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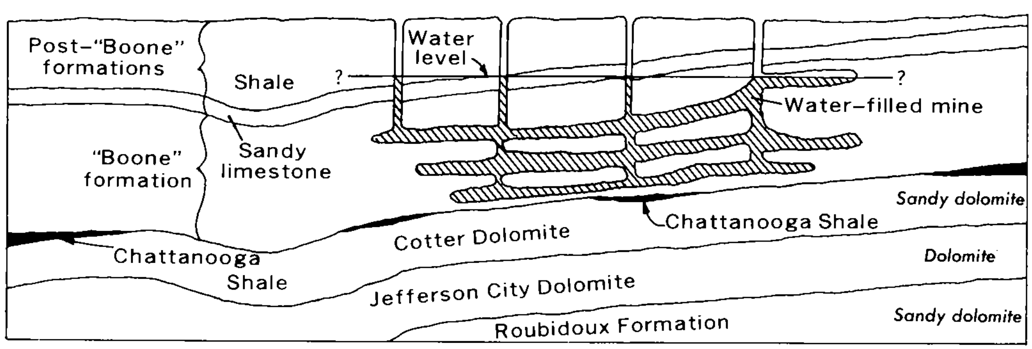
CHEMICAL QUALITY OF WATER IN ABANDONED ZINC MINES IN NORTHEASTERN OKLAHOMA AND SOUTHEASTERN KANSAS

STEPHEN J. PLAYTON, ROBERT E. DAVIS, AND ROGER G. MCCLAFLIN

Prepared by the United States Geological Survey in cooperation with the Oklahoma Geological Survey



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CHARLES J. MANKIN, *Director*
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Title Page Illustration

Generalized section showing relationship of rock formations to water-filled mines (see fig. 2). Ink diagram by Zack T. Morris.

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CHEMICAL QUALITY OF WATER IN ABANDONED ZINC MINES IN NORTHEASTERN OKLAHOMA AND SOUTHEASTERN KANSAS

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Abstract—Onsite measurements of pH, specific conductance, and water temperature show that water in seven mine shafts in northeastern Oklahoma and southeastern Kansas is stratified. With increasing sampling depth, specific conductance and water temperature tend to increase, and pH tends to decrease. Concentrations of dissolved solids and chemical constituents in mine-shaft water, such as total and dissolved metals and dissolved sulfate also increase with depth. The apparently unstable condition created by cooler, denser water overlying warmer, less dense water is offset by the greater density of the lower water strata due to higher dissolved solids content.

Correlation analysis showed that several chemical constituents and properties of mine-shaft water—including dissolved solids, total hardness, and dissolved sulfate, calcium, magnesium, and lithium—are linearly related to specific conductance. None of the constituents or properties of mine-shaft water tested had a significant linear relationship to pH. However, when values of dissolved aluminum, zinc, and nickel were transformed to natural or Napierian logarithms, significant linear correlation to pH resulted.

During the course of the study—September 1975 to June 1977—the water level in a well penetrating the mine workings rose at an average rate of 1.2 feet per month. Usually, the rate of water-level rise was greater than average after periods of relatively high rainfall, and lower than average during periods of relatively low rainfall.

Water in the mine shafts is unsuited for most uses without treatment. The inability of current domestic water-treatment practices to remove high concentrations of toxic metals, such as cadmium and lead, precludes use of the water for a public supply.

INTRODUCTION

Purpose and Scope

Increasing demands for water and decreasing water levels in the heavily pumped Roubidoux Formation in northern Ottawa County, Oklahoma, have led to a search for an alternative source of water. Water in abandoned zinc mines within the Boone Formation of Mississippian age represents a potential alternative supply. However, before any use can be made of the water within the mines, information about its quality is imperative.

In order to provide water-quality information, a study by the U.S. Geological Survey, in cooperation with the Oklahoma Geological Survey, was made. The principal objective of the study was to determine the suitability of the water in the zinc mines for public supply, industrial cooling, and irrigation.

The study originally consisted of three phases:

Phase I.— An intensive reconnaissance of the accessible mine shafts to (a) make field measurements of pH, specific conductance, and water temperature, (b) collect water samples for chemical and physical analyses, and (c) evaluate the data.

Phase II.— Collect and analyze water samples once every 2 months for 1 year to determine any variations in water quality.

Phase III.—Collect and analyze water samples twice a year for 4 years after completion of phase II to determine any annual variations and long-term trends in water quality.

The results of phase I were reported by Playton and Davis (1977). Results of phase II are presented in this report. The principal objective of this study has been fulfilled by phases I and II; therefore, phase III will not be pursued.

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Historical Background[3]

Lead and zinc ore was first discovered in the study area (fig. 1) in 1901, and the first recorded output of sulfide concentrates was made in 1904. During the early years of mining, operations were relatively shallow, extending from 50 to 130 ft in depth. However, as mining progressed, depths to 385 ft were reached.

Land ownership in the area was diverse with many owners holding small tracts, which allowed numerous small companies to obtain leases and simultaneously run mining operations. In 1918, approximately 230 mills were built or were under construction in Oklahoma alone, a figure that approaches the number of individual operations.

Ore bodies reached from one leased tract to the next, and mining activities were extensive throughout the area. Therefore, nearly all of the mines were interconnected, and distinguishing one mine from another was difficult. In fact, even the smaller connective workings were large enough to allow passage of ore trucks.

Production of ores from the mines expanded rapidly from 1915 to 1920; output jumped from 28,000 tons to 502,000 tons. However, the 1920's marked the maturity of the mine field. In the 5 years from 1921 to 1925, the mines in and near the study area yielded 55 percent of the total zinc produced in the United States. The total production through 1964 amounted to over 7 million tons of zinc and just under 2 million tons of lead.

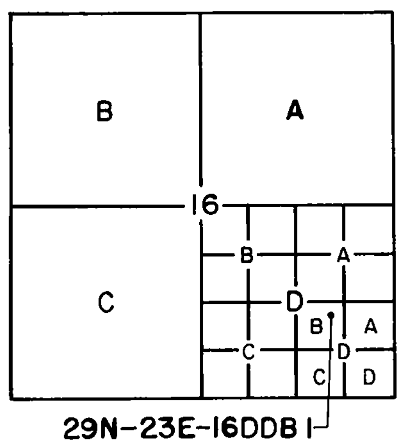
After a brief period of slowdown in the early 1930's, annual production again increased through 1941. However, production in 1941 was still only slightly greater than 50 percent of the output in 1925. During the late 1920's and 1930's, many mines became depleted, forcing smaller companies out of business. These operations were bought by larger companies that were able to continue mining owing to the economy of centralized milling. Also, improved technology allowed recovery of much low-grade ore from tailing sites.

World War II created a high demand for base metals, but ore depletion dictated an industry decline. Because of depressed metal markets in 1957, many operations were suspended or reduced. By mid-1958, all major mining operations were discontinued. Although mining on a small scale has resumed since 1960, most sites have been depleted and abandoned.

[3]Summarized from McKnight and Fischer (1970).

Explanation of Site Numbering System

The standard method of giving location of fractional section, section, township, and range is replaced by the method illustrated in the diagram below. The location of the site indicated by the dot normally would be described as NW¼SE¼SE¼ sec. 16, T. 29 N., R. 23 E. The method used in this report reverses the order and indicates quarter subdivisions of the section by letters. By this method the location of the site is given as 29N-23E-16DDB 1. The final digit (1) is the sequential number of a site within the smallest fractional subdivision.



Conversion Factors

Factors for converting U.S. customary units to metric units are shown to four significant figures.

U.S. customary	*Multiply by*	*Metric*
acre-ft (acre-feet)	1.233×10^{-3}	hm^3 (cubic hectometers)
ft (feet)	.3048	m (meters)
ft^3/s (cubic feet per second)	2.832×10^{-2}	m^3/s (cubic meters per second)
in (inches)	25.40	mm (millimeters)
mi (miles)	1.609	km (kilometers)
ton	9.072×10^{-2}	t (metric ton)

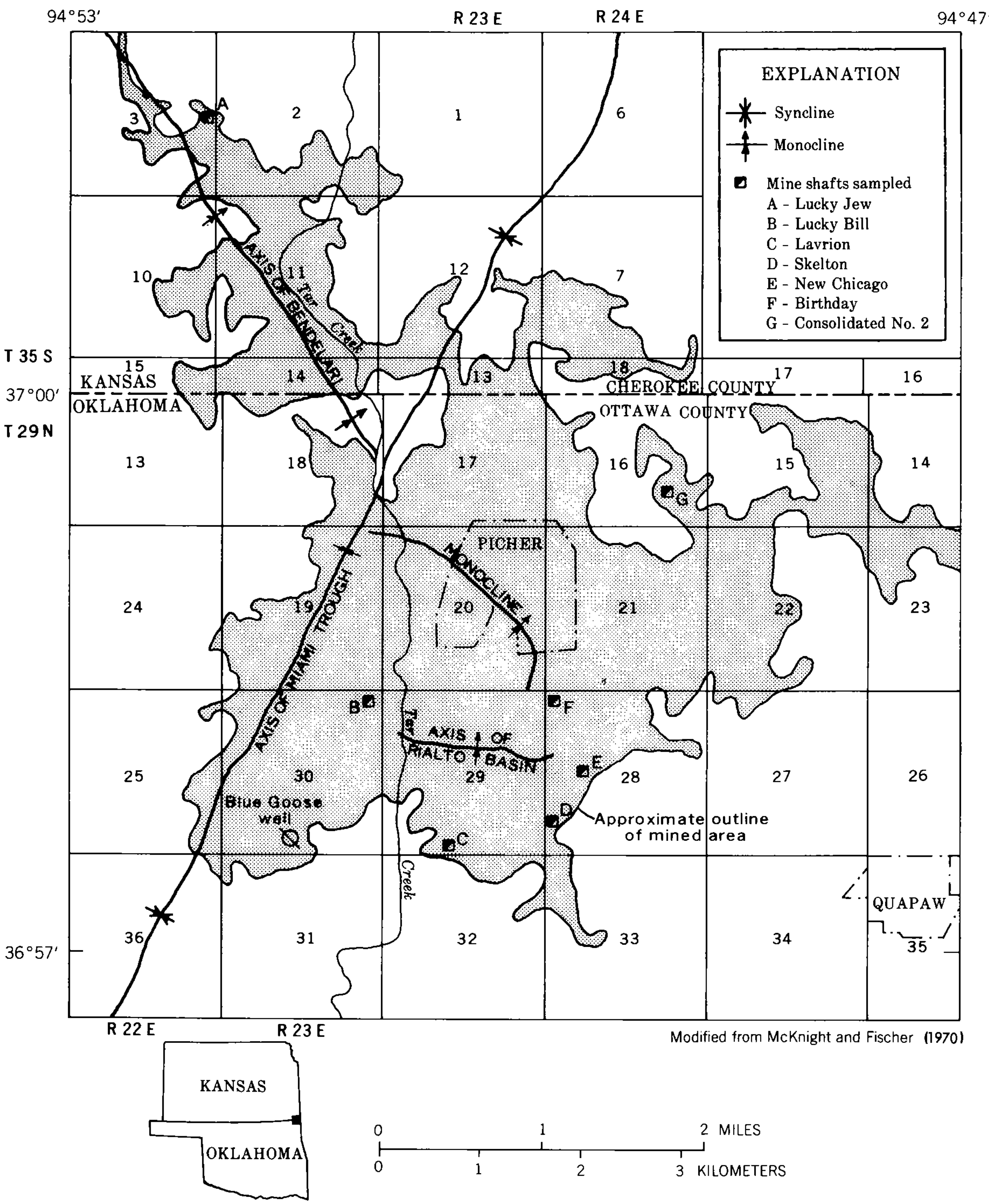


Figure 1. Map of study area (stippling), showing geologic structure, approximate area of mine workings, and locations of sampled shafts.

Acknowledgments

The authors are especially indebted to Gordon E. Hoppe and Harry A. Berkey, of the Northeast Counties of Oklahoma Economic Development Association, for providing encouragement and cooperation from the beginning of the project. Sincere gratitude is extended to C. V. Collins, U.S. Geological Survey, and Douglas C. Brockie, Eagle-Picher Industries, for their invaluable assistance in providing information about the mines. The authors would like to express their thanks to Thomas Bond, U.S. Bureau of Indian Affairs, for providing access to Indian lands in the study area.

Geologic Setting

The study area (fig. 1) is relatively flat prairie in northeastern Oklahoma and southeastern Kansas. The regional dip of the rocks is 15 to 25 ft/mi to the northwest, though locally the dip may differ. The main structural features in the area are the Miami Trough, the Rialto Basin, and the Bendelari Monocline (McKnight and Fischer, 1970, p. 72–75). The Miami Trough is a combination of syncline and graben with a general trend of N. 26° E. The axes of the Rialto Basin and the Bendelari Monocline cross the area in a northwesterly direction. The maximum dip of the rocks in these structures is about 20°.

The abandoned mines are in the Boone Formation, of Mississippian age (fig. 2), which consists of 350 to 400 ft of chert, jasperoid, limestone, and dolomite. The principal ore minerals mined from the Boone were sphalerite and galena. Accessory minerals include chalcopyrite, enargite, luzonite, marcasite, pyrite, and barite. Fracturing within the formation is common, especially in mineralized areas.

The Chattanooga Shale of Mississippian and Devonian age underlies the Boone Formation but is locally absent in the study area. Where the Chattanooga Shale is absent, the Boone Formation lies directly upon an Ordovician sequence consisting of, in descending order, Cotter Dolomite, Jefferson City Dolomite, and Roubidoux Formation. Rocks overlying the Boone Formation are of Late Mississippian and Pennsylvanian age and consist predominantly of shale, with some sandstone and limestone layers.

CHARACTERISTICS OF MINE-SHAFT WATER

Definition of pH and Specific Conductance

The pH of a solution is a measurement of the hydrogen-ion concentration expressed as the negative base 10 logarithm of the hydrogen-ion activity in moles per liter. Val-

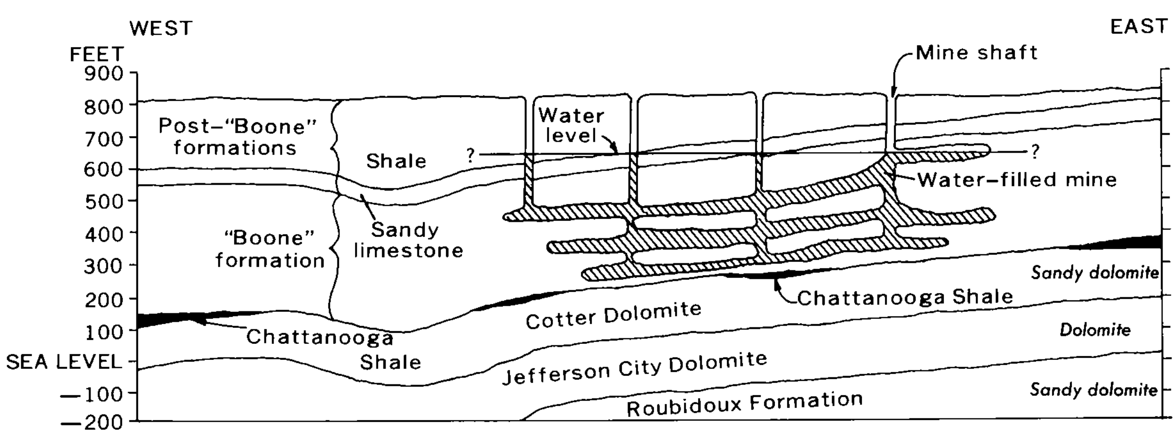


Figure 2. Generalized geologic section showing relationship of rock formations to water-filled mines.

ues of pH may range from 0 to 14. A pH of 7 refers to a neutral solution that contains an equal concentration of hydrogen (H^+) and hydroxyl (OH^-) ions. Solutions within the pH range of 0 to 7 are considered acidic, and those within the range of 7 to 14 are considered basic or alkaline.

