerce 3	12-14-92	1413	51.6	4.2	195	123	79.8	<67	--	<23	54	.3
Commerce 3	12-14-92	1414	51.4	4.13	195	125	79.7	<67	--	<23	55.1	<.2
Commerce 3	01-26-93	1400	44.7	4.34	193	135	73.2	<30.8	<24.3	<1.5	51.5	<1.7
Commerce 3	01-26-93	1401	45	4.53	193	134	73.2	<30.8	<24.3	<1.5	51.9	<1.7
Commerce 3	01-26-93	1403	51.9	2.71	193	123	78.3	61	--	<18	56.5	.1
Commerce 3	01-26-93	1404	53.5	2.26	193	121	77.7	<59	--	<18	55.6	.1

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Boron (µg/L)	Cad- mium (µg/L)	Chro- mium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)	Manga- nese (µg/L)	Mercury (µg/L)
Commerce 2	11-17-92	1250	--	<3	<8	<7	9.8	137	2.8	--	3.2	<.2
Commerce 2	11-17-92	1253	68.5	<1.3	<2.9	<7.1	<26	110	<7.8	22.1	.8	--
Commerce 2	11-17-92	1254	68.2	<2.1	<1.6	3.8	<20	108	<17	24.9	<2.5	--
Commerce 2	12-14-92	1310	--	<4	<3	<5	9.5	165	1.5	--	3.7	<.2
Commerce 2	12-14-92	1313	63	<2.6	<1.4	<1.7	<15	108	<20	30.5	4	--
Commerce 2	12-14-92	1314	62	3.1	1.6	<1.7	<15	126	<20	33.7	5	--
Commerce 2	01-26-93	1130	--	<2.3	<5.7	<10.6	<2.6	118	<1.4	--	4.2	<.2
Commerce 2	01-26-93	1133	109	<1.6	<2.3	<8.2	<38	73	<8.1	44	<2.3	--
Commerce 2	01-26-93	1134	102	<1.6	<2.3	<8.2	<38	91	<8.1	41	<2.3	--
Commerce 3	08-17-92	1340	--	<3.6	<4.1	<14	<2.7	447	<1.2	--	<.8	<.2
Commerce 3	08-17-92	1343	<20	<1.6	<1.9	<4.3	<50	436	<18	37.1	10.9	--
Commerce 3	08-17-92	1344	<18	<1.6	<1.9	<4.3	<50	179	<18	45	9.8	--
Commerce 3	09-23-92	1350	--	<1	<4.5	<2.7	<3.5	416	2.2	--	11.3	.23
Commerce 3	09-23-92	1353	<34	<2.3	<2.4	<3.5	<51	347	<26	45.9	<8	--
Commerce 3	09-23-92	1354	<35	<2.3	<2.4	<3.5	<51	363	<26	45.9	<8	--
Commerce 3	10-21-92	1520	--	<4	<3	<5	<4	374	2.2	--	12.6	<.2
Commerce 3	10-21-92	1523	127	<1.7	1.8	<1.8	<4.8	507	<22	60.2	13.1	--
Commerce 3	10-21-92	1524	133	<1.7	1	2.7	<4.8	399	<22	56.2	15.1	--
Commerce 3	11-17-92	1440	--	<3	<8	<7	<6	400	10.9	--	11.9	<.2
Commerce 3	11-17-92	1443	99	<2.1	<1.6	<2.7	<20	361	<17	44.1	7.3	--
Commerce 3	11-17-92	1444	105	<2.1	<1.6	<2.7	<20	367	<17	46.7	7.3	--
Commerce 3	12-14-92	1410	--	<4	<3	<5	<4	382	1.6	--	11.4	<.2
Commerce 3	12-14-92	1413	105	<2.6	<1.4	<1.7	<15	397	<20	58.5	10	--
Commerce 3	12-14-92	1414	109	<2.6	1.5	<1.7	<15	658	<20	55.7	12.9	--
Commerce 3	01-26-93	1400	--	<2.3	<5.7	<10.6	<2.6	370	<1.4	--	10.9	<.2
Commerce 3	01-26-93	1401	--	<2.3	<5.7	<10.6	<2.6	372	<14	--	12.2	<.2
Commerce 3	01-26-93	1403	97	<1.6	<2.3	<8.2	<38	378	<8.2	54.1	9.9	--
Commerce 3	01-26-93	1404	97	<1.6	<2.3	<8.2	<38	387	<8.2	52.6	8.9	--

Appendix 1. Physical properties and concentrations of major ions and trace elements in samples from wells—Continued

Owner or well name	Date	Time	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Strontium (µg/L)	Thallium (µg/L)	Titanium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
Commerce 2	11-17-92	1250	--	<7	<1	<5	--	<2	--	<6	8.5
Commerce 2	11-17-92	1253	<4.2	<8.1	<13	<1.8	43.1	<4.7	<9	<4.7	<1.3
Commerce 2	11-17-92	1254	<2.8	<8.1	<24	<6.4	43.4	<18	<1.9	<13	<3.6
Commerce 2	12-14-92	1310	--	<5	<1	<4	--	<1	--	<3	6.7
Commerce 2	12-14-92	1313	<1.3	<8.9	<9.9	<7.4	42.8	<15	<5.6	<24	1.7
Commerce 2	12-14-92	1314	3	<8.9	20.6	<7.4	42.7	<15	<5.6	<24	8
Commerce 2	01-26-93	1130	--	<8.8	<9	<4	--	<2.5	--	9.4	4.9
Commerce 2	01-26-93	1133	<3.6	<2.6	<21	<7.8	536	<8	<1.3	<13	<3.2
Commerce 2	01-26-93	1134	<3.6	3	<21	<7.8	550	<8	<1.3	<13	<3.2
Commerce 3	08-17-92	1340	--	<14.5	<1.6	<2	--	<1.2	--	<5	88.1
Commerce 3	08-17-92	1343	<2.3	<5.6	<7.5	<3.8	759	<24	<17	<14	72.1
Commerce 3	08-17-92	1344	<2.3	6.9	<7.5	<3.8	784	<24	<17	<14	<6.1
Commerce 3	09-23-92	1350	--	<5.4	<2.9	<2.5	--	<3.8	--	<2.8	62.8
Commerce 3	09-23-92	1353	<2.2	<4.1	<10	<3.4	72.4	<19	5	<8.6	45.4
Commerce 3	09-23-92	1354	<2.2	9.9	<10	<3.4	72.7	<19	6.1	<8.6	<7.6
Commerce 3	10-21-92	1520	--	<5	1.4	<4	--	<1	--	<3	75.1
Commerce 3	10-21-92	1523	<2.7	<4.6	<26	<6.1	74.5	<10	4.4	<13	49
Commerce 3	10-21-92	1524	2.8	<4.6	<26	<6.1	72.8	<10	5.6	<13	<40
Commerce 3	11-17-92	1440	--	<7	<1	<5	--	<2	--	<6	79
Commerce 3	11-17-92	1443	3.2	<8.1	<24	<6.4	70	<18	3.7	<13	62.5
Commerce 3	11-17-92	1444	<2.8	<8.1	<24	<6.4	71.1	22	2.9	<13	<3.6
Commerce 3	12-14-92	1410	--	<5	<1	<4	--	<1	--	<3	90.9
Commerce 3	12-14-92	1413	<1.3	<8.9	<9.9	<7.4	71.6	<15	<5.6	<24	74.3
Commerce 3	12-14-92	1414	<1.3	<8.9	<9.9	<7.4	71.7	25	6.3	<24	<1.5
Commerce 3	01-26-93	1400	--	<8.8	<9	<4	--	<2.5	--	8	67.6
Commerce 3	01-26-93	1401	--	<8.8	<9	<4	--	<2.5	--	11	68.4
Commerce 3	01-26-93	1403	<3.6	<2.6	<21	<7.8	738	10	4.7	<13	62.3
Commerce 3	01-26-93	1404	<3.6	<2.6	<21	<7.8	743	<8.1	<1.3	<13	<3.2

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Filter type	Sample type	Agency analyzing	Specific conductance (μS/cm)	pH	Temperature (°C)	Alkalinity (mg/L as CaCO ₃)	Calcium (mg/L)	Magnesium (mg/L)
Commerce 4	08-17-92	1430	U	Env	CLP	328	7.85	20	118	29.7	14
Commerce 4	08-17-92	1433	U	Env	RSK	328	7.85	20	118	31.9	15
Commerce 4	08-17-92	1434	F	Env	RSK	328	7.85	20	118	31.4	14.7
Commerce 4	09-23-92	1510	U	Env	CLP	326	7.87	20.1	116	29.6	13.8
Commerce 4	09-23-92	1513	U	Env	RSK	326	7.87	20.1	116	30.6	14.5
Commerce 4	09-23-92	1514	F	Env	RSK	326	7.87	20.1	116	31	14.7
Commerce 4	10-21-92	1340	U	Env	CLP	329	7.99	20.1	120	30.2	13.4
Commerce 4	10-21-92	1343	U	Env	RSK	329	7.99	20.1	120	31.4	15.2
Commerce 4	10-21-92	1344	F	Env	RSK	329	7.99	20.1	120	30.2	14.6
Commerce 4	11-17-92	1550	U	Env	CLP	334	7.8	20	126	30.6	13.7
Commerce 4	11-17-92	1551	U	EnvD	CLP	334	7.8	20	126	30.5	13.6
Commerce 4	11-17-92	1553	U	Env	RSK	334	7.8	20	126	30.7	14.5
Commerce 4	11-17-92	1554	F	Env	RSK	334	7.8	20	126	30.2	14.3
Commerce 4	12-14-92	1500	U	Env	CLP	326	7.8	20	120	28.3	13
Commerce 4	12-14-92	1503	U	Env	RSK	326	7.8	20	120	30.6	14.4
Commerce 4	12-14-92	1504	F	Env	RSK	326	7.8	20	120	32	15
Commerce 4	01-26-93	1440	U	Env	CLP	329	7.64	20	122	30.1	13.9
Commerce 4	01-26-93	1443	U	Env	RSK	329	7.64	20	122	30.6	14.6
Commerce 4	01-26-93	1444	F	Env	RSK	329	7.64	20	122	30.6	14.5
Cook, Joe	01-27-93	1750	U	Env	CLP	463	7.09	16.3	238	105	4.27
Cook, Joe	01-27-93	1753	U	Env	RSK	463	7.09	16.3	238	92.1	3.76
Cook, Joe	01-27-93	1754	F	Env	RSK	463	7.09	16.3	238	91	3.72
Fairland 2	01-26-93	0910	U	Env	CLP	559	7.85	20.5	134	29.5	13.4
Fairland 2	01-26-93	0913	U	Env	RSK	559	7.85	20.5	134	30.4	14.1
Fairland 2	01-26-93	0914	F	Env	RSK	559	7.85	20.5	134	30.7	14.2
Grand Lake Shores	01-27-93	1430	U	Env	CLP	364	7.68	18.4	134	37	14.6
Grand Lake Shores	01-27-93	1431	U	EnvD	CLP	364	7.68	18.4	134	36.4	14.6
Grand Lake Shores	01-27-93	1433	U	Env	RSK	364	7.68	18.4	134	33.4	13.3
Grand Lake Shores	01-27-93	1434	F	Env	RSK	364	7.68	18.4	134	33.7	13.4

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)
Commerce 4	08-17-92	1430	14.1	1.84	144	22.6	--	<42	<32.2	<2.6	36.2	<1.6
Commerce 4	08-17-92	1433	16.2	1.4	144	18.9	19.3	<52	--	<39	38	<5
Commerce 4	08-17-92	1434	15	1.1	144	19.1	19.8	<52	--	<39	38.3	<5
Commerce 4	09-23-92	1510	14.2	1.83	141	20.9	--	<21.4	<16.9	<1.9	35.2	<.4
Commerce 4	09-23-92	1513	15.4	1.3	141	18.4	19.5	<76	--	<5.8	38.7	<.9
Commerce 4	09-23-92	1514	15.9	<1.1	141	18.4	19	<76	--	<5.8	38	<.9
Commerce 4	10-21-92	1340	13.5	1.67	146	17.16	--	<25	<32	2	37.3	<1
Commerce 4	10-21-92	1343	16.1	2.77	146	18.1	19.4	<37	--	<12	40.3	<.2
Commerce 4	10-21-92	1344	15.2	2.86	146	18.1	19.7	<37	--	21	39.2	<.2
Commerce 4	11-17-92	1550	14.1	1.99	154	21	--	<61	<31	<4	38.5	<1
Commerce 4	11-17-92	1551	13.7	1.9	154	18	--	<61	<31	<4	38.4	<1
Commerce 4	11-17-92	1553	14.8	1.8	154	18.2	20	<26	--	<10	38.1	<5
Commerce 4	11-17-92	1554	14.2	1.88	154	17.8	19.8	<26	--	<10	37.1	<5
Commerce 4	12-14-92	1500	13.5	2.32	146	19.1	19.9	<25	<32	<1	36.1	<1
Commerce 4	12-14-92	1503	14.1	2.5	146	18.1	19.3	<67	--	<23	50.9	<.2
Commerce 4	12-14-92	1504	15	2.56	146	17.9	19.1	<67	--	<23	38.4	<.2
Commerce 4	01-26-93	1440	13.5	2.73	149	18.5	19.3	<30.8	<24.3	<1.5	37.4	<1.7
Commerce 4	01-26-93	1443	14.5	1.38	149	18	20	<59	--	<18	38.9	<5
Commerce 4	01-26-93	1444	14.8	1.02	149	18.2	20.1	<59	--	<18	38	.1
Cook, Joe	01-27-93	1750	7.39	.955	290	12.9	4.39	<30.8	<24.3	<1.5	250	<1.7
Cook, Joe	01-27-93	1753	7.07	<.44	290	72.9	12.6	<59	--	<18	234	.1
Cook, Joe	01-27-93	1754	6.79	<.44	290	74.6	14	60	--	<18	231	.1
Fairland 2	01-26-93	0910	56.1	4.05	163	13.2	82.9	<30.8	<24.3	<1.5	26	<1.7
Fairland 2	01-26-93	0913	62.5	2.23	163	12	88	<59	--	<18	27.6	.1
Fairland 2	01-26-93	0914	63.9	2.31	163	11.9	87	73	--	<18	29	<5
Grand Lake Shores	01-27-93	1430	24.1	1.94	163	14.7	25.5	<30.8	<24.3	<1.5	29.2	<1.7
Grand Lake Shores	01-27-93	1431	24.2	1.9	163	14.7	25.1	<30.8	<24.3	<1.5	28	<1.7
Grand Lake Shores	01-27-93	1433	23.8	.55	163	12.7	25.1	<59	--	<18	25.4	<.1
Grand Lake Shores	01-27-93	1434	24.7	<.44	163	12.1	26.3	<59	--	<18	25.1	.2

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Boron (µg/L)	Cad- mium (µg/L)	Chro- mium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/ L)	Lead (µg/L)	Lithium (µg/L)	Manga- nese (µg/L)	Mercury (µg/L)
Commerce 4	08-17-92	1430	--	<3.6	<4.1	<14	<2.7	226	<1.2	--	<.8	<.2
Commerce 4	08-17-92	1433	<10	<1.6	2.2	<4.3	<50	104	<18	16	<3.7	--
Commerce 4	08-17-92	1434	<10	<1.6	<1.9	<4.3	<50	61.9	<18	15.3	4.1	--
Commerce 4	09-23-92	1510	--	<1	<4.5	<2.7	<3.5	94	1.1	--	<4.7	.16
Commerce 4	09-23-92	1513	<19	<2.3	<2.4	<3.5	<51	<94	<26	19.1	<7.8	--
Commerce 4	09-23-92	1514	<19	<2.3	<2.4	<3.5	<51	<94	<26	18.1	<7.8	--
Commerce 4	10-21-92	1340	--	<4	<3	<5	16.3	54.4	1.6	--	3.9	<.2
Commerce 4	10-21-92	1343	54.7	<1.7	<.8	<1.8	<4.8	59	<22	27.8	3.6	--
Commerce 4	10-21-92	1344	52.8	<1.7	1.4	4.9	<4.8	51	<22	28.9	3.6	--
Commerce 4	11-17-92	1550	--	<3	<8	<7	<6	63.2	2.1	--	2.8	<.2
Commerce 4	11-17-92	1551	--	<3	<8	<7	<6	91.4	2.4	--	3.2	<.2
Commerce 4	11-17-92	1553	56.9	<2.1	2.3	<2.7	<20	47.4	<17	20.1	<2.5	--
Commerce 4	11-17-92	1554	43.7	<2.1	2.5	<2.7	<20	36.8	<17	20.3	<2.5	--
Commerce 4	12-14-92	1500	--	<4	<3	<5	5.9	61.6	1.3	--	2.3	<.2
Commerce 4	12-14-92	1503	56	<2.6	2.4	1.8	<15	49	<20	31	4.1	--
Commerce 4	12-14-92	1504	<50	<2.6	<1.4	<1.7	<15	30	<20	28.6	3.1	--
Commerce 4	01-26-93	1440	--	<2.3	<5.7	<10.6	<2.6	110	<1.4	--	2.9	<.2
Commerce 4	01-26-93	1443	39	<1.6	<2.3	<8.2	<38	57	<8.1	22.2	<2.3	--
Commerce 4	01-26-93	1444	32	<1.6	<2.3	<8.2	<38	46	<8.1	22.8	<2.3	--
Cook, Joe	01-27-93	1750	--	<2.3	<5.7	<10.6	<2.6	34	<1.4	--	<1.7	<.2
Cook, Joe	01-27-93	1753	<15	<1.6	<2.3	<8.2	<38	42	<8.2	16	<2.3	--
Cook, Joe	01-27-93	1754	<15	<1.6	2.9	<8.2	<38	18	<8.2	20.6	<2.3	--
Fairland 2	01-26-93	0910	--	<2.3	<5.7	<10.6	<2.6	63	<1.4	--	2.5	<.2
Fairland 2	01-26-93	0913	100	<1.6	<2.3	10.4	<38	20	<8.1	65.7	<2.3	--
Fairland 2	01-26-93	0914	102	<1.6	<2.3	<8.2	<38	20	<8.1	70.5	<2.3	--
Grand Lake Shores	01-27-93	1430	--	<2.3	<5.7	<10.6	<2.6	28	<1.4	--	<1.7	<.2
Grand Lake Shores	01-27-93	1431	--	<2.3	<5.7	<10.6	<2.6	23.1	<1.4	--	<1.7	<.2
Grand Lake Shores	01-27-93	1433	71	<1.6	<2.3	<8.2	<38	<11	<8.1	40.3	<2.3	--
Grand Lake Shores	01-27-93	1434	85	<1.6	<2.3	<8.2	<38	<11	<8.1	36.7	<2.3	--

Appendix 1. Physical properties and concentrations of major ions and trace elements in samples from wells—Continued

Owner or well name	Date	Time	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Strontium (µg/L)	Thallium (µg/L)	Titanium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
Commerce 4	08-17-92	1430	--	<14.5	<1.6	<2	--	<1.2	--	<5	<2.6
Commerce 4	08-17-92	1433	2.6	<5.6	<7.5	<3.8	392	<24	<17	<14	<6.1
Commerce 4	08-17-92	1434	<2.3	<5.6	<7.5	<3.8	393	<24	<17	<14	<6.1
Commerce 4	09-23-92	1510	--	<5.4	<2.9	<2.5	--	<3.8	--	<2.8	11.1
Commerce 4	09-23-92	1513	<2.2	<4.1	<10	<3.4	36.5	<19	5.1	<8.6	24.2
Commerce 4	09-23-92	1514	<2.2	<4.1	<10	<3.4	37.2	<19	<2.4	<8.6	<7.6
Commerce 4	10-21-92	1340	--	<5	1	<4	--	<1	--	<3	11.4
Commerce 4	10-21-92	1343	<2.7	<4.6	<26	<6.1	37.1	<10	<2.6	<13	<40
Commerce 4	10-21-92	1344	<2.7	<4.6	<26	<6.1	35.4	15	4.4	<13	<40
Commerce 4	11-17-92	1550	--	<7	<1	<5	--	<2	--	<6	4.9
Commerce 4	11-17-92	1551	--	<7	<1	<5	--	<2	--	<6	10.6
Commerce 4	11-17-92	1553	<2.8	<8.1	<24	<6.4	36.9	<18	<1.9	<13	<3.5
Commerce 4	11-17-92	1554	<2.8	<8.1	<24	<6.4	36	<18	2.1	<13	<3.5
Commerce 4	12-14-92	1500	--	<5	<1	<4	--	<1	--	<3	3.8
Commerce 4	12-14-92	1503	2.3	<8.9	<9.9	<7.4	35.2	<15	<5.6	<24	1.7
Commerce 4	12-14-92	1504	<1.3	<8.9	20.7	<7.4	36.7	25	<5.6	<24	<1.4
Commerce 4	01-26-93	1440	--	<8.8	<.9	<4	--	<2.5	--	9.1	5.6
Commerce 4	01-26-93	1443	<3.6	8	<21	<7.8	368	<8	2.7	<13	<3.2
Commerce 4	01-26-93	1444	<3.6	<2.6	<21	<7.8	368	<8	<1.3	<13	27.8
Cook, Joe	01-27-93	1750	--	<8.8	<.9	<4	--	<2.5	--	<3.7	46.2
Cook, Joe	01-27-93	1753	<3.6	<2.6	<21	<7.8	436	<8.2	5.9	<13	27.3
Cook, Joe	01-27-93	1754	<3.6	10.1	28	<7.8	428	18.4	5.9	13	27.2
Fairland 2	01-26-93	0910	--	9.4	<.9	<4	--	<2.5	--	4.8	7.4
Fairland 2	01-26-93	0913	<3.6	<2.6	<21	<7.8	630	<8	<1.3	<13	<3.2
Fairland 2	01-26-93	0914	<3.6	3	<21	<7.8	634	<8	<1.3	13	<3.2
Grand Lake Shores	01-27-93	1430	--	<8.8	<.9	<4	--	<2.5	--	<3.7	18.6
Grand Lake Shores	01-27-93	1431	--	<8.8	<.9	<4	--	<2.5	--	<3.7	15.4
Grand Lake Shores	01-27-93	1433	<3.6	<2.6	<21	<7.8	489	<8.1	<1.7	<13	18.6
Grand Lake Shores	01-27-93	1434	<3.6	<2.6	<21	<7.8	498	<8.1	<1.7	<13	<3.2

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Filter type	Sample type	Agency analyzing	Specific conductance (μS/cm)	pH	Temperature (°C)	Alkalinity (mg/L as CaCO ₃)	Calcium (mg/L)	Magnesium (mg/L)
Miami 1	01-27-93	1040	U	Env	CLP	523	7.94	19.6	120	37.1	16.6
Miami 1	01-27-93	1043	U	Env	RSK	523	7.94	19.6	120	32.7	15.3
Miami 1	01-27-93	1044	F	Env	RSK	523	7.94	19.6	120	32.5	15.2
Miami 3	01-27-93	1230	U	Env	CLP	373	7.89	19.2	126	161	74.2
Miami 3	01-27-93	1233	U	Env	RSK	373	7.89	19.2	126	29	13.3
Miami 3	01-27-93	1234	F	Env	RSK	373	7.89	19.2	126	29.5	13.5
Miami 6	01-27-93	0910	U	Env	CLP	589	7.88	19.5	118	31.7	14.4
Miami 6	01-27-93	0913	U	Env	RSK	589	7.88	19.5	118	32.1	14.9
Miami 6	01-27-93	0914	F	Env	RSK	589	7.88	19.5	118	32.4	15
Ogeechee Farms	01-27-93	1620	U	Env	CLP	516	7.8	20.2	128	34.3	15.3
Ogeechee Farms	01-27-93	1623	U	Env	RSK	516	7.8	20.2	128	29.7	13.5
Ogeechee Farms	01-27-93	1624	F	Env	RSK	516	7.8	20.2	128	29.9	13.6
Picher 2	08-17-92	1540	U	Env	CLP	529	7.15	19.9	136	51.9	23.4
Picher 2	08-17-92	1543	U	Env	RSK	529	7.15	19.9	136	56.5	25.3
Picher 2	08-17-92	1544	F	Env	RSK	529	7.15	19.9	136	54.9	24.7
Picher 2	09-22-92	1600	U	Env	CLP	511	7.47	19.9	138	54.6	24.4
Picher 2	09-22-92	1603	U	Env	RSK	511	7.47	19.9	138	56.4	25.6
Picher 2	09-22-92	1604	F	Env	RSK	511	7.47	19.9	138	56.7	25.7
Picher 2	10-20-92	0940	U	Env	CLP	521	7.52	19.8	136	54.3	23.9
Picher 2	10-20-92	0941	U	EnvD	CLP	521	7.52	19.8	136	55.6	24
Picher 2	10-20-92	0943	U	Env	RSK	521	7.52	19.8	136	56.5	25.9
Picher 2	10-20-92	0944	F	Env	RSK	521	7.52	19.8	136	58.7	27
Picher 2	11-16-92	1610	U	Env	CLP	511	7.5	19.6	158	53.2	23
Picher 2	11-16-92	1613	U	Env	RSK	511	7.5	19.6	158	54.3	24.4
Picher 2	11-16-92	1614	F	Env	RSK	511	7.5	19.6	158	56.7	25.6
Picher 2	12-15-92	0850	U	Env	CLP	518	7.25	19.7	138	52.4	23
Picher 2	12-15-92	0853	U	Env	RSK	518	7.25	19.7	138	56.6	25.2
Picher 2	12-15-92	0854	F	Env	RSK	518	7.25	19.7	138	54.8	24.4