Specific conductance is a measure of the ability of water to conduct an electric current across a specified cross section at a given temperature and is usually expressed as μmho/cm at 25°C (micromhos per centimeter at 25° Celsius). The micromho is the reciprocal of ohms $\times$ 10^6. Specific conductance is related to the ionic concentration of dissolved chemical constituents and, therefore, to the dissolved-solids content of the water.

Sampling Frequencies and Methods

During the period April 1976 to June 1977, water samples were collected for physical and chemical analysis from seven mine shafts; six in Oklahoma and one in Kansas (fig. 1). These mine shafts were selected during previous field excursions, using selection criteria based on safety, accessibility, and areal distribution. In April 1976 all seven shafts were sampled. Thereafter, four shafts —Lucky Bill, Birthday, New Chicago, and Consolidated No. 2—were sampled every other month from August 1976 through June 1977. Two mine shafts, Lucky Jew and Skelton, were sampled only twice after April 1976, in October 1976 and June 1977. Lavrion mine shaft was not sampled again, because by July 1976 it had been plugged with concrete. Each time the shafts were sampled, water-level measurements were recorded at each mine shaft and at the Blue Goose well, a well penetrating the mine workings (fig. 1).

When the mine shafts were visited, water samples were collected from one or more points in a vertical profile with a Kemmerer-type sampler made of PVC (polyvinyl chloride) (fig. 3). Field analyses for specific conductance, pH, and water temperature were made from each sample at each sampling depth (figs. 4–9). At selected depths, where pH or specific-conductance values differed significantly from those values ob-

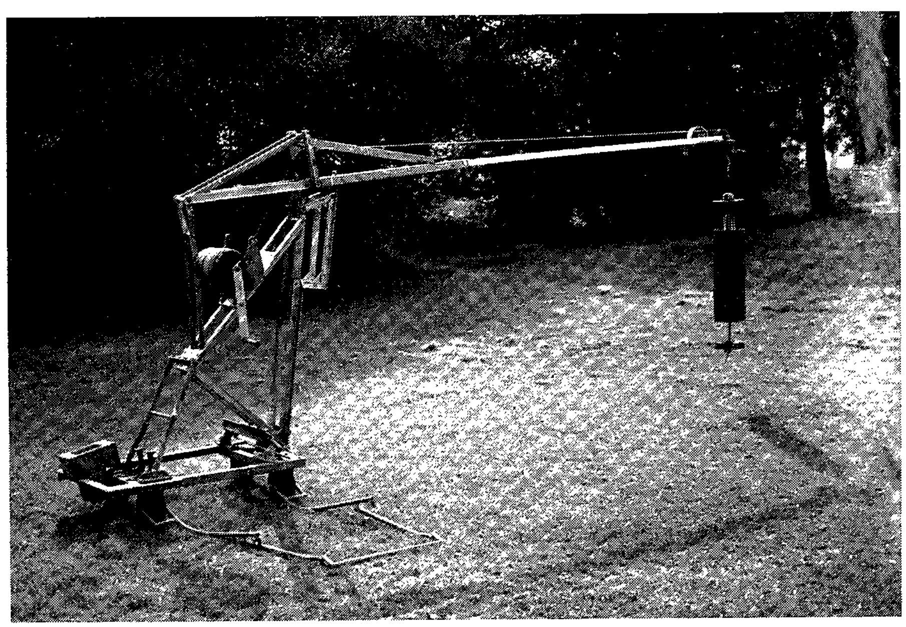


Figure 3. Kemmerer-type PVC sampler and boom apparatus used in collection of water samples from mine shafts.

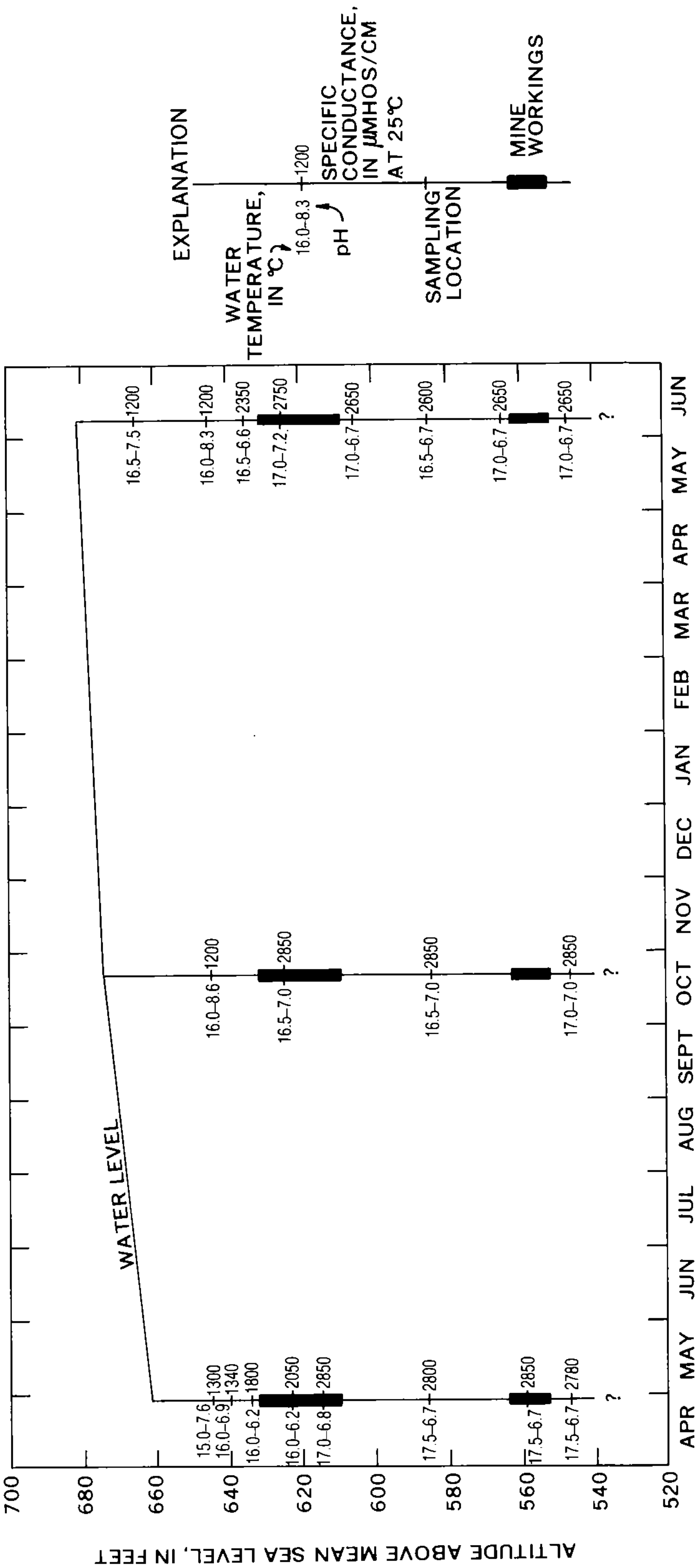


Figure 4. Diagram showing water level, approximate location of mine workings, and temperature, pH, and specific conductance of water at selected depths in Lucky Jew mine shaft, April 1976–June 1977.

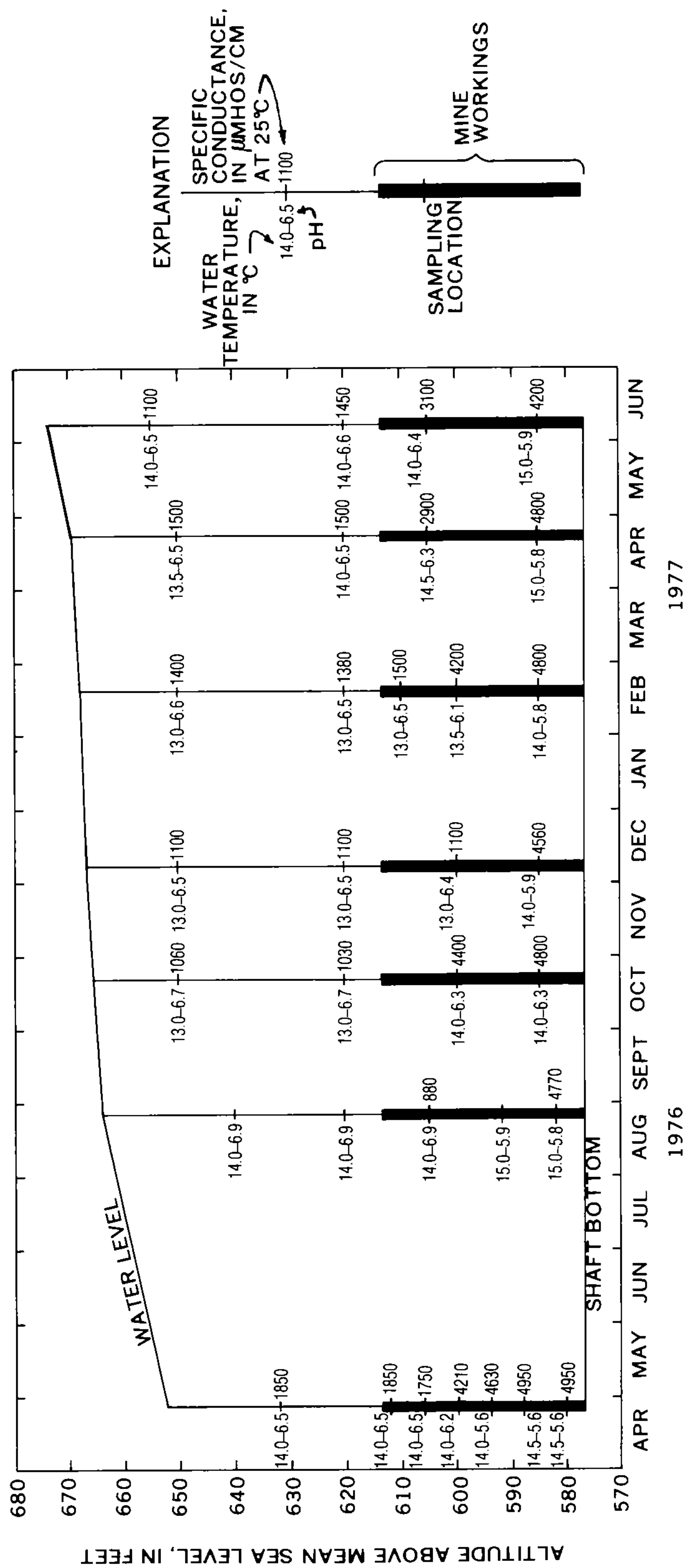


Figure 5. Diagram showing water level, approximate location of mine workings, and temperature, pH, and specific conductance of water at selected depths in Lucky Bill air shaft, April 1976–June 1977.

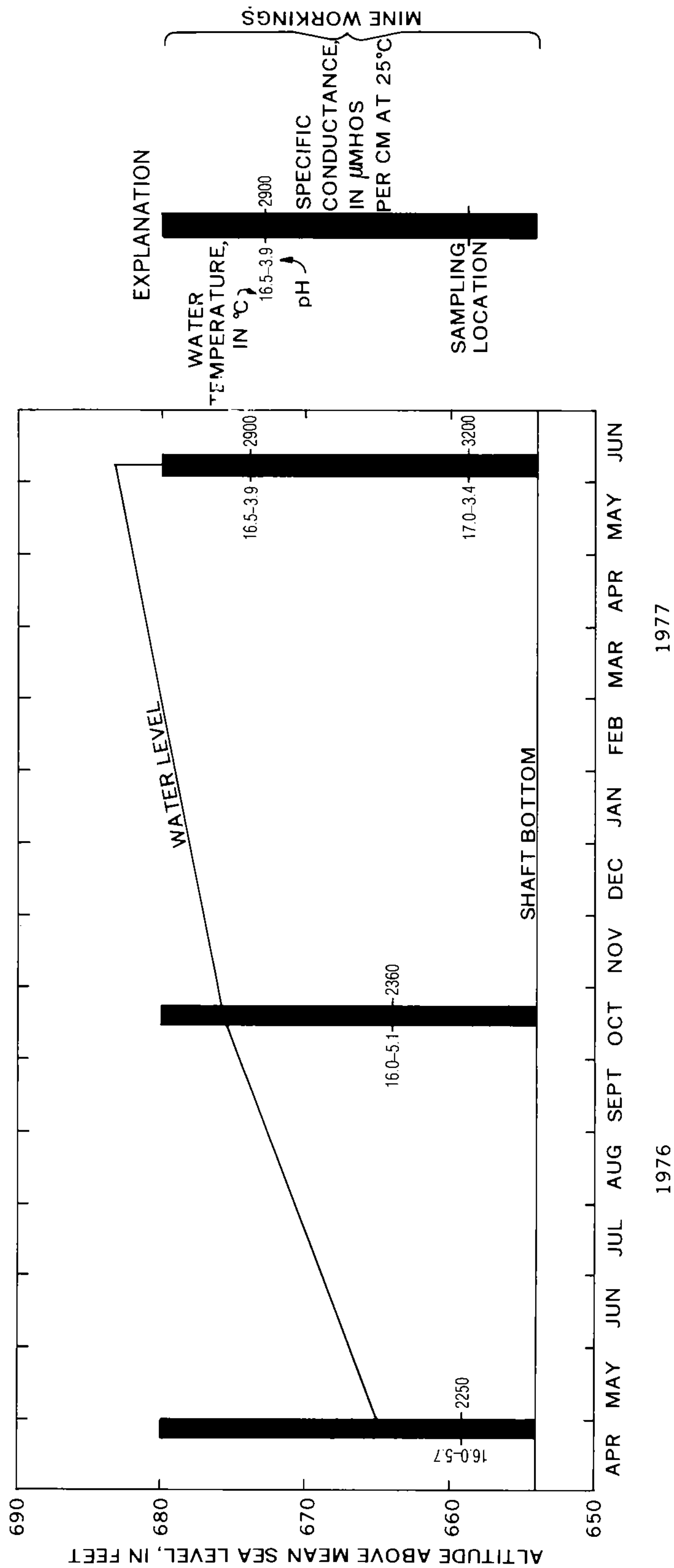


Figure 6. Diagram showing water level, approximate location of mine workings, and temperature, pH, and specific conductance of water at selected depths in Skelton mine shaft, April 1976–June 1977.