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)
Miami 1	01-27-93	1040	51.8	3.92	146	15.5	80.6	<30.8	<24.3	<1.5	27.6	<1.7
Miami 1	01-27-93	1043	54.2	1.12	146	12.8	84.5	64	--	<18	25.8	.1
Miami 1	01-27-93	1044	54.7	.85	146	13.2	83.2	<59	--	<18	25	.1
Miami 3	01-27-93	1230	155	13.8	154	13.4	35.5	<30.8	66.5	<1.5	168	<1.7
Miami 3	01-27-93	1233	29.9	1.98	154	12.2	36.7	106	--	<18	30.6	<5
Miami 3	01-27-93	1234	30	1.19	154	11	37.4	<59	--	<18	30	<.1
Miami 6	01-27-93	0910	59.5	3.62	144	147	111	47.3	<24.3	<1.5	20.8	<1.7
Miami 6	01-27-93	0913	66.7	1.54	144	11.9	106	<59	--	<18	20.9	.1
Miami 6	01-27-93	0914	66.7	1.6	144	11.5	105	<59	--	<18	22.6	.1
Ogeechee Farms	01-27-93	1620	59.6	3.33	156	15.4	72.5	<30.8	<24.3	<1.5	37.6	<1.7
Ogeechee Farms	01-27-93	1623	58.7	1.52	156	13.6	75.2	<59	--	<18	33.6	.1
Ogeechee Farms	01-27-93	1624	59.2	1.01	156	12.5	74.5	64	--	<18	34.5	<.1
Picher 2	08-17-92	1540	12.8	2.2	166	114	--	<42	<32.2	<2.6	68.4	<1.6
Picher 2	08-17-92	1543	14.1	2.2	166	122	10.1	<52	--	<39	73.6	.1
Picher 2	08-17-92	1544	14	2	166	122	11.8	<52	--	<39	71.9	.1
Picher 2	09-22-92	1600	13.6	2.24	168	154	--	<21.4	<16.9	2.9	70.3	<.4
Picher 2	09-22-92	1603	15.3	2	168	119	8.42	<76	--	<5.9	77.8	<.9
Picher 2	09-22-92	1604	15.1	1.9	168	119	8.62	<76	--	<5.9	77.6	<.9
Picher 2	10-20-92	0940	12.9	1.83	166	121.5	--	<25	<32	<1	72.1	<.1
Picher 2	10-20-92	0941	12.7	2.1	166	108	--	<25	<32	<1	72.3	<.1
Picher 2	10-20-92	0943	15	3.01	166	129	4.55	45	--	15	76.6	<.2
Picher 2	10-20-92	0944	18.2	3	166	127	4.05	<37	--	<12	79.8	<.2
Picher 2	11-16-92	1610	12.3	2.23	193	121	--	<61	<31	<4	68.5	<.1
Picher 2	11-16-92	1613	12.5	2.41	193	119	10.5	<26	--	20	68.2	<.5
Picher 2	11-16-92	1614	15.4	2.17	193	120	10.7	<26	--	16	71.7	<.5
Picher 2	12-15-92	0850	12.4	3.06	168	136	11	<25	<32	1.2	68	<.1
Picher 2	12-15-92	0853	13.2	2.77	168	118	9.01	<67	--	<23	69.1	.2
Picher 2	12-15-92	0854	12.7	3.29	168	122	9.44	73	--	<23	67.3	<.2

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Boron (µg/L)	Cad- mium (µg/L)	Chro- mium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)	Manga- nese (µg/L)	Mercury (µg/L)
Miami 1	01-27-93	1040	--	<2.3	<5.7	<10.6	<2.6	71.8	<1.4	--	<1.7	<.2
Miami 1	01-27-93	1043	101	<1.6	<2.3	<8.2	<38	50	<8.1	38.4	<2.3	--
Miami 1	01-27-93	1044	103	1.8	<2.3	<8.2	<38	44	<8.1	39.5	<2.3	--
Miami 3	01-27-93	1230	--	<2.3	5.8	<10.6	19.8	1320	<1.4	--	36.5	<.2
Miami 3	01-27-93	1233	148	2.9	<2.3	<8.2	<38	355	12.8	57.4	10.8	--
Miami 3	01-27-93	1234	159	2.6	<2.3	<8.2	<38	51	<8.1	53.7	6.1	--
Miami 6	01-27-93	0910	--	<2.3	<5.7	<10.6	<2.6	66.5	<1.4	--	3.3	<.2
Miami 6	01-27-93	0913	91	<1.6	<2.3	<8.2	<38	<11	<8.1	50	<2.3	--
Miami 6	01-27-93	0914	101	<1.6	<2.3	<8.2	<38	<11	<8.1	52.6	<2.3	--
Ogeechee Farms	01-27-93	1620	--	<2.3	<5.7	<10.6	19.8	73.6	1.8	--	2.1	<.2
Ogeechee Farms	01-27-93	1623	119	1.6	<2.3	<8.2	<38	32	<8.1	54	<2.3	--
Ogeechee Farms	01-27-93	1624	123	<1.6	2.4	<8.2	<38	30	<8.1	51.7	<2.3	--
Picher 2	08-17-92	1540	--	<3.6	<4.1	<14	<2.7	384	<12	--	<.8	<.2
Picher 2	08-17-92	1543	<16	<1.6	<1.9	<4.3	<50	448	<18	17.3	7.5	--
Picher 2	08-17-92	1544	<15	<1.6	<1.9	<4.3	<50	440	<18	16.8	7.5	--
Picher 2	09-22-92	1600	--	<1	<4.5	<2.7	<3.5	441	2.3	--	7.3	.31
Picher 2	09-22-92	1603	<31	<2.3	<2.4	<3.5	<51	555	<26	22.9	<8	--
Picher 2	09-22-92	1604	<32	<2.3	<2.4	<3.5	<51	380	<26	22.8	<8	--
Picher 2	10-20-92	0940	--	<4	<3	<5	<4	446	2.3	--	7.9	<.2
Picher 2	10-20-92	0941	--	<4	<3	<5	<4	448	1.7	--	7.3	<.2
Picher 2	10-20-92	0943	69.5	<1.7	1.5	3.9	<4.8	462	<22	31.1	9.4	--
Picher 2	10-20-92	0944	66.6	<1.7	<.8	<1.8	<4.8	465	<22	31.3	7.5	--
Picher 2	11-16-92	1610	--	<3	<8	<7	10.7	468	2.2	--	9.1	<.2
Picher 2	11-16-92	1613	56.5	<2.1	<1.6	<2.7	<20	440	<17	22.6	5.3	--
Picher 2	11-16-92	1614	51.4	<2.1	1.6	<2.7	<20	450	<17	22.7	4.4	--
Picher 2	12-15-92	0850	--	<4	<3	<5	<4	432	1.4	--	7.5	<.2
Picher 2	12-15-92	0853	<50	<2.6	<1.4	4.4	<15	448	<20	28	7.4	--
Picher 2	12-15-92	0854	<50	<2.6	<1.4	<1.7	<15	497	<20	31.2	6.4	--

Appendix 1. Physical properties and concentrations of major ions and trace elements in samples from wells—Continued

Owner or well name	Date	Time	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Strontium (µg/L)	Thallium (µg/L)	Titanium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
Miami 1	01-27-93	1040	--	<8.8	<.9	<4	--	<2.5	--	4.1	3.6
Miami 1	01-27-93	1043	<3.6	<2.6	<21	<7.8	503	<8.1	<1.7	<13	<3.2
Miami 1	01-27-93	1044	<3.6	<2.6	<21	<7.8	502	<8.1	<1.9	<13	<3.2
Miami 3	01-27-93	1230	--	15.8	<.9	<4	--	<2.5	--	<3.7	<3.6
Miami 3	01-27-93	1233	<3.6	12.5	<21	<7.8	638	<8	<1.4	18	<3.2
Miami 3	01-27-93	1234	<3.6	.9	<21	<7.8	657	<8.1	<1.8	<13	<3.2
Miami 6	01-27-93	0910	--	<8.8	<.9	<4	--	<2.5	--	9	<3.6
Miami 6	01-27-93	0913	<3.6	3	<21	<7.8	490	<8	<1.3	<13	<3.2
Miami 6	01-27-93	0914	<3.6	<2.6	<21	<7.8	491	<8.1	<1.7	<13	<3.2
Ogeechee Farms	01-27-93	1620	--	<8.8	<.9	<4	--	<2.5	--	<3.7	<3.6
Ogeechee Farms	01-27-93	1623	<3.6	<2.6	<21	<7.8	403	<8.1	<1.9	<13	<3.2
Ogeechee Farms	01-27-93	1624	<3.6	<2.6	<21	<7.8	407	<8.1	<2	13	<3.2
Picher 2	08-17-92	1540	--	<14.5	<1.6	<2	--	<1.2	--	<5	145
Picher 2	08-17-92	1543	7.4	6.6	<7.5	<3.8	723	<24	<17	<14	164
Picher 2	08-17-92	1544	4.6	<5.6	<7.5	<3.8	705	<24	<17	<14	135
Picher 2	09-22-92	1600	--	<5.4	3.7	<2.5	--	<3.8	--	<2.8	166
Picher 2	09-22-92	1603	4.4	<4.1	<10	<3.4	70.9	<19	2.5	<8.6	147
Picher 2	09-22-92	1604	3.5	<4.1	<10	<3.4	71.1	<19	4.7	<8.6	138
Picher 2	10-20-92	0940	--	6.2	1.4	<4	--	<1	--	<3	171
Picher 2	10-20-92	0941	--	12.6	1.3	<4	--	<1	--	<3	177
Picher 2	10-20-92	0943	6.8	6.7	<26	<6.1	71.9	<10	<2.6	<13	139
Picher 2	10-20-92	0944	3.7	<4.6	<26	<6.1	76.4	<10	<2.9	<13	122
Picher 2	11-16-92	1610	--	9.2	<1	<5	--	<2	--	<6	242
Picher 2	11-16-92	1613	5.5	<8.1	<24	<6.4	68.1	<18	2.7	<13	175
Picher 2	11-16-92	1614	5.6	<8.1	<24	<6.4	72.4	<18	<1.9	<13	135
Picher 2	12-15-92	0850	--	<5	<1	<4	--	<1	--	<3	166
Picher 2	12-15-92	0853	3.7	<8.9	15.6	<7.4	71.3	<15	<5.6	<24	157
Picher 2	12-15-92	0854	8.7	<8.9	18.2	8.2	68.9	22	6.2	<24	117

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Filter type	Sample type	Agency analyzing	Specific conductance (μS/cm)	pH	Temperature (°C)	Alkalinity (mg/L as CaCO ₃)	Calcium (mg/L)	Magnesium (mg/L)
Picher 2	01-25-93	1120	U	Env	CLP	516	7.55	19.9	138	57.3	25.7
Picher 2	01-25-93	1123	U	Env	RSK	516	7.55	19.9	138	58.4	26.1
Picher 2	01-25-93	1124	F	Env	RSK	516	7.55	19.9	138	58.1	26
Picher 3	08-17-92	1610	U	Env	CLP	603	7.54	20.1	156	67.2	28.4
Picher 3	08-17-92	1611	U	EnvD	CLP	603	7.54	20.1	156	67.7	28.7
Picher 3	08-17-92	1613	U	Env	RSK	603	7.54	20.1	156	69.5	29.2
Picher 3	08-17-92	1614	F	Env	RSK	603	7.54	20.1	156	69.9	29.5
Picher 3	09-22-92	1700	U	Env	CLP	674	7.32	20	151	76.8	31.6
Picher 3	09-22-92	1703	U	Env	RSK	674	7.32	20	151	81.1	33.7
Picher 3	09-22-92	1704	F	Env	RSK	674	7.32	20	151	79.9	33.1
Picher 3	10-20-92	1050	U	Env	CLP	711	7.28	19.9	156	83.6	33.2
Picher 3	10-20-92	1053	U	Env	RSK	711	7.28	19.9	156	84.6	35.7
Picher 3	10-20-92	1054	F	Env	RSK	711	7.28	19.9	156	85.5	36.3
Picher 3	11-16-92	1710	U	Env	CLP	659	7.26	19.7	151	75.6	30.3
Picher 3	11-16-92	1713	U	Env	RSK	659	7.26	19.7	151	77.5	32.4
Picher 3	11-16-92	1714	F	Env	RSK	659	7.26	19.7	151	78.8	32.8
Picher 3	12-15-92	0920	U	Env	CLP	697	7.16	19.5	160	78.9	31.9
Picher 3	12-15-92	0923	U	Env	RSK	697	7.16	19.5	160	56.1	24.9
Picher 3	12-15-92	0924	F	Env	RSK	697	7.16	19.5	160	81.9	33.6
Picher 3	01-25-93	1200	U	Env	CLP	841	7.28	19.8	178	104	40.4
Picher 3	01-25-93	1203	U	Env	RSK	841	7.28	19.8	178	109	43.2
Picher 3	01-25-93	1204	F	Env	RSK	841	7.28	19.8	178	109	43.3
Picher 4	08-18-92	1210	U	Env	CLP	870	7.57	20.3	176	101	40.6
Picher 4	08-18-92	1213	U	Env	RSK	870	7.57	20.3	176	108	42.9
Picher 4	08-18-92	1214	F	Env	RSK	870	7.57	20.3	176	111	45.1
Picher 4	09-23-92	0910	U	Env	CLP	880	7.02	20.3	170	107	42.5
Picher 4	09-23-92	0911	U	EnvD	CLP	880	7.02	20.3	170	103	41.1
Picher 4	09-23-92	0913	U	Env	RSK	880	7.02	20.3	170	106	42.5
Picher 4	09-23-92	0914	F	Env	RSK	880	7.02	20.3	170	106	42.2

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)
Picher 2	01-25-93	1120	13.8	2.54	168	125	10.9	<30.8	<24.3	<1.5	78.1	<1.7
Picher 2	01-25-93	1123	14.8	<45	168	111	10.1	112	--	<18	81.9	.1
Picher 2	01-25-93	1124	15	<45	168	111	10.1	87	--	<18	81.5	.1
Picher 3	08-17-92	1610	15.1	2.56	190	157	--	<42	<32.2	<2.6	65.2	<1.6
Picher 3	08-17-92	1611	15.2	2.6	190	146	--	<42	<32.2	<2.6	65.4	<1.6
Picher 3	08-17-92	1613	14.9	2.2	190	154	13.7	<52	--	<39	67.2	.1
Picher 3	08-17-92	1614	16.6	2	190	158	16.2	<52	--	<39	68.1	.1
Picher 3	09-22-92	1700	16.7	2.6	189	220	--	<21.4	<16.9	<1.9	57.4	<.4
Picher 3	09-22-92	1703	19.1	2.5	189	200	10.9	<76	--	<5.9	66	<.9
Picher 3	09-22-92	1704	18.2	2.5	189	199	12	<76	--	<5.9	65	<.9
Picher 3	10-20-92	1050	17.3	2.39	190	216.9	--	<25	<32	<1	64.9	<1
Picher 3	10-20-92	1053	20.6	3.38	190	213	9.67	<37	--	14	71.7	<.2
Picher 3	10-20-92	1054	22.8	3.55	190	215	7.71	<37	--	<12	72.3	.3
Picher 3	11-16-92	1710	16	2.66	184	173	--	<61	<31	<4	63.4	<1
Picher 3	11-16-92	1713	17	2.71	184	192	11	<26	--	<11	63.6	<5
Picher 3	11-16-92	1714	18.2	2.71	184	192	13.3	<26	--	17	64.9	<5
Picher 3	12-15-92	0920	18.5	3.13	195	206	14	<25	<32	<1	65.8	<1
Picher 3	12-15-92	0923	13.2	3.07	195	204	12.5	<67	--	<23	67.9	<.2
Picher 3	12-15-92	0924	17.6	3.3	195	203	12.7	<67	--	<23	63.9	<.2
Picher 3	01-25-93	1200	19.2	3.93	217	256	13.4	<30.8	33.3	<1.5	63.1	<1.7
Picher 3	01-25-93	1203	22.6	.59	217	263	12.8	200	--	<18	68.1	<1
Picher 3	01-25-93	1204	22.2	1.3	217	264	12.8	<59	--	<18	67.7	.1
Picher 4	08-18-92	1210	18.1	2.95	215	306	--	<42	<32.2	<2.6	82.4	<1.6
Picher 4	08-18-92	1213	21.4	3.2	215	283	18.4	<52	--	<39	87.4	.1
Picher 4	08-18-92	1214	20.7	3.4	215	279	18.2	<52	--	<39	89.9	.1
Picher 4	09-23-92	0910	19	3.2	207	277	--	<21.4	<16.9	<1.9	82.1	<.4
Picher 4	09-23-92	0911	18.4	3.12	207	292	--	<21.4	<16.9	<1.9	82.1	<.4
Picher 4	09-23-92	0913	20.5	2.8	207	288	16.8	<76	--	<5.9	88.9	<.9
Picher 4	09-23-92	0914	19.6	2.8	207	287	17.1	<76	--	<5.9	87.2	<.9

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Boron (µg/L)	Cad- mium (µg/L)	Chro- mium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)	Manga- nese (µg/L)	Mercury (µg/L)
Picher 2	01-25-93	1120	--	<2.3	<5.7	<10.6	<2.6	395	<14	--	7	<.2
Picher 2	01-25-93	1123	39	<1.6	<2.3	<8.2	<38	401	<8.2	23.6	4	--
Picher 2	01-25-93	1124	31	<1.6	2.6	<8.2	<38	381	<8.2	21.6	4	--
Picher 3	08-17-92	1610	--	<3.6	<4.1	<14	<2.7	397	<12	--	<.8	<.2
Picher 3	08-17-92	1611	--	<3.6	<4.1	<14	<2.7	428	<12	--	<.8	<.2
Picher 3	08-17-92	1613	<17	<1.6	<1.9	<4.3	<50	459	<18	17.7	10	--
Picher 3	08-17-92	1614	<18	<1.6	<1.9	<4.3	<50	<6.1	<18	16.6	<3.7	--
Picher 3	09-22-92	1700	--	<1	<4.5	<2.7	<3.5	358	1.2	--	9.4	2.9
Picher 3	09-22-92	1703	<41	<2.3	<2.4	<3.5	<51	278	<26	24.5	<8.2	--
Picher 3	09-22-92	1704	<40	<2.3	<2.4	<3.5	<51	296	<26	23.4	<8.2	--
Picher 3	10-20-92	1050	--	5.1	<3	<5	<4	324	1.6	--	9	<.2
Picher 3	10-20-92	1053	65.5	<1.7	1.9	3	<4.8	351	<22	34.9	10.4	--
Picher 3	10-20-92	1054	70.8	<1.7	<.8	3	5.7	377	<22	32.4	10.4	--
Picher 3	11-16-92	1710	--	<3	<8	<7	<6	360	1.9	--	9.9	<.2
Picher 3	11-16-92	1713	56	<2.1	<1.6	<2.7	<20	342	<17	23.8	7.1	--
Picher 3	11-16-92	1714	46.1	<2.1	<1.6	<2.7	<20	336	<17	23.9	7	--
Picher 3	12-15-92	0920	--	<4	<3	<5	4.2	348	1.6	--	9.3	<.2
Picher 3	12-15-92	0923	55	3.4	<1.4	4.8	<15	445	<20	33.3	7.4	--
Picher 3	12-15-92	0924	54	<2.6	<1.4	<1.7	<15	342	<20	33.1	6.8	--
Picher 3	01-25-93	1200	--	<2.3	<5.7	<10.6	<2.6	707	<14	--	13.1	<.2
Picher 3	01-25-93	1203	40	<1.6	2.5	<8.2	<38	824	<8.3	26.9	9.1	--
Picher 3	01-25-93	1204	36	<1.6	2.6	<8.2	<38	762	<8.3	34	10.1	--
Picher 4	08-18-92	1210	--	<3.6	<4.1	<14	<2.7	836	<12	--	<.8	<.2
Picher 4	08-18-92	1213	<25	<1.6	<1.9	<4.3	<50	976	<18	33.4	18.7	--
Picher 4	08-18-92	1214	<26	<1.6	<1.9	<4.3	<50	256	<18	33.5	19.3	--
Picher 4	09-23-92	0910	--	<1	<4.5	<2.7	3.8	865	2.8	--	16.7	.23
Picher 4	09-23-92	0911	--	<1	<4.5	<2.7	3.8	830	4.8	--	16.7	.16
Picher 4	09-23-92	0913	<52	<2.3	<2.4	<3.5	<51	772	<26	41.4	<8.6	--
Picher 4	09-23-92	0914	<52	<2.3	<2.4	<3.5	<51	748	<26	39.7	<8.6	--

Appendix 1. Physical properties and concentrations of major ions and trace elements in samples from wells—Continued

Owner or well name	Date	Time	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Strontium (µg/L)	Thallium (µg/L)	Titanium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
Picher 2	01-25-93	1120	--	<8.8	<.9	<4	--	<2.5	--	<3.7	132
Picher 2	01-25-93	1123	<3.6	4	<21	<7.8	746	<8.1	<1.3	<13	127
Picher 2	01-25-93	1124	4.5	6.6	<21	<7.8	742	<8.1	<1.7	<13	101
Picher 3	08-17-92	1610	--	<14.5	<1.6	<2	--	<1.2	--	<5	126
Picher 3	08-17-92	1611	--	<14.5	<1.6	<2	--	<1.2	--	<5	114
Picher 3	08-17-92	1613	6.2	<5.6	<7.5	<3.8	661	<24	<17	<14	122
Picher 3	08-17-92	1614	7.9	<5.6	8	<3.8	680	<24	<17	<14	114
Picher 3	09-22-92	1700	--	<5.4	<2.9	<2.5	--	<3.8	--	<2.8	52.9
Picher 3	09-22-92	1703	3.7	<4.1	<10	<3.4	71.9	<19	<7	<8.6	43.6
Picher 3	09-22-92	1704	5.5	<4.1	<10	<3.4	69	<19	11.4	<8.6	21.4
Picher 3	10-20-92	1050	--	<5	1.1	<4	--	<1	--	<3	42.8
Picher 3	10-20-92	1053	7.5	<4.6	<26	<6.1	81	<10	<2.6	<13	<40
Picher 3	10-20-92	1054	7.8	<4.6	<26	<6.1	82.7	<10	<2.6	<13	<40
Picher 3	11-16-92	1710	--	<7	1	<5	--	<2	--	<6	88.8
Picher 3	11-16-92	1713	6.1	<8.1	<24	<6.4	72.4	<18	<1.9	<13	70
Picher 3	11-16-92	1714	5.9	<8.1	<24	<6.4	72.9	20	3.1	<13	29.8
Picher 3	12-15-92	0920	--	7.9	<1	<4	--	<1	--	<3	42
Picher 3	12-15-92	0923	7.4	13.6	<9.9	<7.4	70.5	30	<5.6	<24	125
Picher 3	12-15-92	0924	1.7	<8.9	18.4	<7.4	76.2	<15	<5.6	<24	38.4
Picher 3	01-25-93	1200	--	<8.8	<.9	<4	--	<2.5	--	10.9	50.7
Picher 3	01-25-93	1203	<3.6	<2.6	<21	<7.8	922	<8.3	2.2	<13	42.1
Picher 3	01-25-93	1204	6.1	<2.6	26	<7.8	919	11.1	<1.3	<13	22.1
Picher 4	08-18-92	1210	--	<14.5	<1.6	<2	--	<1.2	--	<5	156
Picher 4	08-18-92	1213	5.2	7.2	<7.5	<3.8	1160	24	<17	<14	169
Picher 4	08-18-92	1214	<2.3	9.5	10.1	<3.8	1160	<24	<17	<14	79
Picher 4	09-23-92	0910	--	9.6	<2.9	<2.5	--	<3.8	--	<2.8	166
Picher 4	09-23-92	0911	--	9.2	<2.9	<2.5	--	<3.8	--	<2.8	157
Picher 4	09-23-92	0913	<2.2	8.9	<10	<3.4	111	<19	8.5	<8.6	135
Picher 4	09-23-92	0914	<2.2	15.3	<10	<3.4	110	<19	9.6	<8.6	69.4

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Filter type	Sample type	Agency analyzing	Specific conductance (μS/cm)	pH	Temperature (°C)	Alkalinity (mg/L as CaCO ₃)	Calcium (mg/L)	Magnesium (mg/L)
Picher 4	10-20-92	1250	U	Env	CLP	881	7.08	20.3	176	110	41.5
Picher 4	10-20-92	1253	U	Env	RSK	881	7.08	20.3	176	112	45.4
Picher 4	10-20-92	1254	F	Env	RSK	881	7.08	20.3	176	112	45.4
Picher 4	11-17-92	0930	U	Env	CLP	885	7.13	20.3	190	108	40.9
Picher 4	11-17-92	0933	U	Env	RSK	885	7.13	20.3	190	110	43.2
Picher 4	11-17-92	0934	F	Env	RSK	885	7.13	20.3	190	111	43.7
Picher 4	12-15-92	1010	U	Env	CLP	886	6.95	20.5	178	106	41.1
Picher 4	12-15-92	1011	U	EnvD	CLP	886	6.95	20.5	178	105	41.7
Picher 4	12-15-92	1013	U	Env	RSK	886	6.95	20.5	178	81.4	33.3
Picher 4	12-15-92	1014	F	Env	RSK	886	6.95	20.5	178	111	43.2
Picher 4	01-25-93	1330	U	Env	CLP	893	7.07	20.4	177	112	43.6
Picher 4	01-25-93	1333	U	Env	RSK	893	7.07	20.4	177	120	46.7
Picher 4	01-25-93	1334	F	Env	RSK	893	7.07	20.4	177	100	40.4
Quapaw 2	08-18-92	1520	U	Env	CLP	743	7.1	19.5	186	79.6	34.9
Quapaw 2	08-18-92	1523	U	Env	RSK	743	7.1	19.5	186	87.3	37.2
Quapaw 2	08-18-92	1524	F	Env	RSK	743	7.1	19.5	186	90.9	39
Quapaw 2	09-22-92	1330	U	Env	CLP	745	7.24	20	178	81.7	35.5
Quapaw 2	09-22-92	1333	U	Env	RSK	745	7.24	20	178	83.8	36.8
Quapaw 2	09-22-92	1334	F	Env	RSK	745	7.24	20	178	84.1	36.9
Quapaw 2	10-20-92	1440	U	Env	CLP	754	7.2	19.1	176	84.5	34.8
Quapaw 2	10-20-92	1443	U	Env	RSK	754	7.2	19.1	176	88.5	39.1
Quapaw 2	10-20-92	1444	F	Env	RSK	754	7.2	19.1	176	87.7	38.8
Quapaw 2	11-16-92	1320	U	Env	CLP	749	7.24	19.1	175	84.5	35.4
Quapaw 2	11-16-92	1323	U	Env	RSK	749	7.24	19.1	175	85.2	36.8
Quapaw 2	11-16-92	1324	F	Env	RSK	749	7.24	19.1	175	84.1	36.4
Quapaw 2	12-14-92	1610	U	Env	CLP	752	7.24	19.2	184	82.2	35
Quapaw 2	12-14-92	1613	U	Env	RSK	752	7.24	19.2	184	86.4	37
Quapaw 2	12-14-92	1614	F	Env	RSK	752	7.24	19.2	184	84.2	36.1