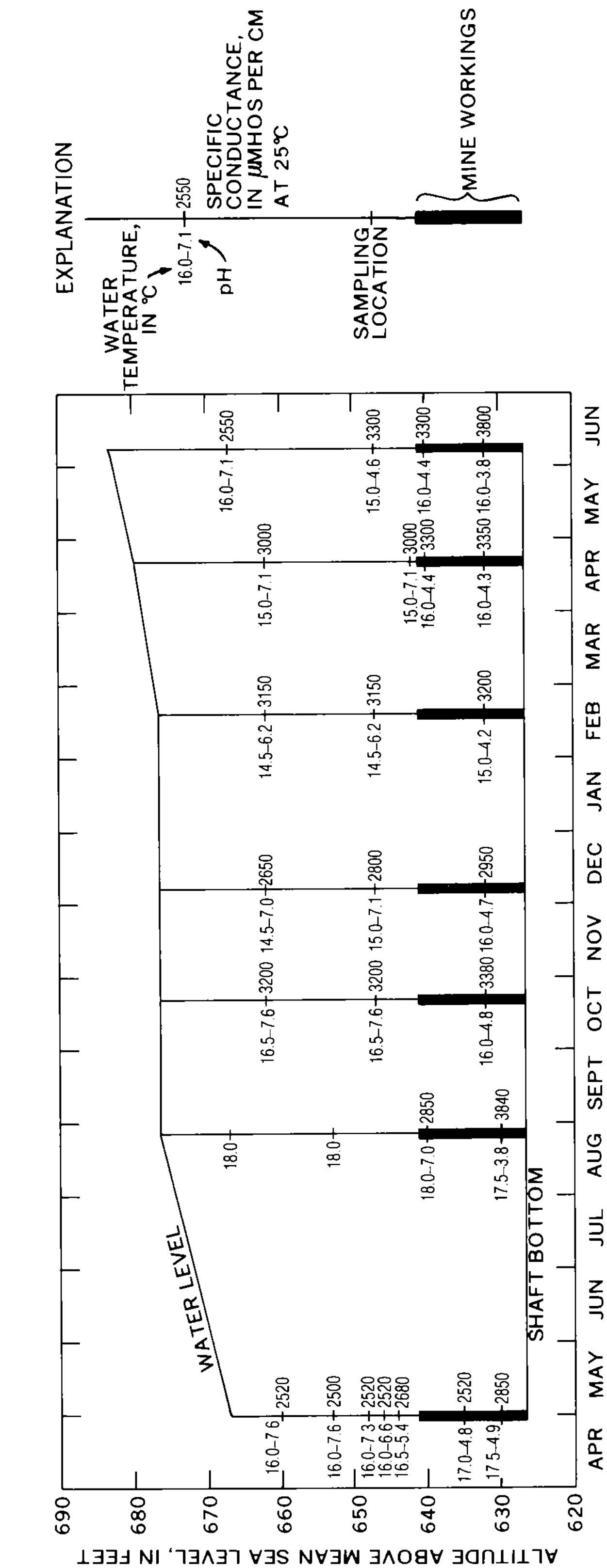


Figure 7. Diagram showing water level, approximate location of mine workings, and temperature, pH, and specific conductance of water at selected depths in New Chicago mine shaft, April 1976–June 1977.

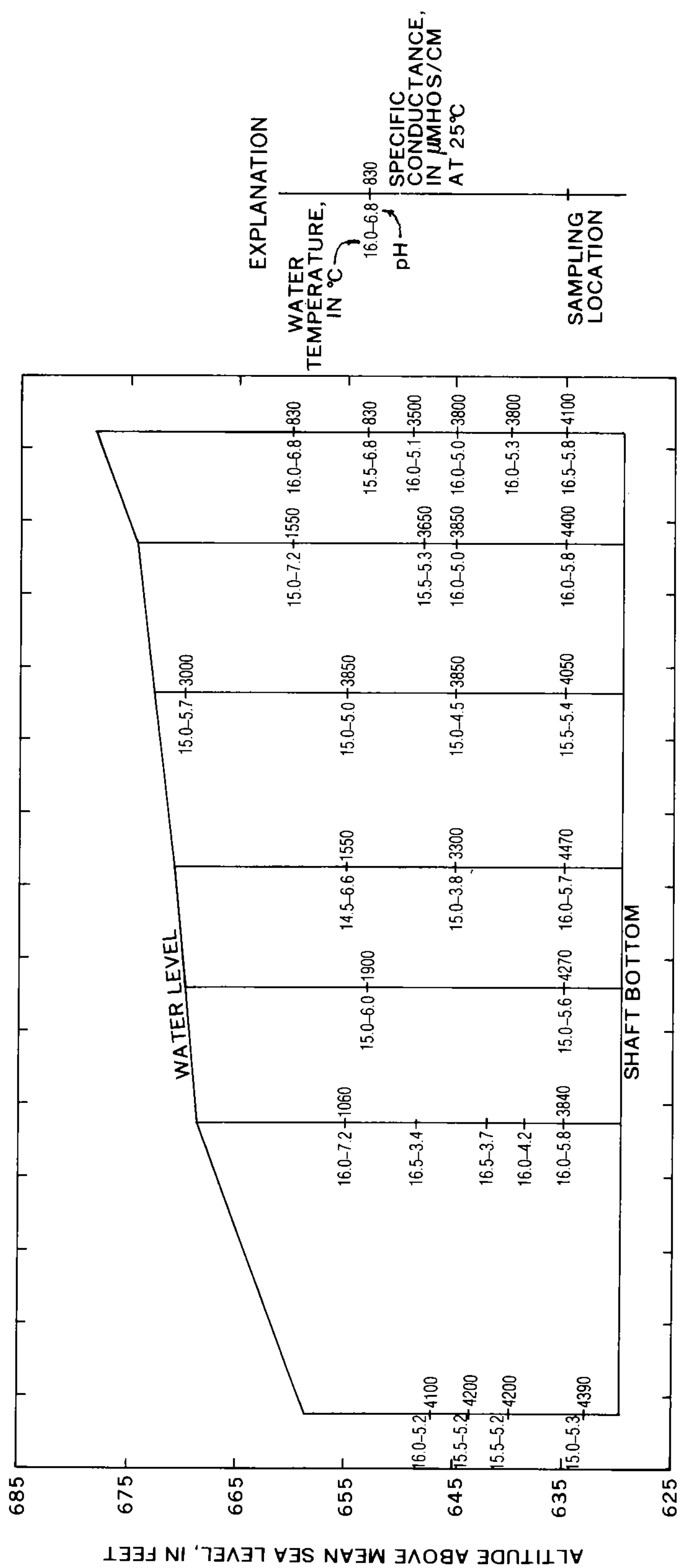


Figure 8. Diagram showing water level and temperature, pH, and specific conductance of water at selected depths in Birthday mine shaft, April 1976–June 1977.

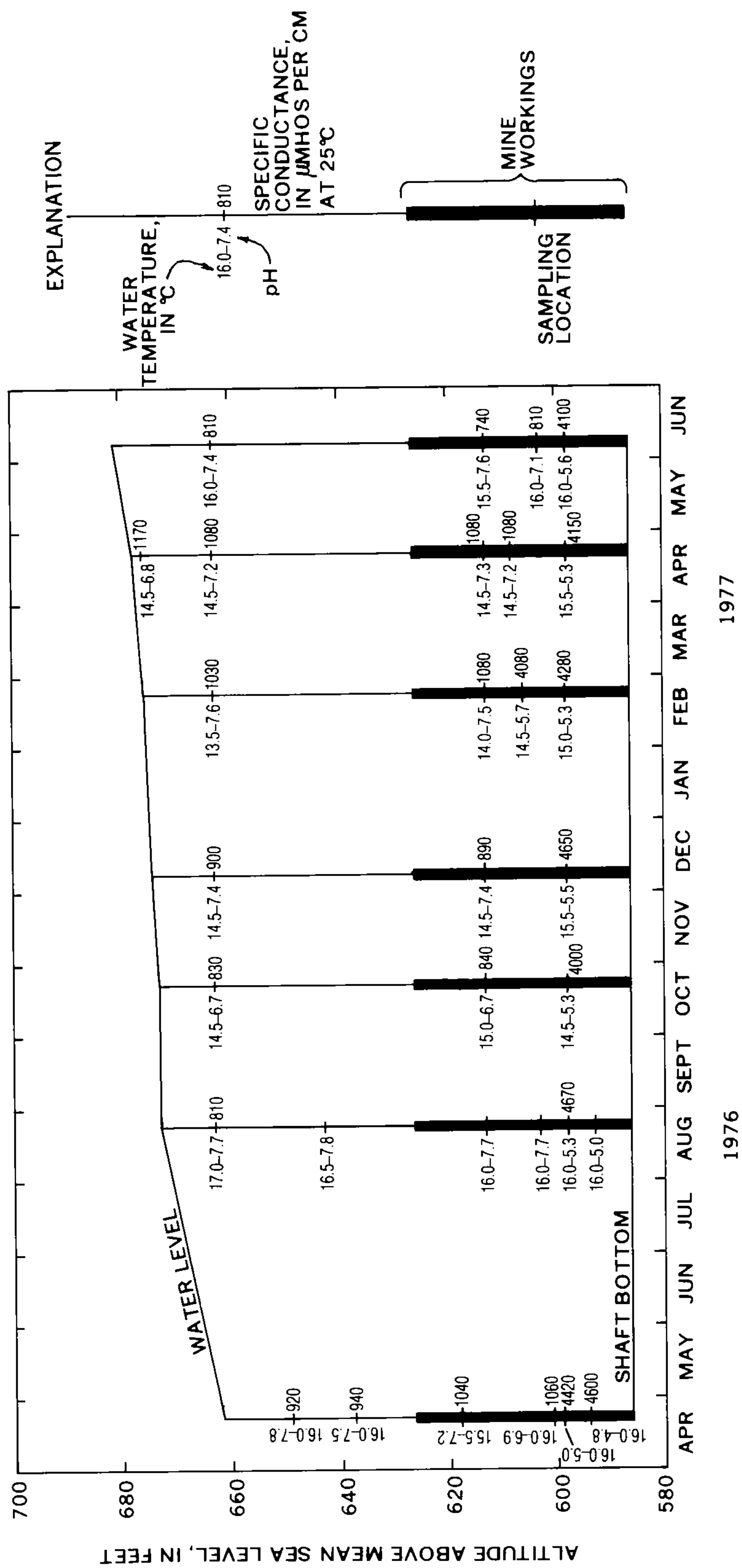


Figure 9. Diagram showing water level, approximate location of mine workings, and temperature, pH, and specific conductance of water at selected depths in Consolidated No. 2 mine shaft, April 1976–June 1977.

served in the upper or lower water strata, samples were collected for more complete laboratory physical and chemical analysis.

Field measurements and water-sample treatments were made using the techniques described by Brown, Skougstad, and Fishman (1970). All samples were analyzed by the U.S. Geological Survey Central Laboratory, using the methods given by Brown, Skougstad, and Fishman (1970).

A list of mine shafts sampled, sampling depths, and months in which samples were collected is given in table 1.

Results of Analyses

No areal trend or seasonal variation in water quality is readily discernible. Results of field and laboratory analyses (tables 2–8) indicate that the water in the mine shafts is stratified. In general, as sampling depths within each mine shaft increased, pH decreased, and specific conductance, water temperature, and dissolved solids increased. Most chemical-constituent concentrations, including dissolved and total metals and dissolved sulfate, increased with sampling depth. For example, in February 1977, in Consolidated No. 2 mine shaft, as sampling depth below the water surface increased from 13 to 78 ft, pH decreased from 7.6 to 5.3 standard units, specific conductance increased from 1,030 to 4,280 μmhos/cm at 25°C, water temperature increased from 13.5 to 15.0°C, dissolved solids increased from 838 to 5,180 mg/L (milligrams per liter), dissolved zinc increased from 3,300 to 300,000 μg/L (micrograms per liter), total iron increased from 120 to 310,000 μg/L, and dissolved sulfate increased from 510 to 3,300 mg/L. Because cooler, denser water overlies warmer, less dense water in the mine shafts, an unstable thermal-stratification condition apparently exists. However, the lower water strata contain significantly larger quantities of dissolved solids than the upper water strata. Thus, the apparently unstable thermal stratification is masked by the greater density of the lower water strata owing to higher dissolved-solids content.

One notable exception to the general stratification trend was observed during five out of seven samplings of Birthday mine-shaft water (fig. 8). The pH values decreased with increasing depth until approximately midway through the water column. The trend then reversed, with increasing pH values being observed with increasing depth. However, pH values near the bottom of the water column were not as high as those measured near the top of the water column. Based upon the available data, no adequate explanation for this anomalous stratification can be offered.

The water in the Lucky Jew mine shaft is chemically anomalous from that in the other mine shafts sampled. The maximum values of many constituents and properties—including dissolved aluminum, cadmium, calcium, fluoride, lead, sulfate, and zinc, and dissolved solids, specific conductance, and total hardness—in Lucky Jew mine-shaft water—were significantly lower than the maximum values of the same constituents and properties in water samples taken from the other mine shafts. Maximum values of dissolved boron, sodium, and chloride were significantly higher in Lucky Jew mine-shaft water than in water from the other mine shafts sampled.

Many of the trace elements, especially the heavy metals, have values reported for both dissolved and total concentrations. The total concentrations are analyzed from an unfiltered sample and, thus, are the sum of the dissolved-constituent concentration and the amount of constituent associated with suspended particles. Dissolved-constituent concentrations are analyzed from a filtered sample and represent the amount of constituent in the dissolved state. Some of the values reported for dissolved-constituent concentration are greater than corresponding values for total-constituent concentration. These anomalies are attributed to sampling errors, computational rounding errors, different sample-preparation techniques, and differences in precision of the analytical methods.

Statistical Summary and Constituent Relationships

A list of chemical and physical properties determined, the number of analyses of each property, and the range, mean, and fiftieth-percentile values for each property

TABLE 1.—LIST OF MINES SAMPLED, APRIL 1976–JUNE 1977

Name of mine (site location)	Land-surface altitude at mine shaft (ft)[1]	Depth to water (ft)[2]							Sampling depths (ft)[2]						
		Apr 1976	Aug 1976	Oct 1976	Dec 1976	Feb 1977	Apr 1977	June 1977	Apr 1976	Aug 1976	Oct 1976	Dec 1976	Feb 1977	Apr 1977	June 1977
Lucky Jew	845	183	--	171	--	--	--	164	200		200				180
(35S-23E-3ADD1)									205		220				200
									211		260				210
									222						
									230	--	298	--	--	--	220
									259						240
									287						260
									298						280
															298
Lucky Bill	810	158	146	144	143	142	140	136	178	170	160	160	160	160	155
(air shaft)									198	190	190	190	190	190	190
(29N-23E-30AAA1)									204	205	210	210	200	205	205
									210	218	225	225	210	225	225
									216	228			225		
									222						
									230						
Lavrion	810	144	--	--	--	--	--	--	150						
(29N-23E-29CDD1)									160						
									170	--	--	--	--	--	--
									182						
									191						
Skelton	825	159	--	148	--	--	--	140	165	--	160	--	--	--	150
(29N-23E-28CCB1)															165
New Chicago	825	160	150	151	150	150	147	144	167	160	165	165	165	165	160
(29N-23E-28CAB1)									174	174	180	180	180	185	180
									179	187	198	195	195	187	187
									183	197				195	195
									192						
									197						
Birthday	815	156	146	145	144	142	141	137	168	160	162	160	145	155	155
(20N-23E-28BBB1)									172	167	180	170	160	167	162
									175	173		180	170	170	166
									182	177			180	180	170
										180					175
															180
Consolidated No. 2	830	166	155	155	153	152	150	146	179	165	165	165	165	152	165
(29N-23E-16DDB1)									191	185	215	215	215	165	215
									210	215	230	230	222	215	225
									227	225			230	220	230
									229	230				230	
									234	235					

1 - Estimated to nearest 5 ft above mean sea level from 7½-minute topographic maps.