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)
Picher 4	10-20-92	1250	17.9	2.89	215	271.9	--	<25	<32	1	85.6	1.4
Picher 4	10-20-92	1253	24.4	4	215	300	20.3	<37	--	<12	96.8	.2
Picher 4	10-20-92	1254	24.7	3.86	215	301	14.4	<37	--	<12	96.6	<.2
Picher 4	11-17-92	0930	18.1	3.14	231	268	--	<61	<31	<4	85.2	<1
Picher 4	11-17-92	0933	19.9	3.34	231	297	19.9	<26	--	16	85.5	<5
Picher 4	11-17-92	0934	21.1	3.35	231	292	17.2	<26	--	12	86.9	<5
Picher 4	12-15-92	1010	18.8	3.4	222	294	19	<25	<32	<1	85.4	<1
Picher 4	12-15-92	1011	19.5	3.57	222	295	19	27.1	<32	1.1	87.6	<1
Picher 4	12-15-92	1013	17.6	3.1	222	294	36.4	<67	--	<23	62.9	<.2
Picher 4	12-15-92	1014	19.8	3.23	222	291	36.4	<67	--	<23	84	<.2
Picher 4	01-25-93	1330	18.8	3.99	216	284	18.4	<30.8	25.2	<1.5	83.7	<1.7
Picher 4	01-25-93	1333	21.8	1.41	216	291	17.5	74	--	<18	92.3	.2
Picher 4	01-25-93	1334	20.3	1.28	216	293	17.5	<9.9	--	<3.6	82.3	<.5
Quapaw 2	08-18-92	1520	18.7	2.41	227	195	--	<42	<32.2	<2.6	31.1	<1.6
Quapaw 2	08-18-92	1523	18.8	2.3	227	182	28.6	<52	--	<39	32.4	.1
Quapaw 2	08-18-92	1524	23	2.7	227	185	27.3	<52	--	<39	32.7	.1
Quapaw 2	09-22-92	1330	19.5	2.5	217	176	--	22.6	<16.9	<1.9	28.1	<.4
Quapaw 2	09-22-92	1333	22	2.6	217	190	27.4	<76	--	<5.9	31.8	<.9
Quapaw 2	09-22-92	1334	20.7	2.6	217	189	27.3	<76	--	<5.9	32.7	<.9
Quapaw 2	10-20-92	1440	19.1	2.28	215	168.6	--	<25	<32	<1	32.6	1
Quapaw 2	10-20-92	1443	25.6	2.87	215	193	28	<37	--	<12	36.2	<.2
Quapaw 2	10-20-92	1444	26.7	3.15	215	190	27.5	<37	--	<12	37.1	<.2
Quapaw 2	11-16-92	1320	19.4	2.56	214	173	--	<61	<31	<4	33.6	<1
Quapaw 2	11-16-92	1323	20.3	2.54	214	187	29.6	<26	--	15	32.1	<5
Quapaw 2	11-16-92	1324	21	2.65	214	184	30.1	<26	--	<11	31.9	>5
Quapaw 2	12-14-92	1610	19	3.81	224	194	28.9	<25	<32	1.1	33	<1
Quapaw 2	12-14-92	1613	21	3.12	224	188	30.3	<67	--	<23	31.9	<.2
Quapaw 2	12-14-92	1614	19.7	3.33	224	193	31.2	<67	--	<23	31.8	<.2

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Boron (µg/L)	Cad- mium (µg/L)	Chro- mium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)	Manga- nese (µg/L)	Mercury (µg/L)
Picher 4	10-20-92	1250	--	5.1	<3	<5	<4	869	1.9	--	18.3	<.2
Picher 4	10-20-92	1253	83.5	<1.7	<.8	3.4	21.8	928	<22	50.2	16.2	--
Picher 4	10-20-92	1254	77	<1.7	<.8	<1.8	<4.8	941	<22	50.2	17	--
Picher 4	11-17-92	0930	--	3.5	<8	<7	8.4	1010	2.6	--	17.9	<.2
Picher 4	11-17-92	0933	68.6	<2.1	4.2	<2.7	<20	964	<17	41.2	15.9	--
Picher 4	11-17-92	0934	67.6	<2.1	<1.6	<2.7	<20	962	<17	41.6	15.8	--
Picher 4	12-15-92	1010	--	<4	<3	<5	31.4	998	<1	--	17.1	<.2
Picher 4	12-15-92	1011	--	<4	<3	<5	<4	1050	2.5	--	17.1	<.2
Picher 4	12-15-92	1013	53	<2.6	<1.4	<1.7	<15	351	<20	33.1	7.8	--
Picher 4	12-15-92	1014	56	<2.6	<1.4	<1.7	<15	1110	<20	47.5	16.8	--
Picher 4	01-25-93	1330	--	<2.3	<5.7	<10.6	<2.6	1110	<14	--	17.4	<.2
Picher 4	01-25-93	1333	55	<1.6	<2.3	<8.2	<38	1210	<8.3	51.7	18	--
Picher 4	01-25-93	1334	58	<1	<6	<1.3	38.2	1090	<5.7	48.1	15.8	--
Quapaw 2	08-18-92	1520	--	<3.6	<4.1	<14	<2.7	878	<12	--	<.8	<.2
Quapaw 2	08-18-92	1523	<22	<1.6	<1.9	<4.3	<50	1040	<18	25	16.2	--
Quapaw 2	08-18-92	1524	<23	<1.6	<1.9	<4.3	<50	1060	<18	30.5	15.3	--
Quapaw 2	09-22-92	1330	--	<1	<4.5	<2.7	<3.5	943	2.3	--	14.8	.61
Quapaw 2	09-22-92	1333	<45	<2.3	<2.4	<3.5	<51	861	<26	37.3	<8.4	--
Quapaw 2	09-22-92	1334	<45	<2.3	<2.4	<3.5	<51	868	<26	35.4	<8.4	--
Quapaw 2	10-20-92	1440	--	<4	<3	<5	<4	883	2.7	--	15.4	<.2
Quapaw 2	10-20-92	1443	48.7	<1.7	<.8	2.3	<4.8	960	<22	41.8	14.1	--
Quapaw 2	10-20-92	1444	57.1	<1.7	<.8	<1.8	<4.8	958	<22	41.3	16	--
Quapaw 2	11-16-92	1320	--	<3	<8	<7	10	947	2	--	15.5	<.2
Quapaw 2	11-16-92	1323	48.3	<2.1	<1.6	<2.7	<20	903	<17	33.2	11.7	--
Quapaw 2	11-16-92	1324	40	<2.1	<1.6	<2.7	<20	880	<17	33.4	11.7	--
Quapaw 2	12-14-92	1610	--	<4	<3	<5	<4	910	1.2	--	13.7	<.2
Quapaw 2	12-14-92	1613	81	<2.6	<1.4	<1.7	<15	918	<20	41.7	12.5	--
Quapaw 2	12-14-92	1614	112	<2.6	<1.4	<1.7	<15	906	<20	42.6	12.6	--

Appendix 1. Physical properties and concentrations of major ions and trace elements in samples from wells—Continued

Owner or well name	Date	Time	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Strontium (µg/L)	Thallium (µg/L)	Titanium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
Picher 4	10-20-92	1250	--	14.7	1.4	<4	--	<1	--	<3	161
Picher 4	10-20-92	1253	<2.8	12.2	<26	<6.2	118	<10	<2.6	<14	135
Picher 4	10-20-92	1254	<2.7	11	<26	<6.1	119	<10	<2.6	<13	58
Picher 4	11-17-92	0930	--	12.9	<5	<5	--	<2	--	<6	169
Picher 4	11-17-92	0933	3	15.8	<24	<6.4	113	20	6.1	<13	154
Picher 4	11-17-92	0934	<2.8	11.5	<24	<6.4	115	21	4.2	<13	48.5
Picher 4	12-15-92	1010	--	31.1	<1	<4	--	<1	--	<3	173
Picher 4	12-15-92	1011	--	<5	<1	<4	--	<1	--	<3	177
Picher 4	12-15-92	1013	5.9	<8.9	<9.9	<7.4	76	27	<5.6	<24	24.2
Picher 4	12-15-92	1014	<1.3	11.9	<9.9	<7.4	110	21	12.3	<24	195
Picher 4	01-25-93	1330	--	14.2	<9	<4	--	<2.5	--	7.2	158
Picher 4	01-25-93	1333	<3.6	11.4	<21	<7.8	1250	14	<1.3	<13	156
Picher 4	01-25-93	1334	<1.9	6.6	<12	<1.7	1290	<8.3	<14	<2.3	44
Quapaw 2	08-18-92	1520	--	<14.5	<1.6	<2	--	<1.2	--	<5	46.7
Quapaw 2	08-18-92	1523	2.8	<5.6	<7.5	<3.8	298	<24	<17	<14	42.1
Quapaw 2	08-18-92	1524	4.4	11.7	<7.5	<3.8	313	<24	<17	<14	83
Quapaw 2	09-22-92	1330	--	<5.4	<2.9	<2.5	--	<3.8	--	<2.8	50.9
Quapaw 2	09-22-92	1333	<2.2	<4.1	<10	<3.4	28.1	<19	6.4	<8.6	39.2
Quapaw 2	09-22-92	1334	4.2	<4.1	<10	<3.4	28	<19	7.6	<8.6	32.8
Quapaw 2	10-20-92	1440	--	<5	<1	<4	--	<1	--	<3	53.2
Quapaw 2	10-20-92	1443	4.5	<4.6	<26	<6.1	30.6	<10	<2.8	<13	<40
Quapaw 2	10-20-92	1444	<2.7	<4.6	<26	<6.1	30.4	<10	<2.8	<13	49
Quapaw 2	11-16-92	1320	--	<7	<1	<5	--	<2	--	<6	70.7
Quapaw 2	11-16-92	1323	4.1	<8.1	<24	<6.4	28.2	21	4.8	<13	32.8
Quapaw 2	11-16-92	1324	4.2	<8.1	<24	<6.4	27.9	<18	3.3	<13	26.7
Quapaw 2	12-14-92	1610	--	<5	<1	<4	--	<1	--	<3	48.9
Quapaw 2	12-14-92	1613	2.1	<8.9	25.9	<7.4	27.4	21	<5.6	<24	38.1
Quapaw 2	12-14-92	1614	4.9	<8.9	24.2	<7.4	26.6	38	5.6	<24	36.9

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Filter type	Sample type	Agency analyzing	Specific conductance (μS/cm)	pH	Temperature (°C)	Alkalinity (mg/L as CaCO ₃)	Calcium (mg/L)	Magnesium (mg/L)
Quapaw 2	01-25-93	1440	U	Env	CLP	760	7.22	19.1	180	86.2	37.1
Quapaw 2	01-25-93	1443	U	Env	RSK	760	7.22	19.1	180	89.8	38.7
Quapaw 2	01-25-93	1444	F	Env	RSK	760	7.22	19.1	180	89.7	38.6
Quapaw 4	08-18-92	1620	U	Env	CLP	274	7.61	19.1	120	27.3	13.5
Quapaw 4	08-18-92	1623	U	Env	RSK	274	7.61	19.1	120	29.5	14.5
Quapaw 4	08-18-92	1624	F	Env	RSK	274	7.61	19.1	120	30.2	14.9
Quapaw 4	09-22-92	1500	U	Env	CLP	300	7.87	19	119	28.8	13.8
Quapaw 4	09-22-92	1503	U	Env	RSK	300	7.87	19	119	29.8	14.5
Quapaw 4	09-22-92	1504	F	Env	RSK	300	7.87	19	119	31.6	15.3
Quapaw 4	10-20-92	1540	U	Env	CLP	269	7.85	19.1	116	28.4	13.3
Quapaw 4	10-20-92	1543	U	Env	RSK	269	7.85	19.1	116	29.2	14.8
Quapaw 4	10-20-92	1544	F	Env	RSK	269	7.85	19.1	116	29.3	14.8
Quapaw 4	11-16-92	1450	U	Env	CLP	275	8.03	19.1	133	26.8	12.8
Quapaw 4	11-16-92	1453	U	Env	RSK	275	8.03	19.1	133	27.5	13.7
Quapaw 4	11-16-92	1454	F	Env	RSK	275	8.03	19.1	133	27.7	13.8
Quapaw 4	12-14-92	1730	U	Env	CLP	300	7.42	19	120	28.1	12.9
Quapaw 4	12-14-92	1733	U	Env	RSK	300	7.42	19	120	29.7	14.1
Quapaw 4	12-14-92	1734	F	Env	RSK	300	7.42	19	120	30	14.3
Quapaw 4	01-25-93	1550	U	Env	CLP	319	7.91	18.8	122	33.5	15
Quapaw 4	01-25-93	1553	U	Env	RSK	319	7.91	18.8	122	34.6	15.8
Quapaw 4	01-25-93	1554	F	Env	RSK	319	7.91	18.8	122	34.7	15.8
RWD 4 Well 2	01-28-93	0830	U	Env	CLP	362	7.83	19.9	124	36.6	16.9
RWD 4 Well 2	01-28-93	0833	U	Env	RSK	362	7.83	19.9	124	33.3	15.7
RWD 4 Well 2	01-28-93	0834	F	Env	RSK	362	7.83	19.9	124	32.9	15.5
RWD 4 Well 3	01-28-93	0930	U	Env	CLP	271	7.78	19.1	116	29.6	14.5
RWD 4 Well 3	01-28-93	0933	U	Env	RSK	271	7.78	19.1	116	29.9	14.9
RWD 4 Well 3	01-28-93	0934	F	Env	RSK	271	7.78	19.1	116	30.7	15.3