2 - Measured from land surface.

TABLE 2.—WATER-QUALITY DATA FROM LUCKY JEW MINE SHAFT, APRIL 1976–JUNE 1977

Sampling depths in ft below land surface; turbidity expressed in NTU (neophelometric turbidity units)

DATE	SAMPLING DEPTH (FT)	PH (UNITS)	TEMPERATURE (DEG C)	SPECIFIC CONDUCTANCE (MICROMHOS)
APR , 1976				
27...	200	7.6	15.0	1300
27...	205	6.9	16.0	1340
27...	211	6.2	16.0	1800
27...	222	6.2	16.0	2050
27...	230	6.8	17.0	2850
27...	259	6.7	17.5	2800
27...	287	6.7	17.5	2850
27...	298	6.7	17.5	2780
OCT				
21...	200	8.6	16.0	1200
21...	220	7.0	16.5	2850
21...	260	7.0	16.5	2850
21...	298	7.0	17.0	2850
JUN , 1977				
09...	180	7.5	16.5	1200
09...	200	8.3	16.0	1200
09...	210	6.6	16.5	2350
09...	220	7.2	17.0	2750
09...	240	6.7	17.0	2650
09...	260	6.7	16.5	2600
09...	280	6.7	17.0	2650
09...	298	6.7	17.0	2650

DATE	SAMPLING DEPTH (FT)	TURBIDITY (NTU)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	TOTAL ACIDITY AS H+ (MG/L)	TOTAL ACIDITY AS CACO3 (MG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	PERCENT SODIUM	SODIUM ADSORPTION RATIO	DISSOLVED POTASSIUM (K) (MG/L)
APR , 1976												
27...	200	1.2	620	500	.1	5.0	220	18	38	12	.7	3.4
27...	222	72	1100	1000	1.4	70	270	92	80	14	1.1	4.5
27...	230	180	1300	1000	.6	30	340	98	200	26	2.5	7.4
27...	298	160	1200	1000	1.4	70	330	97	200	26	2.5	7.6
OCT												
21...	200	1.0	590	460	--	--	210	15	36	12	.6	3.2
21...	220	150	1200	1000	--	--	320	100	200	26	2.5	7.1
JUN , 1977												
09...	200	1.0	740	610	.0	.0	270	16	22	6	.4	2.9
09...	220	350	1200	1000	.9	45	330	92	190	25	2.4	6.9

DATE	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	ALKALINITY AS CACO3 (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED FLUORIDE (F) (MG/L)	DISSOLVED SILICA (SIO2) (MG/L)	DISSOLVED SOLIDS (RESIDUE AT 180 C) (MG/L)	SUSPENDED SOLIDS (MG/L)	DISSOLVED NITRATE (N) (MG/L)	DISSOLVED NITRATE (NO3) (MG/L)	DISSOLVED NITRITE (N) (MG/L)
APR , 1976												
27...	145	0	119	560	3.1	.3	8.5	995	0	.08	.35	.00
27...	62	0	51	1200	6.4	1.3	8.5	1750	79	.07	.31	.00
27...	249	0	204	1300	85	2.1	8.0	2340	95	.00	.00	.00
27...	258	0	212	1300	85	2.1	8.0	2330	87	.01	.04	.00
OCT												
21...	152	0	125	520	3.1	.6	7.8	953	0	.15	.66	.00
21...	228	0	187	1400	80	2.2	7.4	2300	82	.01	.04	.00
JUN , 1977												
09...	160	0	130	600	2.3	.3	9.2	1050	1	.06	.27	.01
09...	230	0	190	1300	80	2.1	8.6	2270	94	.02	.09	.01

TABLE 2.—*Continued*

DATE	DIS-SOLVED NITRITE (NO2) (MG/L)	DIS-SOLVED NITRITE PLUS NITRATE (N) (MG/L)	DIS-SOLVED AMMONIA NITRO-GEN (N) (MG/L)	DIS-SOLVED AMMONIA (NH4) (MG/L)	TOTAL ALUM-INUM (AL) (UG/L)	DIS-SOLVED ALUM-INUM (AL) (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DIS-SOLVED ARSENIC (AS) (UG/L)	TOTAL BARIUM (BA) (UG/L)	DIS-SOLVED BARIUM (BA) (UG/L)	TOTAL BORON (B) (UG/L)	DIS-SOLVED BORON (B) (UG/L)
APR , 1976												
27...	.00	.08	.02	.03	50	10	0	0	0	0	1600	100
27...	.00	.07	.06	.08	80	50	0	0	0	0	1200	140
27...	.00	.00	.40	.52	20	0	8	6	0	0	1100	550
27...	.00	.01	.03	.04	10	0	8	6	0	0	1600	560
OCT												
21...	.00	.15	.00	.00	60	0	1	0	0	0	140	90
21...	.00	.01	.57	.73	2000	300	8	8	0	0	620	560
JUN , 1977												
09...	.03	.07	.03	.04	30	40	0	0	100	100	110	90
09...	.03	.03	.65	.84	150	100	8	6	100	100	600	550

DATE	TOTAL CAD-MIUM (CD) (UG/L)	DIS-SOLVED CAD-MIUM (CD) (UG/L)	TOTAL CHRO-MIUM (CR) (UG/L)	DIS-SOLVED CHRO-MIUM (CR) (UG/L)	TOTAL COBALT (CO) (UG/L)	DIS-SOLVED COBALT (CO) (UG/L)	TOTAL COPPER (CU) (UG/L)	DIS-SOLVED COPPER (CU) (UG/L)	TOTAL IRON (FE) (UG/L)	DIS-SOLVED IRON (FE) (UG/L)	TOTAL LEAD (PB) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)
APR , 1976												
27...	10	4	0	0	<50	0	10	3	0	20	<100	6
27...	<10	4	10	10	200	170	20	3	52000	44000	<100	7
27...	<10	2	10	10	100	31	10	3	52000	50000	<100	2
27...	<10	6	10	10	100	36	10	10	53000	46000	<100	4
OCT												
21...	10	4	0	0	50	1	<10	6	160	10	<100	3
21...	10	1	10	0	150	57	<10	1	58000	57000	100	4
JUN , 1977												
09...	10	8	0	10	<50	0	<10	2	30	30	<100	6
09...	10	2	0	10	50	100	10	2	61000	54000	100	4

DATE	DIS-SOLVED LITHIUM (LI) (UG/L)	TOTAL MAN-GANESE (MN) (UG/L)	DIS-SOLVED MAN-GANESE (MN) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	TOTAL MOLYB-DENUM (MO) (UG/L)	DIS-SOLVED MOLYB-DENUM (MO) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)	TOTAL SELE-NIUM (SE) (UG/L)	DIS-SOLVED SELE-NIUM (SE) (UG/L)	DIS-SOLVED VANA-DIUM (V) (UG/L)
APR , 1976												
27...	40	30	40	1.4	.4	0	0	50	10	0	0	.1
27...	80	5000	5100	.5	.8	0	0	400	370	0	0	.9
27...	200	2600	2300	.8	.8	2	1	300	240	0	0	.9
27...	200	2600	2400	.2	.3	3	1	300	240	0	0	1.5
OCT												
21...	20	10	10	.3	.2	0	0	<50	4	0	0	.2
21...	210	5500	2000	.4	.4	1	1	300	200	0	0	.4
JUN , 1977												
09...	20	10	10	.1	.0	0	0	50	6	0	0	.0
09...	200	1900	1900	.3	.4	0	2	200	250	0	0	.0

DATE	SAMP-LING DEPTH (FT)	TOTAL ZINC (ZN) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)	TOTAL ORGANIC CARBON (C) (MG/L)	METHY-LENE BLUE ACTIVE SUB-STANCE (MG/L)
APR , 1976					
27...	200	830	640	2.0	.00
27...	222	3000	2900	8.0	.00
27...	230	9300	8100	1.7	.00
27...	298	10000	8300	1.7	.00
OCT					
21...	200	730	670	1.8	.00
21...	220	7000	7000	.6	.00
JUN , 1977					
09...	200	2300	2300	1.3	.00
09...	220	7000	6600	1.1	.10

TABLE 3.—WATER-QUALITY DATA FROM LUCKY BILL AIR SHAFT, APRIL 1976–JUNE 1977

Sampling depths in ft below land surface

DATE	SAMPLING DEPTH (FT)	PH (UNITS)	TEMPERATURE (DEG C)	SPECIFIC CONDUCTANCE (MICROMHOS)
APR , 1976				
22...	178	6.5	14.0	1850
22...	198	6.5	14.0	1850
22...	204	6.5	14.0	1750
22...	210	6.1	14.0	4210
22...	216	5.6	14.0	4630
22...	222	5.6	14.5	4950
22...	230	5.6	14.5	4950
AUG				
26...	170	6.9	14.0	760
26...	190	6.9	14.0	795
26...	205	6.9	14.0	880
26...	218	5.9	15.0	--
26...	228	5.8	15.0	4770
OCT				
20...	160	6.7	13.0	1060
20...	190	6.7	13.0	1030
20...	210	6.3	14.0	4400
20...	225	6.3	14.0	4800
DEC				
07...	160	6.5	13.0	1100
07...	190	6.5	13.0	1100
07...	210	6.4	13.0	1100
07...	225	5.9	14.0	4560
FEB , 1977				
17...	160	6.6	13.0	1400
17...	190	6.5	13.0	1380
17...	200	6.5	13.0	1500
17...	210	6.1	13.5	4200
17...	225	5.8	14.0	4800
APR				
21...	160	6.5	13.5	1500
21...	190	6.5	14.0	1500
21...	205	6.3	14.5	2900
21...	225	5.8	15.0	4800
JUN				
07...	155	6.5	14.0	1100
07...	190	6.6	14.0	1450
07...	205	6.4	14.0	3100
07...	225	5.9	15.0	4200

DATE	SAMPLING DEPTH (FT)	TURBIDITY (NTU)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	TOTAL ACIDITY AS H+ (MG/L)	TOTAL ACIDITY AS CACO3 (MG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	PERCENT SODIUM	SODIUM ADSORPTION RATIO	DISSOLVED POTASSIUM (K) (MG/L)
APR , 1976												
22...	178	2.1	910	600	2.6	129	300	39	57	12	.8	8.5
22...	210	180	2100	2100	11	546	500	210	68	7	.6	4.5
22...	222	100	2200	2200	22	1090	480	250	87	8	.8	6.0
AUG												
26...	205	1.0	450	250	.5	25	160	13	16	7	.3	4.0
26...	228	160	2100	2100	25	1240	490	220	90	8	.8	9.2
OCT												
20...	190	1.4	520	340	--	--	180	16	19	7	.4	4.5
20...	225	3.3	2400	2400	--	--	470	290	92	8	.8	8.2
DEC												
07...	190	2.0	580	340	1.5	74	200	19	23	8	.4	4.7
07...	225	140	2300	2300	27	1340	490	260	81	7	.7	7.0
FEB , 1977												
17...	190	2.0	640	380	1.7	84	220	21	29	9	.5	5.4
17...	225	180	2300	2300	23	1140	480	260	82	7	.8	6.5
APR												
21...	190	1.0	780	520	2.0	99	270	26	36	9	.6	6.2
21...	225	160	2400	2400	11	546	520	270	85	7	.8	6.8
JUN												
07...	155	.30	570	320	1.6	79	190	23	26	9	.5	4.7
07...	225	220	2400	2400	24	1190	500	280	86	7	.8	6.2

TABLE 3.—*Continued*

DATE	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	ALKALINITY AS CACO3 (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED FLUORIDE (F) (MG/L)	DISSOLVED SILICA (SIO2) (MG/L)	DISSOLVED SOLIDS (RESIDUE AT 180 C) (MG/L)	SUSPENDED SOLIDS (MG/L)	DISSOLVED NITRATE (N) (MG/L)	DISSOLVED NITRATE (NO3) (MG/L)	DISSOLVED NITRITE (N) (MG/L)
APR , 1976												
22...	375	0	308	810	10	.3	19	1580	3	.15	.66	.00
22...	59	0	48	2800	13	5.0	8.1	4380	209	.01	.04	.01
22...	25	0	21	3000	16	9.2	7.6	5470	174	.00	.00	.01
AUG												
26...	246	0	202	320	3.6	.3	19	687	0	--	--	--
26...	1	0	1	3400	21	9.4	9.0	--	175	--	--	--
OCT												
20...	216	0	177	380	4.0	.7	11	830	12	.16	.71	.00
20...	11	0	9	3500	23	7.5	7.8	5920	15	.03	.13	.00
DEC												
07...	289	0	237	430	4.6	.1	19	904	0	--	--	--
07...	35	0	29	3100	20	6.6	8.8	5370	170	--	--	--
FEB , 1977												
17...	310	0	254	510	14	1.2	22	1030	0	--	--	--
17...	0	0	0	3300	18	7.4	10	5230	183	--	--	--
APR												
21...	320	0	260	610	6.6	.4	19	1200	5	--	--	--
21...	0	0	0	3500	15	7.9	11	5520	172	--	--	--
JUN												
07...	300	0	250	420	4.5	.2	19	910	0	.19	.84	.01
07...	6	0	5	3400	15	7.9	10	5650	156	.03	.13	.01

DATE	DISSOLVED NITRITE (NO2) (MG/L)	DISSOLVED NITRITE PLUS NITRATE (N) (MG/L)	DISSOLVED AMMONIA NITROGEN (N) (MG/L)	DISSOLVED AMMONIA (NH4) (MG/L)	TOTAL ALUMINUM (AL) (UG/L)	DISSOLVED ALUMINUM (AL) (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DISSOLVED ARSENIC (AS) (UG/L)	TOTAL BARIUM (BA) (UG/L)	DISSOLVED BARIUM (BA) (UG/L)	TOTAL BORON (B) (UG/L)	DISSOLVED BORON (B) (UG/L)
APR , 1976												
22...	.00	.15	.03	.04	60	10	14	0	0	0	180	180
22...	.03	.02	.33	.43	2000	2000	2	2	0	0	240	180
22...	.03	.01	.49	.63	5500	5700	8	7	0	0	250	220
AUG												
26...	--	--	--	--	40	20	--	--	--	--	110	100
26...	--	--	--	--	10000	10000	--	--	--	--	240	290
OCT												
20...	.00	.16	.01	.01	40	0	0	0	0	0	120	100
20...	.00	.03	.58	.75	10000	5000	13	11	0	0	290	220
DEC												
07...	--	--	--	--	50	0	--	--	--	--	140	110
07...	--	--	--	--	8000	5000	--	--	--	--	310	240
FEB , 1977												
17...	--	--	--	--	40	0	--	--	--	--	140	130
17...	--	--	--	--	4500	4500	--	--	--	--	310	200
APR												
21...	--	--	--	--	20000	0	--	--	--	--	250	130
21...	--	--	--	--	5000	5000	--	--	--	--	320	200
JUN												
07...	.03	.20	.00	.00	30	20	0	0	100	100	160	150
07...	.03	.04	.53	.68	5500	5500	8	11	600	600	310	210