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)
Quapaw 2	01-25-93	1440	19.9	3.51	219	187	28	<30.8	<24.3	<1.5	32.4	<1.7
Quapaw 2	01-25-93	1443	22.4	.61	219	183	28	<59	--	<18	33.3	.2
Quapaw 2	01-25-93	1444	22.3	.76	219	202	34.7	<59	--	<18	33.8	<.1
Quapaw 4	08-18-92	1620	6.67	1.56	146	15.3	--	<42	<32.2	<2.6	9.6	<1.6
Quapaw 4	08-18-92	1623	6.91	1.3	146	13.8	7.47	<52	--	<39	9.1	<.5
Quapaw 4	08-18-92	1624	6.64	1.5	146	14.3	7.27	<52	--	<39	8.8	<.5
Quapaw 4	09-22-92	1500	7.77	1.44	145	18.6	--	<21.4	<16.9	<1.9	8.2	<.4
Quapaw 4	09-22-92	1503	8.45	1.5	145	16.7	9.15	<76	--	<5.8	10.7	<.9
Quapaw 4	09-22-92	1504	9.43	1.5	145	17.1	9.78	<80	--	<6.1	12	<.1
Quapaw 4	10-20-92	1540	5.31	.664	142	13.5	--	<25	<32	<.1	9.1	<.1
Quapaw 4	10-20-92	1543	7.29	1.71	142	19.3	5.48	52	--	21	11	<.2
Quapaw 4	10-20-92	1544	7.56	1.62	142	19.1	5.21	<37	--	19	10	<.2
Quapaw 4	11-16-92	1450	5.63	1.3	162	13	--	<61	<31	<.4	9.6	<.1
Quapaw 4	11-16-92	1453	5.88	1.32	162	11.2	6.5	<26	--	<10	8.3	<.5
Quapaw 4	11-16-92	1454	5.96	1.23	162	10.8	7.24	32	--	13	9.4	<.5
Quapaw 4	12-14-92	1730	7.51	1.41	146	19.1	10.9	<25	<32	1.1	10.6	<.1
Quapaw 4	12-14-92	1733	7.87	2.65	146	18.6	10.2	83	--	<23	11.6	<.2
Quapaw 4	12-14-92	1734	7.73	2.26	146	19.2	10.6	<67	--	<23	11.4	.3
Quapaw 4	01-25-93	1550	8.49	2.8	149	23.8	10.8	<30.8	<24.3	<1.5	13.7	<1.7
Quapaw 4	01-25-93	1553	9.41	.48	149	25.8	10.7	97	--	<18	14	<.5
Quapaw 4	01-25-93	1554	9.29	.62	149	26.6	10.6	<59	--	<18	14	.1
RWD 4 Well 2	01-28-93	0830	19.8	2.57	151	14.1	29	<30.8	<24.3	<1.5	17	<1.7
RWD 4 Well 2	01-28-93	0833	20.6	<.44	151	13	29.6	<59	--	<18	14.5	<.1
RWD 4 Well 2	01-28-93	0834	20.3	.81	151	13	29.7	<59	--	<18	14.9	.1
RWD 4 Well 3	01-28-93	0930	4.34	2.26	141	13.4	10.6	<30.8	<24.3	<1.5	5.6	<1.7
RWD 4 Well 3	01-28-93	0933	4.38	<.44	141	12.7	9.76	<59	--	<18	5.6	<.1
RWD 4 Well 3	01-28-93	0934	4.51	<.44	141	12.6	9.88	<59	--	<18	5.2	<.1

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Boron (µg/L)	Cad- mium (µg/L)	Chro- mium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/ L)	Lead (µg/L)	Lithium (µg/L)	Manga- nese (µg/L)	Mercury (µg/L)
Quapaw 2	01-25-93	1440	--	<2.3	<5.7	<10.6	<2.6	893	<14	--	14.6	<.2
Quapaw 2	01-25-93	1443	20	<1.6	<2.3	<8.2	<38	970	<8.2	34.8	14.5	--
Quapaw 2	01-25-93	1444	27	<1.6	<2.3	<8.2	<38	990	<8.2	39.3	13.6	--
Quapaw 4	08-18-92	1620	--	<3.6	<4.1	<14	<2.7	29.9	<1.2	--	<.8	<.2
Quapaw 4	08-18-92	1623	<9.4	<1.6	<1.9	<4.3	<50	<6.1	<18	7.2	<3.7	--
Quapaw 4	08-18-92	1624	<9.4	<1.6	<1.9	<4.3	<50	<6.1	<18	7.2	<3.7	--
Quapaw 4	09-22-92	1500	--	<1	<4.5	<2.7	<3.5	24.7	4.6	--	<4.7	.23
Quapaw 4	09-22-92	1503	<19	<2.3	<2.4	4.3	<51	1120	<26	13.3	<7.8	--
Quapaw 4	09-22-92	1504	<20	<2.4	<2.5	<3.7	<53	<99	<27	13.9	<8.1	--
Quapaw 4	10-20-92	1540	--	<4	<3	<5	<4	6.7	1.7	--	<2	<.2
Quapaw 4	10-20-92	1543	22.1	<1.7	<.8	<1.8	<4.8	34	<22	12.2	<2.5	--
Quapaw 4	10-20-92	1544	15.5	<1.7	1	<1.8	<4.8	<15	<22	12.2	<2.5	--
Quapaw 4	11-16-92	1450	--	<3	<8	<7	7.3	33.7	2.1	--	<2	<.2
Quapaw 4	11-16-92	1453	19.9	<2.1	<1.6	<2.7	<20	20.9	<17	8.6	<2.5	--
Quapaw 4	11-16-92	1454	17	<2.1	<1.6	4.8	<20	<8.5	<17	8.4	<2.5	--
Quapaw 4	12-14-92	1730	--	<4	<3	<5	<4	19.3	<1	--	<2	<.2
Quapaw 4	12-14-92	1733	188	2.9	<1.4	<1.7	<15	65	<20	22	3.2	--
Quapaw 4	12-14-92	1734	<50	<2.6	<1.4	<1.7	<15	33	<20	21.6	4.1	--
Quapaw 4	01-25-93	1550	--	<2.3	<5.7	<10.6	<2.6	43.7	<1.4	--	4.1	<.2
Quapaw 4	01-25-93	1553	<15	2.2	<2.3	<8.2	<38	<11	<8.1	17.8	<2.3	--
Quapaw 4	01-25-93	1554	<15	<1.6	<2.3	<8.2	<38	12	<8.1	19.4	<2.3	--
RWD 4 Well 2	01-28-93	0830	--	<2.3	<5.7	<10.6	<2.6	236	<1.4	--	2.2	<.2
RWD 4 Well 2	01-28-93	0833	39	<1.6	<2.3	<8.2	<38	204	<8.1	18.6	<2.3	--
RWD 4 Well 2	01-28-93	0834	32	<1.6	<2.3	<8.2	<38	202	<8.1	20.9	<2.3	--
RWD 4 Well 3	01-28-93	0930	--	<2.3	<5.7	<10.6	<2.6	75.5	<1.4	--	3.3	<.2
RWD 4 Well 3	01-28-93	0933	<15	<1.6	<2.3	<8.2	<38	24	<8.1	6.8	<2.3	--
RWD 4 Well 3	01-28-93	0934	<15	<1.6	<2.3	<8.2	<38	39	<8.1	<4.6	<2.3	--

Appendix 1. Physical properties and concentrations of major ions and trace elements in samples from wells—Continued

Owner or well name	Date	Time	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Strontium (µg/L)	Thallium (µg/L)	Titanium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
Quapaw 2	01-25-93	1440	--	<8.8	<.9	<4	--	<25	--	8.7	47.2
Quapaw 2	01-25-93	1443	<3.6	<2.6	<21	<7.8	310	<8.2	<1.3	<13	38.1
Quapaw 2	01-25-93	1444	<3.6	<2.6	<21	<7.8	307	<8.2	<1.3	<13	30.2
Quapaw 4	08-18-92	1620	--	<14.5	<1.6	<2	--	<1.2	--	<5	9.6
Quapaw 4	08-18-92	1623	6.5	<5.6	8.3	<3.8	229	<24	<17	<14	<6.1
Quapaw 4	08-18-92	1624	8.4	<5.6	<7.5	<3.8	229	<24	<17	<14	9.5
Quapaw 4	09-22-92	1500	--	<5.4	<2.9	<2.5	--	<3.8	--	<2.8	5.2
Quapaw 4	09-22-92	1503	6.1	<4.1	<10	<3.4	28.8	<19	<2.4	<8.6	11.8
Quapaw 4	09-22-92	1504	5.3	<4.3	<11	<3.6	32.3	<19	<2.5	<9	<7.9
Quapaw 4	10-20-92	1540	--	<5	<1	<4	--	<1	--	<3	<3
Quapaw 4	10-20-92	1543	6.7	<4.6	<26	<6.1	22.1	<10	<2.6	<13	<40
Quapaw 4	10-20-92	1544	4.6	<4.6	<26	<6.1	22.4	<10	<2.7	<13	<40
Quapaw 4	11-16-92	1450	--	<7	<1	<5	--	<2	--	<6	9.8
Quapaw 4	11-16-92	1453	8.5	<8.1	<24	<6.4	20.4	<18	3	<13	<3.5
Quapaw 4	11-16-92	1454	8.7	<8.1	<24	<6.4	20.8	<18	<1.9	<13	<3.5
Quapaw 4	12-14-92	1730	--	<5	<1	<4	--	<1	--	<3	<3
Quapaw 4	12-14-92	1733	4	<8.9	<9.9	<7.4	29.6	26	<5.6	<24	<1.4
Quapaw 4	12-14-92	1734	5.7	<8.9	23.8	<7.4	29.2	22	6.8	<24	<1.4
Quapaw 4	01-25-93	1550	--	24.1	<.9	<4	--	<2.5	--	8.9	3.6
Quapaw 4	01-25-93	1553	<3.6	<2.6	28	<7.8	431	<8	<1.3	<13	<3.2
Quapaw 4	01-25-93	1554	<3.6	<2.6	<21	<7.8	436	<8	<1.3	<13	<3.2
RWD 4 Well 2	01-28-93	0830	--	<8.8	<.9	<4	--	<2.5	--	<3.7	<3.6
RWD 4 Well 2	01-28-93	0833	<3.6	<2.6	<21	<7.8	189	<8.1	<2	<13	<3.2
RWD 4 Well 2	01-28-93	0834	<3.6	<2.6	<21	<7.8	186	<8.1	<2	<13	<3.2
RWD 4 Well 3	01-28-93	0930	--	9.2	<.9	<4	--	<2.5	--	9.1	5
RWD 4 Well 3	01-28-93	0933	<3.6	<2.6	<21	<7.8	88.3	<8.1	<1.7	<13	<3.2
RWD 4 Well 3	01-28-93	0934	<3.6	<2.6	<21	<7.8	90.6	<8.1	<1.9	<13	<3.2

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Filter type	Sample type	Agency analyzing	Specific conductance (μS/cm)	pH	Temperature (°C)	Alkalinity (mg/L as CaCO ₃)	Calcium (mg/L)	Magnesium (mg/L)
RWD 4 Well 4	08-18-92	0930	U	Env	CLP	259	7.49	19.2	118	27.1	14.9
RWD 4 Well 4	08-18-92	0933	U	Env	RSK	259	7.49	19.2	118	29.6	16.2
RWD 4 Well 4	08-18-92	0934	F	Env	RSK	259	7.49	19.2	118	29.5	16
RWD 4 Well 4	09-22-92	1110	U	Env	CLP	256	7.95	19.4	118	26.6	14.4
RWD 4 Well 4	09-22-92	1113	U	Env	RSK	256	7.95	19.4	118	28.7	15.8
RWD 4 Well 4	09-22-92	1114	F	Env	RSK	256	7.95	19.4	118	28.6	15.8
RWD 4 Well 4	10-20-92	1640	U	Env	CLP	262	8.08	19.3	120	28.3	14.6
RWD 4 Well 4	10-20-92	1643	U	Env	RSK	262	8.08	19.3	120	28.3	15.9
RWD 4 Well 4	10-20-92	1644	F	Env	RSK	262	8.08	19.3	120	28.6	16.1
RWD 4 Well 4	11-16-92	1050	U	Env	CLP	261	7.85	19.3	137	27.7	14.6
RWD 4 Well 4	11-16-92	1051	U	EnvD	CLP	261	7.85	19.3	137	27.2	14.3
RWD 4 Well 4	11-16-92	1053	U	Env	RSK	261	7.85	19.3	137	27.7	15.3
RWD 4 Well 4	11-16-92	1054	F	Env	RSK	261	7.85	19.3	137	27.9	15.4
RWD 4 Well 4	12-15-92	1130	U	Env	CLP	254	7.77	19.3	120	26.4	14.2
RWD 4 Well 4	12-15-92	1133	U	Env	RSK	254	7.77	19.3	120	27.1	14.7
RWD 4 Well 4	12-15-92	1134	F	Env	RSK	254	7.77	19.3	120	28.2	15.4
RWD 4 Well 4	01-25-93	1640	U	Env	CLP	260	7.8	19.2	118	26.9	14.5
RWD 4 Well 4	01-25-93	1643	U	Env	RSK	260	7.8	19.2	118	29.4	16.1
RWD 4 Well 4	01-25-93	1644	F	Env	RSK	260	7.8	19.2	118	29.4	16
RWD 6 Well 1	01-26-93	1700	U	Env	CLP	444	7.59	19.8	124	28.2	12.8
RWD 6 Well 1	01-26-93	1703	U	Env	RSK	444	7.59	19.8	124	28.6	13.1
RWD 6 Well 1	01-26-93	1704	F	Env	RSK	444	7.59	19.8	124	28.9	13.2