TABLE 3.—WATER-QUALITY DATA FROM LUCKY BILL AIR SHAFT, APRIL 1976–JUNE 1977—*Continued*

DATE	TOTAL CADMIUM (CD) (UG/L)	DIS-SOLVED CADMIUM (CD) (UG/L)	TOTAL CHROMIUM (CR) (UG/L)	DIS-SOLVED CHROMIUM (CR) (UG/L)	TOTAL COBALT (CO) (UG/L)	DIS-SOLVED COBALT (CO) (UG/L)	TOTAL COPPER (CU) (UG/L)	DIS-SOLVED COPPER (CU) (UG/L)	TOTAL IRON (FE) (UG/L)	DIS-SOLVED IRON (FE) (UG/L)	TOTAL LEAD (PB) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)
APR , 1976												
22...	180	9	0	0	<50	2	30	10	350	290	450	250
22...	400	420	10	10	600	53	20	4	160000	150000	300	69
22...	460	490	10	10	650	43	30	13	290000	270000	500	400
AUG												
26...	70	10	--	--	--	--	--	--	380	370	100	90
26...	380	370	--	--	--	--	--	--	350000	330000	400	400
OCT												
20...	80	12	0	0	50	2	<10	11	80	20	200	150
20...	350	330	20	10	850	43	20	7	370000	240000	300	350
DEC												
07...	100	13	--	--	--	--	--	--	150	150	200	97
07...	380	360	--	--	--	--	--	--	340000	270000	300	200
FEB , 1977												
17...	110	10	--	--	--	--	--	--	170	70	<100	98
17...	330	340	--	--	--	--	--	--	320000	300000	300	250
APR												
21...	600	140	--	--	--	--	--	--	240	60	400	150
21...	310	340	--	--	--	--	--	--	320000	290000	300	250
JUN												
07...	110	8	10	0	<50	0	20	8	180	20	200	99
07...	300	350	20	20	800	800	20	8	320000	310000	300	250

DATE	DIS-SOLVED LITHIUM (LI) (UG/L)	TOTAL MANGANESE (MN) (UG/L)	DIS-SOLVED MANGANESE (MN) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	TOTAL MOLYBDENUM (MO) (UG/L)	DIS-SOLVED MOLYBDENUM (MO) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)	TOTAL SELENIUM (SE) (UG/L)	DIS-SOLVED SELENIUM (SE) (UG/L)	DIS-SOLVED VANADIUM (V) (UG/L)
APR , 1976												
22...	70	80	60	.3	.3	0	0	100	47	3	3	.0
22...	160	4800	5000	.3	.3	1	0	4000	3000	1	0	21
22...	210	6100	5700	.3	.2	2	0	5400	4200	0	0	130
AUG												
26...	20	20	20	--	--	--	--	<50	17	--	--	.5
26...	220	6600	6500	--	--	--	--	4600	5000	--	--	--
OCT												
20...	30	30	30	.1	.0	0	0	50	24	2	2	.7
20...	220	6000	6000	.1	.1	0	1	5000	5000	0	0	120
DEC												
07...	30	50	50	--	--	--	--	200	28	--	--	.0
07...	110	5300	5400	--	--	--	--	6000	4100	--	--	120
FEB , 1977												
17...	40	60	50	--	--	--	--	50	31	--	--	.0
17...	200	6000	5500	--	--	--	--	3900	3900	--	--	.0
APR												
21...	50	2700	50	--	--	--	--	1800	49	--	--	.0
21...	210	5900	5500	--	--	--	--	3900	4000	--	--	110
JUN												
07...	40	10	20	.1	.0	0	0	<50	20	3	3	.0
07...	210	5800	6200	.2	.0	1	0	4500	4500	0	0	150

TABLE 3.—*Continued*

DATE	SAMP-LING DEPTH (FT)	TOTAL ZINC (ZN) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)	TOTAL ORGANIC CARBON (C) (MG/L)	METHY-LENE BLUE ACTIVE SUB-STANCE (MG/L)
APR , 1976					
22...	178	68000	68000	4.0	.10
22...	210	350000	280000	2.2	.20
22...	222	480000	490000	2.9	.80
AUG					
26...	205	20000	20000	--	--
26...	228	470000	450000	--	--
OCT					
20...	190	46000	25000	3.4	.10
20...	225	440000	440000	3.2	.00
DEC					
07...	190	27000	27000	--	--
07...	225	430000	420000	--	--
FEB , 1977					
17...	190	36000	35000	--	--
17...	225	420000	410000	--	--
APR					
21...	190	49000	49000	--	--
21...	225	--	412000	--	--
JUN					
07...	155	39000	39000	3.2	.10
07...	225	440000	440000	1.6	.10

determined are given in table 9. The fiftieth percentile is included as a measure of central tendency in addition to the mean, because the mean is significantly affected by extreme values of small samples.

In general, correlation is defined as the degree of association of two or more random variables. For this study, correlation is used to define the degree of linear association of two chemical or physical water-quality characteristics. The correlation coefficient is a numerical representation of the degree of association and ranges between -1 and $+1$. Correlation coefficients of -1 and $+1$ represent complete inverse and direct correlative associations, respectively, and a value of 0 indicates no correlative association. For hydrologic applications, a correlation coefficient greater than 0.7 or less than -0.7 is necessary to indicate a significant correlative association (V. Yevjevich, Colorado State University, oral communication, 1976).

According to the above criterion, several chemical properties of the mine-shaft water, including dissolved sulfate, calcium, magnesium, lithium, dissolved solids, and total hardness, demonstrate significant correlation to specific conductance (table 10). None of the chemical properties statistically analyzed showed significant correlation to pH (table 11). However, when values of dissolved aluminum, zinc, and nickel were transformed to natural or Napierian logarithms, significant correlation was observed between the transformed variable and pH (table 12). Dissolved iron, manganese, and zinc concentrations in the mine-shaft water are significantly correlated to dissolved sulfate (table 13). Transformation of dissolved iron, manganese, and zinc values to natural or Napierian logarithms did not significantly affect their correlative association to dissolved sulfate (table 14). Transformed values of dissolved aluminum, however, were significantly correlated to dissolved sulfate, whereas untransformed values were not (table 14).

Regression represents a mathematical equation expressing one random variable as being correlatively related to another random variable. For this investigation, least-squares regression analysis was used to linearly relate one chemical or physical water-quality characteristic to another. The results of the regression analyses, the slopes and intercepts of the linear relations, are shown in tables 10–14. Figures 10–12 show graphical examples of the regression analyses.

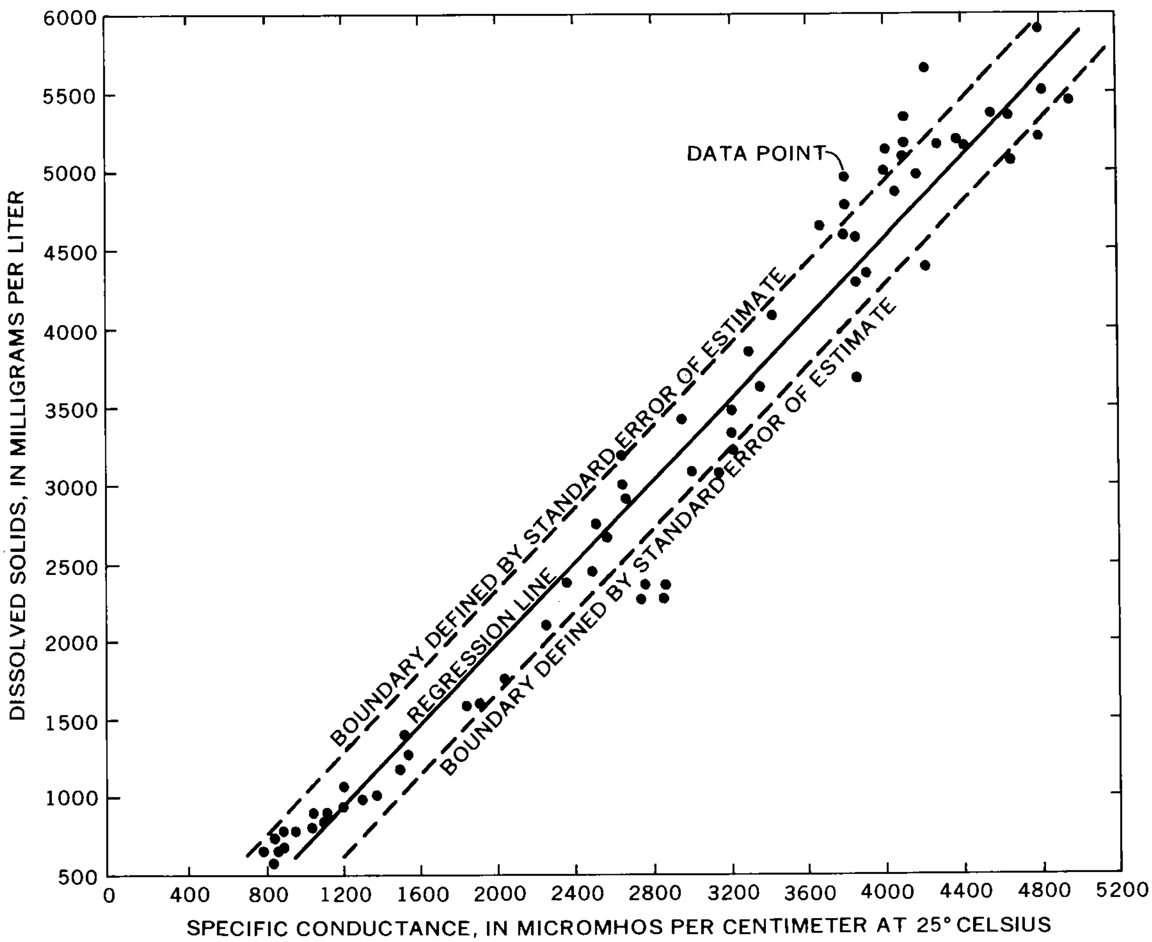


Figure 10. Graph showing relationship of dissolved-solids concentration to specific conductance of mine-shaft water.

TABLE 4.—WATER-QUALITY DATA FROM LAVRION MINE SHAFT, APRIL 1976

Sampling depths in ft below land surface

DATE	SAMPLING DEPTH (FT)	PH (UNITS)	TEMPERATURE (DEG C)	SPECIFIC CONDUCTANCE (MICROMHOS)
APR , 1976				
28...	150	5.5	14.5	2340
28...	160	4.8	14.5	3420
28...	170	4.8	14.5	3720
28...	182	3.9	15.0	3680
28...	191	4.7	15.0	3900

DATE	SAMPLING DEPTH (FT)	TURBIDITY (NTU)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	TOTAL ACIDITY AS H+ (MG/L)	TOTAL ACIDITY AS CACO3 (MG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	PERCENT SODIUM	SODIUM ADSORPTION RATIO	DISSOLVED POTASSIUM (K) (MG/L)
APR , 1976												
28...	160	37	1700	1700	17	844	470	120	45	6	.5	4.0
28...	182	10	1800	1800	23	1140	510	130	55	6	.6	4.5
28...	191	12	1800	1800	20	993	520	120	53	6	.5	4.3

TABLE 4.—*Continued*

DATE	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	ALKALINITY AS CACO3 (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED FLUORIDE (F) (MG/L)	DISSOLVED SILICA (SIO2) (MG/L)	DISSOLVED SOLIDS (RESIDUE AT 180 C) (MG/L)	SUSPENDED SOLIDS (MG/L)	DISSOLVED NITRATE (N) (MG/L)	DISSOLVED NITRATE (NO3) (MG/L)	DISSOLVED NITRITE (N) (MG/L)
APR , 1976												
28...	0	0	0	2500	7.2	9.8	13	4080	16	.00	.00	.00
28...	0	0	0	2900	8.0	15	17	4650	4	.00	.00	.00
28...	0	0	0	2700	7.8	14	16	4360	0	.04	.18	.00

DATE	DISSOLVED NITRITE (NO2) (MG/L)	DISSOLVED NITRITE PLUS NITRATE (N) (MG/L)	DISSOLVED AMMONIA NITROGEN (N) (MG/L)	DISSOLVED AMMONIA (NH4) (MG/L)	TOTAL ALUMINUM (AL) (UG/L)	DISSOLVED ALUMINUM (AL) (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DISSOLVED ARSENIC (AS) (UG/L)	TOTAL BARIUM (BA) (UG/L)	DISSOLVED BARIUM (BA) (UG/L)	TOTAL BORON (B) (UG/L)	DISSOLVED BORON (B) (UG/L)
APR , 1976												
28...	.00	.00	.34	.44	11000	14000	0	0	0	0	130	120
28...	.00	.00	.49	.63	26000	29000	0	0	0	0	400	150
28...	.00	.04	.45	.58	280000	26000	1	1	0	0	280	140

DATE	TOTAL CADMIUM (CD) (UG/L)	DISSOLVED CADMIUM (CD) (UG/L)	TOTAL CHROMIUM (CR) (UG/L)	DISSOLVED CHROMIUM (CR) (UG/L)	TOTAL COBALT (CO) (UG/L)	DISSOLVED COBALT (CO) (UG/L)	TOTAL COPPER (CU) (UG/L)	DISSOLVED COPPER (CU) (UG/L)	TOTAL IRON (FE) (UG/L)	DISSOLVED IRON (FE) (UG/L)	TOTAL LEAD (PB) (UG/L)	DISSOLVED LEAD (PB) (UG/L)
APR , 1976												
28...	980	10	20	30	400	36	130	140	67000	76000	300	20
28...	860	13	60	60	600	45	130	160	140000	130000	300	16
28...	830	13	70	60	650	44	130	120	160000	130000	200	10

DATE	DISSOLVED LITHIUM (LI) (UG/L)	TOTAL MANGANESE (MN) (UG/L)	DISSOLVED MANGANESE (MN) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DISSOLVED MERCURY (HG) (UG/L)	TOTAL MOLYBDENUM (MO) (UG/L)	DISSOLVED MOLYBDENUM (MO) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DISSOLVED NICKEL (NI) (UG/L)	TOTAL SELENIUM (SE) (UG/L)	DISSOLVED SELENIUM (SE) (UG/L)	DISSOLVED VANADIUM (V) (UG/L)
APR , 1976												
28...	140	4800	4400	.2	.1	0	0	2000	2300	1	0	22
28...	200	7800	6500	.1	.2	0	0	3800	3400	1	1	60
28...	200	8400	6300	.0	.0	0	0	4000	3100	1	0	39

DATE	SAMPLING DEPTH (FT)	TOTAL ZINC (ZN) (UG/L)	DISSOLVED ZINC (ZN) (UG/L)	TOTAL ORGANIC CARBON (C) (MG/L)	METHYLENE BLUE ACTIVE SUBSTANCE (MG/L)
APR , 1976					
28...	160	340000	390000	1.8	.00
28...	182	420000	420000	1.4	.00
28...	191	440000	430000	1.6	.00

TABLE 5.—WATER-QUALITY DATA FROM SKELTON MINE SHAFT, APRIL 1976–JUNE 1977

Sampling depths in ft below land surface

DATE	SAMPLING DEPTH (FT)	PH (UNITS)	TEMPERATURE (DEG C)	SPECIFIC CONDUCTANCE (MICROMHOS)
APR , 1976				
26...	165	5.7	16.0	2250
OCT				
18...	160	5.1	16.0	2360
JUN , 1977				
06...	150	3.9	16.5	2900
06...	165	3.4	17.0	3200

DATE	SAMPLING DEPTH (FT)	TURBIDITY (NTU)	HARDNESS (CA,MG) (MG/L)	NON-CARBONATE HARDNESS (MG/L)	TOTAL ACIDITY AS H+ (MG/L)	TOTAL ACIDITY AS CACO3 (MG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	PERCENT SODIUM	SODIUM ADSORPTION RATIO	DISSOLVED POTASSIUM (K) (MG/L)
APR , 1976												
26...	165	26	1300	1200	2.5	124	450	38	22	4	.3	1.8
OCT												
18...	160	23	1300	1300	--	--	440	45	25	4	.3	1.6
JUN , 1977												
06...	165	4.8	1600	1600	14	695	500	88	33	4	.4	1.3

DATE	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	ALKALINITY AS CACO3 (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED FLUORIDE (F) (MG/L)	DISSOLVED SILICA (SIO2) (MG/L)	DISSOLVED SOLIDS (RESIDUE AT 180 C) (MG/L)	SUSPENDED SOLIDS (MG/L)	DISSOLVED NITRATE (N) (MG/L)	DISSOLVED NITRATE (NO3) (MG/L)	DISSOLVED NITRITE (N) (MG/L)
APR , 1976												
26...	59	0	48	1300	4.7	1.8	12	2120	11	.11	.49	.01
OCT												
18...	9	0	7	1600	4.6	2.9	14	2400	27	.01	.04	.00
JUN , 1977												
06...	0	0	0	2300	5.0	2.3	18	3480	7	.02	.09	.00

DATE	DISSOLVED NITRITE (NO2) (MG/L)	DISSOLVED NITRITE PLUS NITRATE (N) (MG/L)	DISSOLVED AMMONIA NITROGEN (N) (MG/L)	DISSOLVED AMMONIA (NH4) (MG/L)	TOTAL ALUMINUM (AL) (UG/L)	DISSOLVED ALUMINUM (AL) (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DISSOLVED ARSENIC (AS) (UG/L)	TOTAL BARIUM (BA) (UG/L)	DISSOLVED BARIUM (BA) (UG/L)	TOTAL BORON (B) (UG/L)	DISSOLVED BORON (B) (UG/L)
APR , 1976												
26...	.03	.12	.08	.10	680	540	1	0	0	0	1700	60
OCT												
18...	.00	.01	.19	.24	6000	5500	2	1	0	0	100	70
JUN , 1977												
06...	.00	.02	.26	.33	26000	30000	2	1	100	200	170	110

DATE	TOTAL CADMIUM (CD) (UG/L)	DISSOLVED CADMIUM (CD) (UG/L)	TOTAL CHROMIUM (CR) (UG/L)	DISSOLVED CHROMIUM (CR) (UG/L)	TOTAL COBALT (CO) (UG/L)	DISSOLVED COBALT (CO) (UG/L)	TOTAL COPPER (CU) (UG/L)	DISSOLVED COPPER (CU) (UG/L)	TOTAL IRON (FE) (UG/L)	DISSOLVED IRON (FE) (UG/L)	TOTAL LEAD (PB) (UG/L)	DISSOLVED LEAD (PB) (UG/L)
APR , 1976												
26...	160	9	10	0	150	89	20	3	8900	140	100	1
OCT												
18...	490	470	10	10	200	49	60	48	29000	28000	200	30
JUN , 1977												
06...	1100	1200	150	140	300	350	200	220	70	60	200	350

TABLE 5.—*Continued*

DATE	DIS-SOLVED LITHIUM (LI) (UG/L)	TOTAL MAN-GANESE (MN) (UG/L)	DIS-SOLVED MAN-GANESE (MN) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	TOTAL MOLYB-DENUM (MO) (UG/L)	DIS-SOLVED MOLYB-DENUM (MO) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)	TOTAL SELE-NIUM (SE) (UG/L)	DIS-SOLVED SELE-NIUM (SE) (UG/L)	DIS-SOLVED VANA-DIUM (V) (UG/L)
APR , 1976												
26...	60	620	670	.5	1.3	1	0	600	500	0	0	.0
OCT												
18...	70	740	760	.4	.8	0	0	650	600	1	1	1.2
JUN , 1977												
06...	140	1600	1600	.2	.2	0	0	1100	1300	1	1	11

DATE	SAMP-LING DEPTH (FT)	TOTAL ZINC (ZN) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)	TOTAL ORGANIC CARBON (C) (MG/L)	METHY-LENE BLUE ACTIVE SUB-STANCE (MG/L)
APR , 1976					
26...	165	59000	47000	.9	.00
OCT					
18...	160	110000	110000	.6	.00
JUN , 1977					
06...	165	250000	250000	.7	.00

Also shown in tables 10–14 are the standard errors of estimate for each linear-regression analysis performed. The standard error of estimate is defined as the standard deviation of the residual differences between values estimated by regression analysis and actual values. Therefore, approximately two-thirds of the residuals would fall within the range defined by the standard error of estimate. In cases where the linear regressions were analyzed between the independent variable and a dependent variable transformed by natural or Napierian logarithms, the standard errors of estimate are given in logarithmic units.

Suitability of Mine-Shaft Water for Selected Uses

Water-quality requirements for different major water uses, such as agriculture, industry, and public supply, differ considerably. In fact, water suitable for one user may not be suitable for another even within the same broad water-use category. Also, two raw waters whose characteristics, although different, cause them to be rated poor supplies may not be equivalent. One water may be amenable to economic treatment, whereas the other may not. Therefore, the suitability of water for a specific use depends not only on the characteristics of the water, but also on the treatment process available.

In this report the criteria for judging the suitability of mine-shaft water for selected uses were obtained from the report *Water Quality Criteria, 1972,* prepared by the National Academy of Sciences and the National Academy of Engineering. Tables 15–19 give chemical and physical properties, their recommended maximum values, and the percentage of samples in which the recommended maximum values were exceeded for each of the respective water uses: public water supply; fresh, once-through, industrial cooling water; fresh, makeup-recycle, industrial cooling water; brackish industrial cooling water; and general irrigation water. The water-quality properties given in tables 15–19 are not the only ones on which the judgment of suitability for use is based. Rather, they are the constituents and properties for which excessive values were observed in water from one or more of the sampled mine shafts.

Raw water within the mines is not suitable without treatment for any of the uses considered. Because of the number and wide distribution of samples containing excessive concentrations of metals, such as cadmium and lead, and because of the inability of current domestic water-treatment practices to remove them, the mine-shaft water is not suitable as a source of public water supply.

As previously stated, water-quality requirements differ considerably even within a single water-use category. This is especially true for the broad water-use categories of agriculture and industry. Therefore, each potential agricultural or industrial water user must decide what water-quality characteristics are necessary or undesirable and then determine from the available data whether necessary treatment is technologically available and economically practical.

Hydrology of the Mined Area

Because movement of highly mineralized water from the mines into streams or the Roubidoux Formation, the principal aquifer in the area, would have deleterious effects on water quality, recharge to and discharge from the mined areas are important. At present, recharge to the mines, from surface runoff into open shafts during periods of heavy precipitation and through solution cavities and fractures in the surrounding Boone Formation, is relatively unhindered. As a result, the abandoned mines are steadily filling with highly mineralized water, and they contained by mid-1976 an estimated 100,000 acre-ft (D. C. Brockie, oral communication). The rate of recharge to the mines, estimated from pumping rates required to dewater the mines, is 22 ft^3/s, resulting in an average rise in the water level of about 1.5 ft/month since cessation of mining activities (D. C. Brockie, oral communication, 1976). The total discharge from the Boone Formation in Ottawa County in 1948, considering all sources of discharge, was estimated at 43 ft^3/s (Reed and others, 1955). Subsurface recharge to

TABLE 6.—WATER-QUALITY DATA FROM NEW CHICAGO MINE SHAFT, APRIL 1976–JUNE 1977

Sampling depths in ft below land surface

DATE	SAMPLING DEPTH (FT)	PH (UNITS)	TEMPERATURE (DEG C)	SPECIFIC CONDUCTANCE (MICROMHOS)
APR , 1976				
29...	167	7.6	16.0	2520
29...	174	7.6	16.0	2500
29...	179	7.3	16.0	2520
29...	181	6.6	16.0	2520
29...	183	5.4	16.5	2680
29...	192	4.8	17.0	2520
29...	197	4.9	17.5	2850
AUG				
26...	160	--	18.0	--
26...	174	--	18.0	--
26...	187	7.0	18.0	2850
26...	197	3.8	17.5	3840
OCT				
20...	165	7.6	16.5	3200
20...	180	7.6	16.5	3200
20...	195	4.8	16.0	3200
DEC				
06...	165	7.0	14.5	2650
06...	180	7.1	15.0	2800
06...	195	4.7	16.0	2950
FEB , 1977				
17...	165	6.2	14.5	3150
17...	180	6.2	14.5	3150
17...	195	4.2	15.0	3200
APR				
21...	165	7.1	15.0	3000
21...	185	7.1	15.0	3000
21...	187	4.4	16.0	3300
21...	195	4.3	16.0	3350
JUN				
08...	160	7.1	16.0	2550
08...	180	4.6	15.0	3300
08...	187	4.4	16.0	3300
08...	195	3.8	16.0	3800

TABLE 6.—*Continued*

DATE	SAMPLING DEPTH (FT)	TURBIDITY (NTU)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	TOTAL ACIDITY AS H+ (MG/L)	TOTAL ACIDITY AS CACO3 (MG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	PERCENT SODIUM	SODIUM ADSORPTION RATIO	DISSOLVED POTASSIUM (K) (MG/L)
APR , 1976												
29...	174	4.6	1600	1500	.8	40	430	130	29	4	.3	2.9
29...	192	10	1600	1600	4.6	228	490	82	28	4	.3	1.9
29...	197	38	1600	1600	5.9	293	500	86	28	4	.3	1.6
AUG												
26...	187	3.8	2000	1900	.4	20	520	170	34	4	.3	4.1
26...	197	11	1800	1800	15	745	510	130	36	4	.4	2.8
OCT												
20...	165	160	2100	2000	--	--	490	210	140	13	1.3	4.3
20...	195	75	1900	1800	--	--	510	140	36	4	.4	3.1
DEC												
06...	165	8.4	2100	2000	.8	40	500	200	44	4	.4	3.7
06...	195	90	1900	1900	8.2	407	510	140	36	4	.4	3.1
FEB , 1977												
17...	165	8.0	2000	1900	1.7	84	490	180	44	5	.4	3.4
17...	195	45	1800	1800	6.0	298	500	140	39	4	.4	3.2
APR												
21...	165	1.3	2000	1900	.7	35	490	190	45	5	.4	4.0
21...	195	.50	2100	2100	5.0	248	600	140	39	4	.4	3.2
JUN												
08...	160	.80	1700	1600	.2	10	470	130	32	4	.3	3.2
08...	180	10	1900	1900	12	596	530	140	38	4	.4	3.5
08...	195	39	2100	2100	23	1140	500	200	57	6	.5	4.0

DATE	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	ALKALINITY AS CACO3 (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED FLUORIDE (F) (MG/L)	DISSOLVED SILICA (SIO2) (MG/L)	DISSOLVED SOLIDS (RESIDUE AT 180 C) (MG/L)	SUSPENDED SOLIDS (MG/L)	DISSOLVED NITRATE (N) (MG/L)	DISSOLVED NITRATE (NO3) (MG/L)	DISSOLVED NITRITE (N) (MG/L)
APR , 1976												
29...	114	0	94	1800	4.5	1.0	9.3	2450	4	.12	.53	.00
29...	9	0	7	2000	4.6	2.2	11	2750	5	.03	.13	.00
29...	6	0	5	2100	4.8	2.6	12	2930	16	.01	.04	.00
AUG												
26...	166	0	136	1900	8.8	1.1	14	2990	0	--	--	--
26...	0	0	0	2300	8.1	7.2	16	3670	36	--	--	--
OCT												
20...	168	0	138	2300	7.4	1.9	12	3210	173	.21	.93	.00
20...	5	0	4	2300	5.8	5.4	14	3480	90	.07	.31	.00
DEC												
06...	94	0	77	2000	7.0	1.3	12	3170	1	--	--	--
06...	0	0	0	2600	5.6	2.9	15	3410	57	--	--	--
FEB , 1977												
17...	24	0	20	2000	7.3	1.9	11	3090	0	--	--	--
17...	0	0	0	2200	14	3.9	14	3330	25	--	--	--
APR												
21...	110	0	90	1900	7.3	1.4	13	3060	3	--	--	--
21...	0	0	0	2500	72	8.0	15	3630	6	--	--	--
JUN												
08...	180	0	150	1600	4.8	.9	13	2690	0	.18	.80	.00
08...	0	0	0	2400	5.4	8.3	19	3850	3	.01	.04	.01
08...	0	0	0	3000	6.2	1.0	19	4800	2	.01	.04	.01

TABLE 6.—WATER-QUALITY DATA FROM NEW CHICAGO MINE SHAFT, APRIL 1976–JUNE 1977—*Continued*

DATE	DIS-SOLVED NITRITE (NO2) (MG/L)	DIS-SOLVED NITRITE PLUS NITRATE (N) (MG/L)	DIS-SOLVED AMMONIA NITRO-GEN (N) (MG/L)	DIS-SOLVED AMMONIA (NH4) (MG/L)	TOTAL ALUM-INUM (AL) (UG/L)	DIS-SOLVED ALUM-INUM (AL) (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DIS-SOLVED ARSENIC (AS) (UG/L)	TOTAL BARIUM (BA) (UG/L)	DIS-SOLVED BARIUM (BA) (UG/L)	TOTAL BORON (B) (UG/L)	DIS-SOLVED BORON (B) (UG/L)
APR , 1976												
29...	.00	.12	.01	.01	200	30	0	0	0	0	330	130
29...	.00	.03	.02	.03	3100	110	0	0	0	0	190	160
29...	.00	.01	.09	.12	3700	5400	1	0	0	0	190	180
AUG												
26...	--	--	--	--	130	80	--	--	--	--	90	70
26...	--	--	--	--	2900	0	--	--	--	--	210	140
OCT												
20...	.00	.21	.00	.00	130	20	1	0	0	0	100	70
20...	.00	.07	.15	.19	14000	13000	1	1	0	0	150	100
DEC												
06...	--	.20	--	--	340	10	--	--	--	--	120	80
06...	--	--	--	--	12000	14000	--	--	--	--	150	100
FEB , 1977												
17...	--	--	--	--	1400	820	--	--	--	--	110	80
17...	--	--	--	--	9000	0	--	--	--	--	140	130
APR												
21...	--	--	--	--	140	0	--	--	--	--	110	70
21...	--	--	--	--	26000	26000	--	--	--	--	140	140
JUN												
08...	.00	.18	.01	.01	20	10	0	0	100	100	100	70
08...	.03	.02	.27	.35	23000	24000	0	0	100	200	210	150
08...	.03	.02	.46	.62	42000	42000	2	1	100	100	260	200