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)
RWD 4 Well 4	08-18-92	0930	2.66	.996	144	9.3	--	<42	<32.2	<2.6	5.2	<1.6
RWD 4 Well 4	08-18-92	0933	3.15	<1	144	8.58	5.93	<52	--	<39	43.8	.3
RWD 4 Well 4	08-18-92	0934	2.67	<1	144	9.17	5.98	<52	--	<39	9.9	<5
RWD 4 Well 4	09-22-92	1110	2.75	.801	144	7.45	--	<21.4	<16.9	<1.9	4.7	<.4
RWD 4 Well 4	09-22-92	1113	3.28	<1.1	144	8.99	6.81	<76	--	<5.8	5.6	<.9
RWD 4 Well 4	09-22-92	1114	3.17	<1.1	144	8.87	7.04	<76	--	<5.8	6.2	<.9
RWD 4 Well 4	10-20-92	1640	2.8	<.494	146	7.42	--	<25	<32	<1	6.4	<1
RWD 4 Well 4	10-20-92	1643	3.44	1.55	146	8.89	7.34	<37	--	<12	6.9	<.2
RWD 4 Well 4	10-20-92	1644	3.54	1.44	146	9.11	7.33	<37	--	<12	6.8	<.2
RWD 4 Well 4	11-16-92	1050	3.11	.893	167	4	--	<61	<31	<4	6.8	<1
RWD 4 Well 4	11-16-92	1051	3.06	.866	167	7	--	<61	<31	<4	7.1	<1
RWD 4 Well 4	11-16-92	1053	3.15	.83	167	8.64	7.92	<26	--	<10	5.9	<5
RWD 4 Well 4	11-16-92	1054	3.18	.78	167	11.1	19.2	<26	--	<10	5.5	<5
RWD 4 Well 4	12-15-92	1130	2.71	1.23	146	11.2	8.93	<25	<32	<1	7.1	<1
RWD 4 Well 4	12-15-92	1133	2.69	2.03	146	8.95	7.8	83	--	<23	7.1	<.2
RWD 4 Well 4	12-15-92	1134	2.8	1.39	146	9.04	7.84	<67	--	<23	6.5	<.2
RWD 4 Well 4	01-25-93	1640	2.92	1.76	144	10.2	8.71	<30.8	<24.3	<1.5	6.8	<1.7
RWD 4 Well 4	01-25-93	1643	3.37	<.44	144	9.03	7.68	89	--	<18	6.4	.1
RWD 4 Well 4	01-25-93	1644	3.08	<.44	144	8.82	7.62	<59	--	<18	7.2	<.1
RWD 6 Well 1	01-26-93	1700	45.4	3.58	151	135	60.4	<30.8	34.1	<1.5	30.9	<1.7
RWD 6 Well 1	01-26-93	1703	50.1	1.85	151	10.9	62.7	148	--	<18	32.8	.1
RWD 6 Well 1	01-26-93	1704	51.8	1.75	151	10.6	62.7	<59	--	<18	32.7	<5

Appendix 1. Physical properties and concentrations of major ions and trace elements in water samples from wells—Continued

Owner or well name	Date	Time	Boron (µg/L)	Cad- mium (µg/L)	Chro- mium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/ L)	Lead (µg/L)	Lithium (µg/L)	Manga- nese (µg/L)	Mercury (µg/L)
RWD 4 Well 4	08-18-92	0930	--	<3.6	<4.1	<14	<2.7	44	<1.2	--	<.8	<.2
RWD 4 Well 4	08-18-92	0933	<14	<1.6	2	<4.3	<50	39.2	<18	<7.2	6.8	--
RWD 4 Well 4	08-18-92	0934	<9.9	<1.6	<1.9	<4.3	<50	34.3	<18	<7.2	<3.7	--
RWD 4 Well 4	09-22-92	1110	--	<1	<4.5	<2.7	<3.5	53.6	1.8	--	<4.7	.53
RWD 4 Well 4	09-22-92	1113	<20	<2.3	<2.4	<3.5	<51	<94	<26	<6.9	<7.8	--
RWD 4 Well 4	09-22-92	1114	<20	<2.3	3.1	<3.5	<51	<94	<26	<6.9	<7.8	--
RWD 4 Well 4	10-20-92	1640	--	<4	<3	<5	<4	36.6	1.6	--	2.1	<.2
RWD 4 Well 4	10-20-92	1643	5.9	<1.7	<.8	<1.8	<4.8	56	<22	10	<2.5	--
RWD 4 Well 4	10-20-92	1644	9.9	<1.7	1.8	<1.8	<4.8	37	<22	7.8	<2.5	--
RWD 4 Well 4	11-16-92	1050	--	<3	<8	<7	7.3	56	8.8	--	<2	<.2
RWD 4 Well 4	11-16-92	1051	--	<3	<8	<7	<6	49.2	1.3	--	<2	<.2
RWD 4 Well 4	11-16-92	1053	<6.3	<2.1	<1.6	<2.7	<20	31.3	<17	3.2	<2.5	--
RWD 4 Well 4	11-16-92	1054	<6.3	<2.1	<1.6	<2.7	<20	42	<17	3.6	<2.5	--
RWD 4 Well 4	12-15-92	1130	--	<4	<3	<5	25.4	138	1.7	--	2.2	<.2
RWD 4 Well 4	12-15-92	1133	<50	<2.6	<1.4	2	<15	31	25	15	.3	--
RWD 4 Well 4	12-15-92	1134	<50	<2.6	<1.4	1.9	<15	38	<20	13.3	2.2	--
RWD 4 Well 4	01-25-93	1640	--	<2.3	<5.7	<10.6	<2.6	62.9	<1.4	--	2	<.2
RWD 4 Well 4	01-25-93	1643	<15	<1.6	<2.3	<8.2	<38	64	<8.1	<4.6	<2.3	--
RWD 4 Well 4	01-25-93	1644	<15	<1.6	<2.3	<8.2	<38	48	<8.1	<4.6	<2.3	--
RWD 6 Well 1	01-26-93	1700	--	<2.3	<5.7	<10.6	6	56.6	<1.4	--	2.1	<.2
RWD 6 Well 1	01-26-93	1703	124	<1.6	<2.3	<8.2	<38	47	<8.1	71.4	<2.3	--
RWD 6 Well 1	01-26-93	1704	121	<1.6	<2.3	<8.2	<38	30	<8.1	70.9	<2.3	--

Appendix 1. Physical properties and concentrations of major ions and trace elements in samples from wells—Continued

Owner or well name	Date	Time	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Strontium (µg/L)	Thallium (µg/L)	Titanium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
RWD 4 Well 4	08-18-92	0930	--	<14.5	<1.6	<2	--	<1.2	--	<5	<2.6
RWD 4 Well 4	08-18-92	0933	7.1	<5.6	<7.5	<3.8	42.6	<24	72	<14	<6.1
RWD 4 Well 4	08-18-92	0934	5.2	<5.6	7.5	<3.8	42.2	<24	<17	<14	<6.1
RWD 4 Well 4	09-22-92	1110	--	<5.4	<2.9	<2.5	--	<3.8	--	<2.8	4.7
RWD 4 Well 4	09-22-92	1113	<2.2	<4.1	<10	<3.4	4.2	<19	<2.4	<8.6	<7.6
RWD 4 Well 4	09-22-92	1114	4	<4.1	<10	<3.4	3.9	<19	<2.4	<8.6	<7.6
RWD 4 Well 4	10-20-92	1640	--	<5	<1	<4	--	<1	--	<3	<3
RWD 4 Well 4	10-20-92	1643	5.6	<4.6	<26	<6.1	4.2	<10	3.3	<13	<40
RWD 4 Well 4	10-20-92	1644	6.2	<4.6	<26	<6.1	4.2	<10	<2.6	<13	<40
RWD 4 Well 4	11-16-92	1050	--	<7	<1	<5	--	<2	--	<6	6.1
RWD 4 Well 4	11-16-92	1051	--	<7	<1	<5	--	<2	--	<6	4.9
RWD 4 Well 4	11-16-92	1053	4.3	<8.1	<24	<6.4	3.8	<18	<1.9	<13	<3.5
RWD 4 Well 4	11-16-92	1054	5.1	<8.1	<24	<6.4	3.7	<18	<1.9	<13	<3.5
RWD 4 Well 4	12-15-92	1130	--	6.3	<1	<4	--	<1	--	<3	17.2
RWD 4 Well 4	12-15-92	1133	3.9	<8.9	15.9	11.4	3.6	16	<5.6	<24	<1.4
RWD 4 Well 4	12-15-92	1134	4.9	<8.9	<9.9	<7.4	3.7	<15	<5.6	<24	<1.4
RWD 4 Well 4	01-25-93	1640	--	<8.8	<.9	<4	--	<2.5	--	6.1	<3.6
RWD 4 Well 4	01-25-93	1643	3.7	<2.6	<21	<7.8	44	<8.1	<2	<13	<3.2
RWD 4 Well 4	01-25-93	1644	<3.6	<2.6	<21	<7.8	44.1	<8.1	<2.2	<13	12.5
RWD 6 Well 1	01-26-93	1700	--	<8.8	<.9	<4	--	<2.5	--	6.4	<3.6
RWD 6 Well 1	01-26-93	1703	<3.6	<2.6	<21	<7.8	584	<8	2.7	<13	<3.2
RWD 6 Well 1	01-26-93	1704	<3.6	<2.6	<21	<7.8	591	<8	<1.3	<13	<3.2

Appendix 2. Concentrations of major ions and trace elements in quality-assurance blank samples

[Filter type: F, filtered; U, unfiltered. Agency analyzing: CLP, U.S. Environmental Protection Agency contract laboratory program; RSK, U.S. Environmental Protection Agency Robert S. Kerr Environmental Research Laboratory. mg/L, milligrams per liter; --, sample not analyzed for this constituent]

Owner or well name	Date	Time	Filter type	Blank type	Agency analyzing	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
Cardin	09-22-92	0902	U	Field	CLP	.0501	<.0408	.0566	<.242	1.69
Cardin	09-22-92	0905	F	Field	RSK	.045	<.11	<.062	<1.1	<.05
Cardin	12-14-92	0922	U	Field	CLP	<.032	<.046	<.023	<.494	<.2
Cardin	12-14-92	0925	F	Field	RSK	.033	<.022	<.076	<.49	<.5
Cardin	01-25-93	0922	U	Field	CLP	.305	.0983	.242	.442	<.025
Cardin	01-25-93	0925	F	Field	RSK	<.12	<.045	<.04	<.44	<.05
Commerce 1	08-17-92	0932	U	Field	CLP	.22	.0524	.201	<.34	<5
Commerce 1	08-17-92	0935	F	Field	RSK	<.16	<.25	<.078	<1	<.05
Commerce 3	10-21-92	1522	U	Field	CLP	.133	<.046	<.046	<.494	<1
Commerce 3	10-21-92	1525	F	Field	RSK	.131	.152	.084	.94	<.05
Commerce 4	09-23-92	1512	U	Field	CLP	.0581	<.0408	.0593	<.242	1.39
Commerce 4	09-23-92	1515	F	Field	RSK	<.022	<.11	<.062	<1.1	<.05
Commerce 4	11-17-92	1552	U	Field	CLP	.212	<.044	.0679	<.123	<1
Commerce 4	11-17-92	1555	F	Field	RSK	.027	<.035	<.017	<.35	<.05
Commerce 4	01-26-93	1442	U	Field	CLP	.248	.0634	.291	.978	<.025
Commerce 4	01-26-93	1445	F	Field	RSK	<.12	<.045	<.04	<.44	<.05
Grand Lake Shores	01-27-93	1432	U	Field	CLP	.232	<.0593	.249	<.426	<.025
Grand Lake Shores	01-27-93	1435	F	Field	RSK	<.12	<.045	<.04	<.44	<.05
Picher 2	10-20-92	0942	U	Field	CLP	<.032	<.046	<.046	<.494	<1
Picher 2	10-20-92	0945	F	Field	RSK	.056	.109	.032	.71	<.05
Quality assurance	08-17-92	0936	U	Trip	CLP	.251	.0441	.19	<.34	<5
Quality assurance	09-23-92	1606	U	Trip	CLP	.0292	<.0408	.0517	<.242	2.11
Quality assurance	10-22-92	1206	U	Trip	CLP	<.032	<.046	<.046	<.494	<1
Quality assurance	11-16-92	0806	U	Trip	CLP	<.088	<.044	.0428	.141	1
Quality assurance	12-14-92	0806	U	Trip	CLP	<.032	<.046	<.023	<.494	<.2
Quality assurance	01-25-93	0806	U	Trip	CLP	.262	.093	.284	<.426	<.05

Appendix 2. Concentrations of major ions and trace elements in quality-assurance blank samples—Continued