DATE	TOTAL CAD-MIUM (CD) (UG/L)	DIS-SOLVED CAD-MIUM (CD) (UG/L)	TOTAL CHRO-MIUM (CR) (UG/L)	DIS-SOLVED CHRO-MIUM (CR) (UG/L)	TOTAL COBALT (CO) (UG/L)	DIS-SOLVED COBALT (CO) (UG/L)	TOTAL COPPER (CU) (UG/L)	DIS-SOLVED COPPER (CU) (UG/L)	TOTAL IRON (FE) (UG/L)	DIS-SOLVED IRON (FE) (UG/L)	TOTAL LEAD (PB) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)
APR , 1976												
29...	50	11	0	10	100	88	10	2	390	40	<100	11
29...	350	16	10	0	200	0	50	17	2100	100	100	66
29...	360	130	20	20	250	0	50	36	18000	20000	100	120
AUG												
26...	50	10	--	--	--	--	--	--	510	80	100	14
26...	920	630	--	--	--	--	--	--	83000	67000	400	500
OCT												
20...	20	16	10	10	50	8	<10	3	490	30	100	1
20...	430	410	50	30	350	64	120	100	61000	55000	300	300
DEC												
06...	100	11	--	--	--	--	--	--	1000	30	100	1
06...	400	390	--	--	--	--	--	--	60000	59000	300	250
FEB , 1977												
17...	150	8	--	--	--	--	--	--	950	30	<100	10
17...	320	340	--	--	--	--	--	--	42000	41000	200	200
APR												
21...	60	65	--	--	--	--	--	--	350	60	100	100
21...	570	560	--	--	--	--	--	--	120000	100000	300	300
JUN												
08...	20	12	10	10	<50	2	20	2	90	50	100	4
08...	500	510	60	60	350	400	120	130	110000	120000	400	350
08...	850	860	150	140	600	600	240	260	190000	210000	400	400

TABLE 6.—*Continued*

DATE	DIS-SOLVED LITHIUM (LI) (UG/L)	TOTAL MAN-GANESE (MN) (UG/L)	DIS-SOLVED MAN-GANESE (MN) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	TOTAL MOLYB-DENUM (MO) (UG/L)	DIS-SOLVED MOLYB-DENUM (MO) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)	TOTAL SELE-NIUM (SE) (UG/L)	DIS-SOLVED SELE-NIUM (SE) (UG/L)	DIS-SOLVED VANA-DIUM (V) (UG/L)
APR , 1976												
29...	50	310	310	.8	.4	1	1	200	150	0	0	.5
29...	90	1300	1100	.3	.3	1	0	800	700	1	1	.7
29...	110	1300	1400	.5	.5	0	0	900	1000	1	1	2.7
AUG												
26...	60	400	380	--	--	--	--	100	91	--	--	.7
26...	180	3500	2800	--	--	--	--	1800	1600	--	--	32
OCT												
20...	70	200	200	.1	.2	0	1	100	100	1	1	.1
20...	130	2000	1500	.1	.2	0	0	1100	1100	1	1	24
DEC												
06...	80	440	420	--	--	--	--	900	500	--	--	.0
06...	130	1700	1900	--	--	--	--	1200	1200	--	--	18
FEB , 1977												
17...	110	840	820	--	--	--	--	500	500	--	--	.0
17...	130	1800	1800	--	--	--	--	1000	1100	--	--	22
APR												
21...	90	400	420	--	--	--	--	250	250	--	--	.0
21...	180	2500	2500	--	--	--	--	1700	1600	--	--	7.0
JUN												
08...	60	220	220	.1	.2	0	0	50	100	0	0	.0
08...	190	2800	3100	.2	.0	0	0	1600	1700	2	2	.0
08...	260	4200	4600	.2	.2	0	0	2600	2900	1	1	17

DATE	SAMP-LING DEPTH (FT)	TOTAL ZINC (ZN) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)	TOTAL ORGANIC CARBON (C) (MG/L)	METHY-LENE BLUE ACTIVE SUB-STANCE (MG/L)
APR , 1976					
29...	174	18000	16000	3.4	.40
29...	192	110000	100000	3.6	.00
29...	197	110000	120000	3.5	.00
AUG					
26...	187	17000	17000	--	--
26...	197	260000	200000	--	--
OCT					
20...	165	6300	6500	3.3	.00
20...	195	140000	130000	.8	.00
DEC					
06...	165	50000	26000	--	--
06...	195	130000	130000	--	--
FEB , 1977					
17...	165	55000	53000	--	--
17...	195	120000	120000	--	--
APR					
21...	165	22000	22000	--	--
21...	195	170000	170000	--	--
JUN					
08...	160	7000	7300	3.1	.10
08...	180	190000	190000	.8	.00
08...	195	350000	340000	3.2	.10

TABLE 7.—WATER-QUALITY DATA FROM BIRTHDAY MINE SHAFT, APRIL 1976–JUNE 1977

Sampling depths in ft below land surface

DATE	SAMP-LING DEPTH (FT)	PH (UNITS)	TEMPER-ATURE (DEG C)	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)
APR , 1976				
23...	168	5.2	16.0	4100
23...	172	5.2	15.5	4200
23...	175	5.2	15.5	4200
23...	182	5.3	15.0	4390
AUG				
25...	160	7.2	16.0	1060
25...	167	3.4	17.0	--
25...	173	3.7	16.5	--
25...	177	4.2	16.0	--
25...	180	5.8	16.0	3840
OCT				
19...	162	6.0	15.0	1900
19...	180	5.6	15.0	3800
DEC				
07...	160	6.6	14.5	1550
07...	170	3.8	15.0	3300
07...	180	5.7	16.0	4000
FEB , 1977				
18...	145	5.7	15.0	3000
18...	160	5.0	15.0	3850
18...	170	4.5	15.0	3850
18...	180	5.4	15.5	4050
APR				
21...	155	7.2	15.0	1550
21...	167	5.3	15.5	3650
21...	170	5.0	16.0	3850
21...	180	5.8	16.0	4400
JUN				
08...	155	6.8	16.0	830
08...	162	6.8	15.5	830
08...	166	5.1	16.0	3500
08...	170	5.0	16.0	3800
08...	175	5.3	16.0	3800
08...	180	5.8	16.5	4100

DATE	SAMP-LING DEPTH (FT)	TUR-BID-ITY (NTU)	HARD-NESS (CA,MG) (MG/L)	NON-CAR-BONATE HARD-NESS (MG/L)	TOTAL ACIDITY AS H+ (MG/L)	TOTAL ACIDITY AS CACO3 (MG/L)	DIS-SOLVED CAL-CIUM (CA) (MG/L)	DIS-SOLVED MAG-NE-SIUM (MG) (MG/L)	DIS-SOLVED SODIUM (NA) (MG/L)	PERCENT SODIUM	SODIUM AD-SORP-TION RATIO	DIS-SOLVED PO-TAS-SIUM (K) (MG/L)
APP , 1976												
23...	166	80	2200	2200	17	844	490	230	52	5	.5	2.7
23...	182	72	2200	2200	18	894	490	240	53	5	.5	2.6
AUG												
25...	160	.80	540	460	.2	10	160	35	29	10	.5	3.7
25...	160	140	1600	1600	13	646	420	130	40	5	.4	3.8
OCT												
19...	162	24	890	850	--	--	250	64	40	9	.6	4.9
19...	180	160	2100	2100	--	--	490	220	47	5	.4	4.1
DEC												
07...	160	9.8	830	740	.4	20	230	62	63	14	1.0	6.3
07...	180	130	2400	2400	18	894	540	260	46	4	.4	3.0
FEB , 1977												
18...	160	55	1900	1900	20	993	480	180	54	6	.5	4.2
18...	180	80	2100	2100	20	993	490	210	51	5	.5	3.8
APR												
21...	155	2.1	730	660	.2	10	200	55	59	15	1.0	4.6
21...	170	33	2000	2000	9.0	447	470	190	61	6	.6	4.6
21...	180	95	2500	2500	10	497	570	270	47	4	.4	3.2
JUN												
08...	155	7.9	410	330	.2	10	120	27	19	9	.4	3.7
08...	170	110	2200	2200	22	1090	500	230	63	6	.6	5.0
08...	180	400	2500	2400	19	943	540	270	44	4	.4	3.5

TABLE 7.—*Continued*

DATE	BICAR-BONATE (HCO3) (MG/L)	CAR-BONATE (CO3) (MG/L)	ALKA-LINITY AS CACO3 (MG/L)	DIS-SOLVED SULFATE (SO4) (MG/L)	DIS-SOLVED CHLO-RIDE (CL) (MG/L)	DIS-SOLVED FLUO-RIDE (F) (MG/L)	DIS-SOLVED SILICA (SIO2) (MG/L)	DIS-SOLVED SOLIDS (RESI-DUE AT 180 C) (MG/L)	SUS-PENDED SOLIDS (MG/L)	DIS-SOLVED NITRATE (N) (MG/L)	DIS-SOLVED NITRATE (NO3) (MG/L)	DIS-SOLVED NITRITE (N) (MG/L)
APR , 1976												
23...	8	0	7	3000	6.7	8.1	11	5150	138	.01	.04	.00
23...	24	0	20	3000	6.8	7.2	11	5200	134	.03	.13	.00
AUG												
25...	107	0	88	520	3.2	.4	6.8	864	0	--	--	--
25...	1	0	1	2100	9.1	2.9	10	--	156	--	--	--
OCT												
19...	51	0	42	1000	4.7	1.8	6.4	1590	29	.01	.04	.00
19...	45	0	37	3100	7.3	2.5	12	4620	165	.01	.04	.01
DEC												
07...	112	0	92	870	5.5	.5	7.8	1390	3	--	--	--
07...	0	0	0	3500	6.9	1.1	12	5000	149	--	--	--
FEB , 1977												
18...	0	0	0	2900	7.4	8.6	13	4570	115	--	--	--
18...	0	0	0	3200	6.8	6.5	13	4860	216	--	--	--
APR												
21...	84	0	69	760	3.4	1.1	4.9	1260	9	--	--	--
21...	0	0	0	2700	6.4	7.6	13	4300	70	--	--	--
21...	0	0	0	3100	6.9	1.2	12	5100	186	--	--	--
JUN												
08...	94	0	77	360	2.3	.6	6.8	630	4	.36	1.6	.04
08...	0	0	0	3200	6.9	8.6	14	4960	84	.06	.27	.01
08...	39	0	32	3200	7.2	.4	9.4	5340	156	.05	.22	.01

DATE	DIS-SOLVED NITRITE (NO2) (MG/L)	DIS-SOLVED NITRITE PLUS NITRATE (N) (MG/L)	DIS-SOLVED AMMONIA NITRO-GEN (N) (MG/L)	DIS-SOLVED AMMONIA (NH4) (MG/L)	TOTAL ALUM-INUM (AL) (UG/L)	DIS-SOLVED ALUM-INUM (AL) (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DIS-SOLVED ARSENIC (AS) (UG/L)	TOTAL BARIUM (BA) (UG/L)	DIS-SOLVED BARIUM (BA) (UG/L)	TOTAL BORON (B) (UG/L)	DIS-SOLVED BORON (B) (UG/L)
APR , 1976												
23...	.00	.01	.35	.45	9100	8600	2	1	0	0	220	200
23...	.00	.03	.33	.43	8800	8900	2	2	0	0	240	200
AUG												
25...	--	--	--	--	60	40	--	--	--	--	110	90
25...	--	--	--	--	4000	4000	--	--	--	--	130	240
OCT												
19...	.00	.01	.19	.24	980	600	1	1	0	0	150	110
19...	.03	.02	.17	.22	4000	3200	0	0	0	0	220	160
DEC												
07...	--	--	--	--	60	0	--	--	--	--	190	140
07...	--	--	--	--	4000	2000	--	--	--	--	230	170
FEB , 1977												
18...	--	--	--	--	13000	13000	--	--	--	--	240	150
18...	--	--	--	--	8900	7900	--	--	--	--	220	160
APR												
21...	--	--	--	--	180	20	--	--	--	--	120	90
21...	--	--	--	--	11000	11000	--	--	--	--	230	150
21...	--	--	--	--	1000	1000	--	--	--	--	230	160
JUN												
08...	.13	.40	.14	.18	70	50	0	0	100	100	110	70
08...	.03	.07	.51	.66	6200	2900	3	3	100	100	260	180
08...	.03	.06	.03	.04	100	100	6	6	100	200	250	200

TABLE 7.—WATER-QUALITY DATA FROM BIRTHDAY MINE SHAFT, APRIL 1976–JUNE 1977—*Continued*

DATE	TOTAL CAD-MIUM (CD) (UG/L)	DIS-SOLVED CAD-MIUM (CD) (UG/L)	TOTAL CHRO-MIUM (CR) (UG/L)	DIS-SOLVED CHRO-MIUM (CR) (UG/L)	TOTAL COBALT (CO) (UG/L)	DIS-SOLVED COBALT (CO) (UG/L)	TOTAL COPPER (CU) (UG/L)	DIS-SOLVED COPPER (CU) (UG/L)	TOTAL IRON (FE) (UG/L)	DIS-SOLVED IRON (FE) (UG/L)	TOTAL LEAD (PB) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)
APR , 1976												
23...	880	900	20	20	580	550	50	36	110000	110000	300	79
23...	900	900	10	20	600	580	50	60	110000	10000	300	93
AUG												
25...	60	60	--	--	--	--	--	--	240	210	<100	12
25...	270	230	--	--	--	--	--	--	110000	89000	300	40
OCT												
19...	130	8	10	0	150	74	<10	2	15000	13000	100	51
19...	100	60	20	0	600	71	10	2	150000	110000	200	13
DEC												
07...	<10	1	--	--	--	--	--	--	2000	710	100	2
07...	160	60	--	--	--	--	--	--	160000	83000	300	67
FEB , 1977												
18...	350	360	--	--	--	--	--	--	190000	180000	300	300
18...	360	370	--	--	--	--	--	--	210000	200000	300	300
APR												
21...	130	140	--	--	--	--	--	--	280	140	100	50
21...	280	300	--	--	--	--	--	--	190000	170000	300	200
21...	100	80	--	--	--	--	--	--	200000	200000	200	200
JUN												
08...	60	55	0	10	<50	9	<10	8	710	90	<100	7
08...	260	180	10	20	650	700	70	90	240000	220000	200	40
08...	80	20	10	20	800	800	10	4	230000	230000	300	17