Owner or well name	Date	Time	Chloride (mg/L)	Aluminum (µg/L)	Anti-mony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)	Boron (µg/L)	Cadmium (µg/L)	Chromium (µg/L)
Cardin	09-22-92	0902	--	<21.4	<16.9	<1.9	<2.9	<.4	--	<1	<4.5
Cardin	09-22-92	0905	<.05	<76	--	<5.8	<.4	<.9	<7.6	<2.3	<2.4
Cardin	12-14-92	0922	<.15	<25	<32	1.5	<1	<1	--	<4	<3
Cardin	12-14-92	0925	<.05	71	--	<23	2.1	<.2	<50	<2.6	<1.4
Cardin	01-25-93	0922	<.02	<30.8	<24.3	<1.5	2.2	<1.7	--	<2.3	<5.7
Cardin	01-25-93	0925	<.05	<59	--	<18	<1.3	<5	<15	2.2	<2.3
Commerce 1	08-17-92	0932	--	<42	<32.2	<2.6	<1.6	<1.6	--	<3.6	<4.1
Commerce 1	08-17-92	0935	<.05	<52	--	<39	<1.1	<5	5.5	<1.6	<1.9
Commerce 3	10-21-92	1522	--	43.9	<32	<1	5.3	<1	--	<4	<3
Commerce 3	10-21-92	1525	<.05	<37	--	<12	<1.1	<.2	<4.1	<1.7	.9
Commerce 4	09-23-92	1512	--	<21.4	<16.9	<1.9	<2.9	<.4	--	<1	<4.5
Commerce 4	09-23-92	1515	.23	<76	--	<5.8	<.4	<.9	<7.6	<2.3	<2.4
Commerce 4	11-17-92	1552	--	<61	<31	<4	<1	<1	--	<3	<8
Commerce 4	11-17-92	1555	<.05	<26	--	<10	<1.5	<5	<6.3	<2.1	<1.6
Commerce 4	01-26-93	1442	<.02	<30.8	<24.3	<1.5	1.8	<1.7	--	<2.3	<5.7
Commerce 4	01-26-93	1445	<.05	<59	--	<18	<1.3	<1	<15	<1.6	<2.3
Grand Lake Shores	01-27-93	1432	<.02	<30.8	<24.3	<1.5	1.4	<1.7	--	<2.3	<5.7
Grand Lake Shores	01-27-93	1435	<.05	<59	--	<18	<1.3	.1	<15	<1.6	<2.3
Picher 2	10-20-92	0942	--	<25	<32	<1	<1	<1	--	<4	<3
Picher 2	10-20-92	0945	<.05	<37	--	12	<1.1	<.2	4.6	2	2.7
Quality assurance	08-17-92	0936	--	<42	<32.2	<2.6	<1.6	<1.6	--	<3.6	<4.1
Quality assurance	09-23-92	1606	--	<21.4	<16.9	<1.9	<2.9	<.4	--	<1	<4.5
Quality assurance	10-22-92	1206	--	<25	<32	<1	<1	<1	--	<4	<3
Quality assurance	11-16-92	0806	--	<61	<31	<4	<1	<1	--	<3	<8
Quality assurance	12-14-92	0806	<.15	<25	<32	<1	<1	<1	--	<4	<3
Quality assurance	01-25-93	0806	<.02	<30.8	<24.3	<1.5	2.6	<1.7	--	<2.3	<5.7

Appendix 2. Concentrations of major ions and trace elements in quality-assurance blank samples—Continued

Owner or well name	Date	Time	Cobalt ($\mu\text{g/L}$)	Copper ($\mu\text{g/L}$)	Iron ($\mu\text{g/L}$)	Lead ($\mu\text{g/L}$)	Lithium ($\mu\text{g/L}$)	Man- ganese ($\mu\text{g/L}$)	Mercury ($\mu\text{g/L}$)	Molyb- denum ($\mu\text{g/L}$)
Cardin	09-22-92	0902	<2.7	<3.5	18.4	2.6	--	<4.7	.16	--
Cardin	09-22-92	0905	<3.5	<51	<94	<26	<6.9	<7.6	--	<2.2
Cardin	12-14-92	0922	<5	13	19.1	<1	--	<2	<.2	--
Cardin	12-14-92	0925	<1.7	<16	12	<20	<2.5	<.1	--	2.9
Cardin	01-25-93	0922	<10.6	3.2	41.5	<1.4	--	<1.7	<.2	--
Cardin	01-25-93	0925	<8.2	<38	<11	<8.1	<4.6	<2.3	--	<3.6
Commerce 1	08-17-92	0932	<14	<2.7	19.6	2.9	--	<.8	.2	--
Commerce 1	08-17-92	0935	<4.3	<50	<6.1	<18	<7.2	<3.7	--	<2.3
Commerce 3	10-21-92	1522	<5	<4	<6	<1	--	<2	<.2	--
Commerce 3	10-21-92	1525	<1.8	<4.8	<15	<22	6.7	<2.5	--	<2.7
Commerce 4	09-23-92	1512	<2.7	<3.5	16.8	1.7	--	<4.7	.16	--
Commerce 4	09-23-92	1515	<3.5	<51	<94	<26	<6.9	<7.6	--	<2.2
Commerce 4	11-17-92	1552	<7	8.1	23.6	2.4	--	<2	<.2	--
Commerce 4	11-17-92	1555	<2.7	<20	<8.5	<17	<2.5	<2.5	--	<2.8
Commerce 4	01-26-93	1442	<10.6	<2.6	30.2	<1.4	--	<1.7	<.2	--
Commerce 4	01-26-93	1445	<8.2	<38	<11	<8.1	<4.6	<2.3	--	<3.6
Grand Lake Shores	01-27-93	1432	<10.6	2.8	19.8	1.8	--	<1.7	<.2	--
Grand Lake Shores	01-27-93	1435	<8.2	<38	<11	<8.1	<4.6	<2.3	--	<3.6
Picher 2	10-20-92	0942	<5	4.4	<6	1	--	<2	<.2	--
Picher 2	10-20-92	0945	3	<4.8	<15	<22	4.4	<2.5	--	<2.7
Quality assurance	08-17-92	0936	<14	<2.7	62.3	<1.2	--	<.8	<.2	--
Quality assurance	09-23-92	1606	<2.7	<3.5	<11.6	2.3	--	<4.7	.16	--
Quality assurance	10-22-92	1206	<5	<4	<6	<1	--	<2	<.2	--
Quality assurance	11-16-92	0806	<7	6.5	<15	17800	--	<2	<.2	--
Quality assurance	12-14-92	0806	<5	4.1	<6	<1	--	<2	<.2	--
Quality assurance	01-25-93	0806	<10.6	3.8	32.9	<1.4	--	1.7	<.2	--

Appendix 2. Concentrations of major ions and trace elements in quality-assurance blank samples—Continued

Owner or well name	Date	Time	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Strontium (µg/L)	Thallium (µg/L)	Titanium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
Cardin	09-22-92	0902	<5.4	<2.9	<2.5	--	<3.8	--	<2.8	3.9
Cardin	09-22-92	0905	<4.1	<10	<3.4	<5	<19	<2.4	<8.6	<7.6
Cardin	12-14-92	0922	8.5	<1	<4	--	<1	--	<3	<3
Cardin	12-14-92	0925	<9	13	9.6	.1	<15	<5.7	<24	3.8
Cardin	01-25-93	0922	<8.8	<.9	<4	--	<2.5	--	<3.7	<3.6
Cardin	01-25-93	0925	9	<21	<7.8	<1.3	<8	<1.3	<13	<3.2
Commerce 1	08-17-92	0932	<14.5	<1.6	<2	--	<1.2	--	<5	12
Commerce 1	08-17-92	0935	<5.6	<7.5	<3.8	<2.1	<24	<17	<14	29.4
Commerce 3	10-21-92	1522	<5	<1	<4	--	<1	--	<3	<3
Commerce 3	10-21-92	1525	<4.6	<26	<6.1	<5	<10	<2.6	<13	<40
Commerce 4	09-23-92	1512	<5.4	<2.9	<2.5	--	<3.8	--	<2.8	4.7
Commerce 4	09-23-92	1515	<4.1	16	<3.4	<5	<19	<2.4	<8.6	<7.6
Commerce 4	11-17-92	1552	<7	<1	<5	--	<2	--	<6	7.3
Commerce 4	11-17-92	1555	<8.1	<24	<6.4	<5	<18	<1.9	<13	<3.5
Commerce 4	01-26-93	1442	<8.8	<.9	<4	--	<2.5	--	7.4	<3.6
Commerce 4	01-26-93	1445	<2.6	<21	<7.8	<1.3	<8	<1.3	<13	13.2
Grand Lake Shores	01-27-93	1432	<8.8	<.9	<4	--	<2.5	--	<3.7	<3.6
Grand Lake Shores	01-27-93	1435	<2.6	<21	<7.8	<1.3	<8	<1.7	<13	<3.2
Picher 2	10-20-92	0942	<5	<1	<4	--	<1	--	<3	<3
Picher 2	10-20-92	0945	<4.6	<26	<6.1	<5	<10	<2.6	<13	<40
Quality assurance	08-17-92	0936	<14.5	<1.6	<2	--	<1.2	--	<5	9.8
Quality assurance	09-23-92	1606	<5.4	<2.9	<2.5	--	<3.8	--	<2.8	3.3
Quality assurance	10-22-92	1206	<5	<1	<4	--	<1	--	<3	<3
Quality assurance	11-16-92	0806	<7	<1	<5	--	<2	--	<6	16.8
Quality assurance	12-14-92	0806	<5	<1	<4	--	<1	--	<3	<3
Quality assurance	01-25-93	0806	<8.8	<.9	<4	--	<2.5	--	<3.7	6.8

Appendix 2. Concentrations of major ions and trace elements in quality-assurance blank samples—Continued

Owner or well name	Date	Time	Filter type	Blank type	Agency analyzing	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
Quapaw 4	08-18-92	1622	U	Field	CLP	.233	.0541	.257	<.34	<5
Quapaw 4	08-18-92	1625	F	Field	RSK	.18	<.25	<.078	<1	<.05
RWD 4 Well 4	11-16-92	1052	U	Field	CLP	<.088	<.044	.0557	.156	<1
RWD 4 Well 4	11-16-92	1055	F	Field	RSK	.04	<.035	<.017	<.35	<.05
RWD 4 Well 4	12-15-92	1132	U	Field	CLP	<.032	<.046	<.023	.577	<.2
RWD 4 Well 4	12-15-92	1135	F	Field	RSK	.044	.069	<.076	.85	<.05

Appendix 1. Concentrations of major ions and trace elements in quality-assurance blank samples—Continued

Owner or well name	Date	Time	Chloride (mg/L)	Aluminum (µg/L)	Antimony (µg/L)	Arsenic (µg/L)	Barium (µg/L)	Beryllium (µg/L)	Boron (µg/L)	Cadmium (µg/L)	Chromium (µg/L)
Quapaw 4	08-18-92	1622	--	<42	<32.2	<2.6	<1.6	<1.6	--	<3.6	<4.1
Quapaw 4	08-18-92	1625	<.05	<52	--	<39	<1.1	<5	16.3	<1.6	<1.9
RWD 4 Well 4	11-16-92	1052	--	141	<31	<4	1.2	<1	--	<3	<8
RWD 4 Well 4	11-16-92	1055	<.05	<26	--	<10	<1.5	<5	<6.3	<2.1	2.9
RWD 4 Well 4	12-15-92	1132	<.15	<25	<32	<1	2	<1	--	<4	<3
RWD 4 Well 4	12-15-92	1135	<.05	<68	--	<23	<2	<.2	<50	<2.6	<1.4

Appendix 2. Concentrations of major ions and trace elements in quality-assurance blank samples—Continued

Owner or well name	Date	Time	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)	Man- ganese (µg/L)	Mercury (µg/L)	Molyb- denum (µg/L)
Quapaw 4	08-18-92	1622	<14	<2.7	22.7	<1.2	--	<.8	<.2	--
Quapaw 4	08-18-92	1625	<4.3	<50	8.6	<18	<7.2	<3.7	--	<2.3
RWD 4 Well 4	11-16-92	1052	<7	<6	30.1	1.9	--	<2	<.2	--
RWD 4 Well 4	11-16-92	1055	3.7	<20	<8.5	<17	<2.5	<2.5	--	<2.8
RWD 4 Well 4	12-15-92	1132	<5	4.1	7.1	<1	--	<2	<.2	--
RWD 4 Well 4	12-15-92	1135	<1.7	<16	41	28	5.5	1.1	--	<1.3

Appendix 2. Concentrations of major ions and trace elements in quality-assurance blank samples—Continued

Owner or well name	Date	Time	Nickel (µg/L)	Selenium (µg/L)	Silver (µg/L)	Strontium (µg/L)	Thallium (µg/L)	Titanium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
Quapaw 4	08-18-92	1622	<14.5	<1.6	<2	--	<1.2	--	<5	6
Quapaw 4	08-18-92	1625	<5.6	<7.5	<3.8	<2.1	<24	<17	<14	<6
RWD 4 Well 4	11-16-92	1052	<7	<1	<5	--	<2	--	<6	29.5
RWD 4 Well 4	11-16-92	1055	<8.1	<24	<6.4	<5	<18	<1.9	<13	<3.5
RWD 4 Well 4	12-15-92	1132	<5	<1	<4	--	<1	--	<3	<3
RWD 4 Well 4	12-15-92	1135	<8.9	11.4	<7.4	.1	<15	<5.7	<24	8.8