DATE	DIS-SOLVED LITHIUM (LI) (UG/L)	TOTAL MAN-GANESE (MN) (UG/L)	DIS-SOLVED MAN-GANESE (MN) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	TOTAL MOLYB-DENUM (MO) (UG/L)	DIS-SOLVED MOLYB-DENUM (MO) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)	TOTAL SELE-NIUM (SE) (UG/L)	DIS-SOLVED SELE-NIUM (SE) (UG/L)	DIS-SOLVED VANA-DIUM (V) (UG/L)
APR , 1976												
23...	250	5500	5600	.9	.7	0	0	3700	3300	1	0	39
23...	250	5500	5500	.9	1.0	0	0	3900	3500	0	0	36
AUG												
25...	20	70	70	--	--	--	--	<50	50	--	--	.4
25...	120	12000	7400	--	--	--	--	2000	1800	--	--	--
OCT												
19...	50	1300	930	.2	.0	0	0	500	500	2	1	.8
19...	150	9000	9000	.0	.1	0	0	2500	2500	0	0	49
DEC												
07...	40	1800	1500	--	--	--	--	500	150	--	--	.0
07...	160	11000	10000	--	--	--	--	8000	2900	--	--	45
FEB , 1977												
18...	160	5200	5000	--	--	--	--	2900	3100	--	--	110
18...	160	7400	7000	--	--	--	--	3000	3200	--	--	100
APR												
21...	30	300	300	--	--	--	--	100	97	--	--	.0
21...	160	5000	4400	--	--	--	--	2900	2900	--	--	50
21...	140	15000	14000	--	--	--	--	2800	3000	--	--	50
JUN												
08...	20	160	190	.4	.0	0	0	50	50	0	0	.0
08...	200	5000	5200	.1	.2	0	0	3000	3500	0	0	130
08...	140	13000	13000	.1	.0	0	0	2800	3000	0	0	50

TABLE 7.—*Continued*

DATE	SAMPLING DEPTH (FT)	TOTAL ZINC (ZN) (UG/L)	DISSOLVED ZINC (ZN) (UG/L)	TOTAL ORGANIC CARBON (C) (MG/L)	METHYLENE BLUE ACTIVE SUBSTANCE (MG/L)
APR , 1976					
23...	168	470000	490000	.0	.00
23...	182	490000	490000	.0	.00
AUG					
25...	160	9200	9400	--	--
25...	180	340000	260000	--	--
OCT					
19...	162	65000	65000	4.2	.00
19...	180	370000	360000	5.4	.00
DEC					
07...	160	54000	4400	--	--
07...	180	390000	390000	--	--
FEB , 1977					
18...	160	340000	340000	--	--
18...	180	390000	380000	--	--
APR					
21...	155	8400	8300	--	--
21...	170	310000	270000	--	--
21...	180	410000	370000	--	--
JUN					
08...	155	6400	6700	2.4	.00
08...	170	340000	340000	4.6	.10
08...	180	410000	400000	5.1	.10

the Boone Formation is derived mainly from the outcrop area to the east. In the study area, direct recharge to the Boone is minimal, owing to the overlying impervious shale. The amount and direction of discharge from the area is unknown.

Periodic water-level measurements made in the Blue Goose well from September 1975 to February 1980 (fig. 13) show that the water level rose at an average rate of 2.6 ft/month. Generally, the water-level rise was greatest after periods of high precipitation and after the mine workings were filled with water (figs. 6, 13). The equilibrium water level probably will approximate the level that existed before mining and accompanying dewatering began. Although no definite information regarding the pre-mining static water level is available, Siebenthal (1908) indicated that Tar Creek (fig. 1) is the likely drainage level for the region. Tar Creek is approximately 790 ft above mean sea level in the southern part of the study area and approximately 840 ft above mean sea level in the northern part. In the vicinity of the Blue Goose well, Tar Creek is approximately 800 ft above mean sea level. Therefore, based on the assumption that the equilibrium water-level altitude is 800 ft above mean sea level and on the fact that the rate of water-level rise has apparently declined, the present water level in the Blue Goose well should be near equilibrium. In the future, the water level should fluctuate about the present level. Eventually, the water in the mines will move down gradient toward major drainage basins in the area.

Siebenthal (1915) stated that the chemical characteristics of water in mines in the Miami, Oklahoma, mining district were similar to those of the deep wells in the same area. Also, the quantity of water pumped from the mines required to keep the work areas dry remained relatively constant, being essentially free of seasonal variations. Siebenthal concluded that the water in the mines in the Miami mining district was supplied under artesian pressure from deeper formations such as the Roubidoux, the source of water supply to most municipalities in the area. Brockie, Hare, and Dingess (1968) also implied a hydraulic connection between the Roubidoux and Boone Formations by concluding that the origin of the ores mined in the area was from warm, saline, ore-bearing solutions that migrated through the Cambrian–Ordovician formations and upward into the Mississippian formations

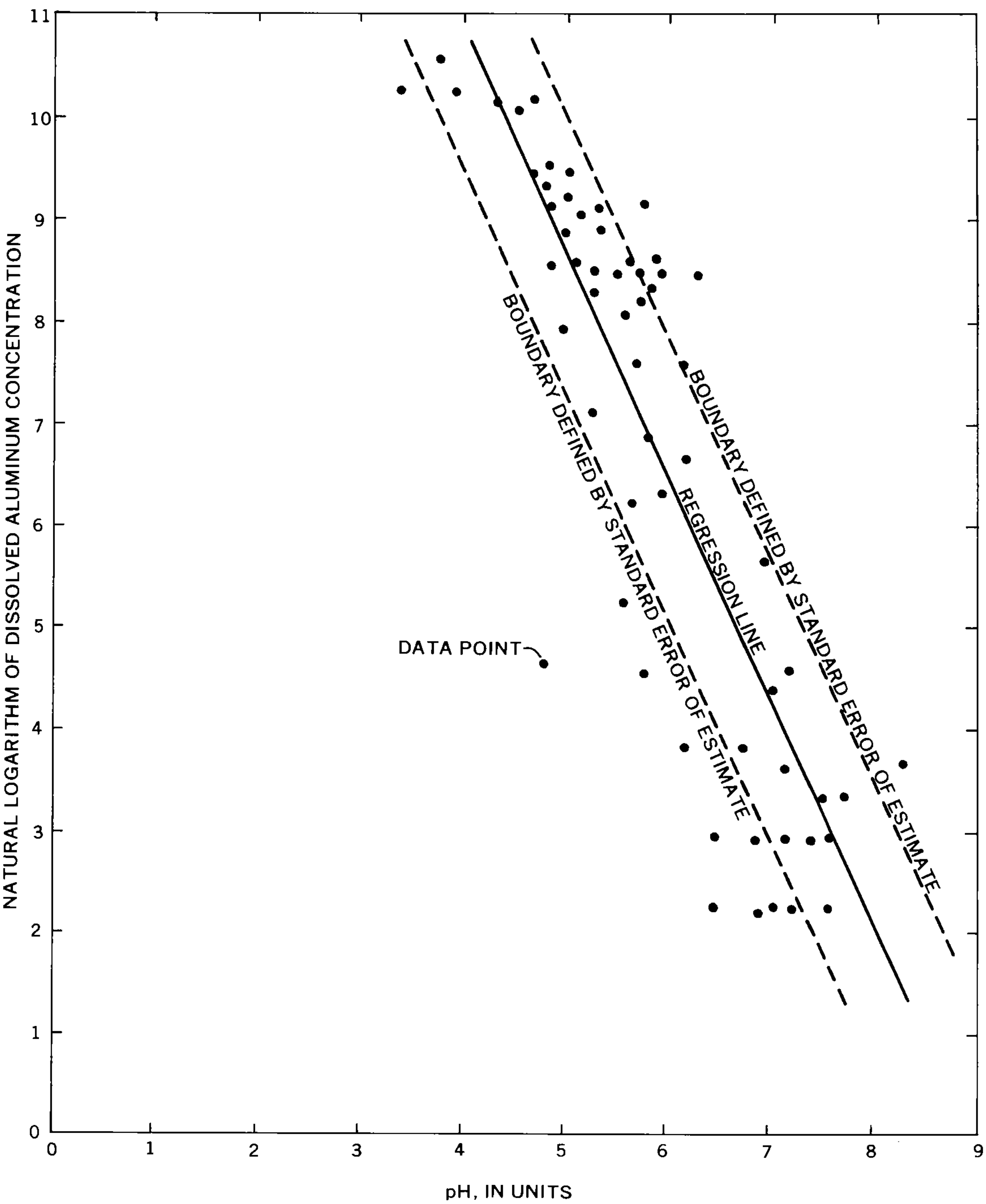


Figure 11. Graph showing logarithmic relationship of dissolved aluminum concentration to pH of mine-shaft water. Untransformed values of dissolved aluminum concentration given in micrograms per liter.

where zones of weakness, such as the Miami Trough and windows in the Chattanooga Shale, were present. Siebenthal (1915, p. 274) further stated:

So also there must be a constant deep-seated increment to the mine waters of all the mining districts of the Joplin region, though this increment may be almost completely masked by the seasonal variations.

If there is hydraulic connection between the mined areas of the Boone Formation and the underlying Roubidoux Formation as Siebenthal contended, then continued heavy pumping and drawdown in the Roubidoux, coupled with increasing water levels in the mines, will cause the difference in head between the two formations to decrease. If the decrease in head differential is such that it is reversed, downward migration of contaminated mine water into the Roubidoux is possible.

Reed and others (1955) noted that a considerable volume of water is discharged through many springs from the Boone Formation east of the study area in eastern Ottawa County, Oklahoma. In addition, rural wells withdraw water for domestic and stock use from the Boone outside of the mined areas. A possibility exists, therefore, that after reaching equilibrium level, water in the mined areas will migrate sufficiently to contaminate the rural domestic and stock wells. However, Barks (1977), in a study of the Joplin area, Missouri, noted that contamination of the shallow aquifer by the highly mineralized mine water was limited to the immediate area of mining. In the same report, Barks observed that streams

TABLE 8.—WATER-QUALITY DATA FROM CONSOLIDATED NO. 2 MINE SHAFT, APRIL 1976–JUNE 1977

Sampling depths in ft below land surface

DATE	SAMPLING DEPTH (FT)	PH (UNITS)	TEMPERATURE (DEG C)	SPECIFIC CONDUCTANCE (MICROMHOS)
APR , 1976				
20...	179	7.8	16.0	920
20...	191	7.5	16.0	940
21...	210	7.2	15.5	1040
21...	227	6.9	16.0	1080
21...	229	5.0	16.0	4420
21...	234	4.8	16.0	4600
AUG				
25...	165	7.7	17.0	810
25...	185	7.8	16.5	--
25...	215	7.7	16.0	--
25...	225	7.7	16.0	--
25...	230	5.3	16.0	4670
25...	235	5.0	16.0	--
OCT				
19...	165	6.7	14.5	830
19...	215	6.7	15.0	840
19...	230	5.3	14.5	4000
DEC				
07...	165	7.4	14.5	900
07...	215	7.4	14.5	890
07...	230	5.5	15.5	4650
FEB , 1977				
17...	165	7.6	13.5	1030
17...	215	7.5	14.0	1080
17...	222	5.7	14.5	4080
17...	230	5.3	15.0	4280
APR				
21...	152	6.8	14.5	1170
21...	165	7.2	14.5	1080
21...	215	7.3	14.5	1080
21...	220	7.2	14.5	1080
21...	230	5.3	15.5	4150
JUN				
07...	165	7.4	16.0	810
07...	215	7.6	15.5	740
07...	225	7.1	16.0	810
07...	230	5.6	16.0	4100

TABLE 8.—WATER-QUALITY DATA FROM CONSOLIDATED NO. 2 MINE SHAFT, APRIL 1976–JUNE 1977–*Continued*

DATE	SAMPLING DEPTH (FT)	TURBIDITY (NTU)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	TOTAL ACIDITY AS H+ (MG/L)	TOTAL ACIDITY AS CACO3 (MG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	PERCENT SODIUM	SODIUM ADSORPTION RATIO	DISSOLVED POTASSIUM (K) (MG/L)
APR , 1976												
20...	191	3.0	520	470	.2	10	170	24	10	4	.2	1.7
21...	227	5.0	550	510	.2	10	180	25	11	4	.2	1.8
21...	229	88	2200	2200	18	894	500	240	80	7	.7	2.2
21...	234	72	2300	2300	23	1140	520	240	8.0	1	.1	2.2
AUG												
25...	165	1.0	440	370	.1	5.0	150	16	7.1	3	.1	1.6
25...	230	140	1300	1300	18	894	340	100	43	7	.5	3.4
OCT												
19...	165	3.0	480	420	--	--	160	20	8.9	4	.2	2.0
19...	230	130	2200	2200	--	--	510	230	81	7	.7	4.1
DEC												
07...	165	1.1	520	460	.1	5.0	170	23	9.7	4	.2	1.9
07...	230	45	2400	2400	20	993	560	240	77	7	.7	3.9
FEB , 1977												
17...	165	1.0	570	520	.1	5.0	180	29	12	4	.2	2.1
17...	230	160	2200	2200	21	1040	520	230	81	7	.7	3.6
APR												
21...	165	1.0	570	520	.1	5.0	180	29	12	4	.2	2.1
21...	230	70	2200	2200	11	546	510	230	77	7	.7	3.4
JUN												
07...	165	1.0	440	380	.0	.0	150	16	7.1	3	.1	1.4
07...	230	200	2200	2200	22	1090	510	220	80	7	.7	3.8

DATE	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	ALKALINITY AS CACO3 (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED FLUORIDE (F) (MG/L)	DISSOLVED SILICA (SIO2) (MG/L)	DISSOLVED SOLIDS (RESIDUE AT 180 C) (MG/L)	SUSPENDED SOLIDS (MG/L)	DISSOLVED NITRATE (N) (MG/L)	DISSOLVED NITRATE (NO3) (MG/L)	DISSOLVED NITRITE (N) (MG/L)
APR , 1976												
20...	64	0	53	460	2.1	.3	10	795	4	.26	1.2	.00
21...	57	0	47	520	1.7	.4	9.8	841	3	.24	1.1	.00
21...	0	0	0	3100	6.2	1.9	8.4	5160	106	.00	.00	.01
21...	0	0	0	3200	6.6	1.6	9.8	5380	36	.01	.04	.00
AUG												
25...	81	0	66	360	.5	.4	11	648	--	--	--	--
25...	1	0	1	1600	9.1	1.7	11	--	93	--	--	--
OCT												
19...	76	0	62	440	1.1	.7	11	722	12	.22	.97	.00
19...	7	0	6	3400	7.0	2.4	7.7	5160	186	.42	1.9	.00
DEC												
07...	71	0	58	490	1.3	.3	12	768	0	--	--	--
07...	20	0	16	3500	7.0	1.9	9.2	5090	74	--	--	--
FEB , 1977												
17...	57	0	47	510	3.1	.5	13	838	0	--	--	--
17...	0	0	0	3300	6.8	3.5	8.0	5180	93	--	--	--
APR												
21...	55	0	45	500	1.8	.6	12	845	2	--	--	--
21...	0	0	0	3000	6.3	1.5	8.8	4970	73	--	--	--
JUN												
07...	78	0	64	370	1.1	.4	12	622	0	.21	.93	.00
07...	0	0	0	3100	5.9	1.8	8.4	5100	114	.02	.09	.01

TABLE 8.—*Continued*

DATE	DIS-SOLVED NITRITE (NO2) (MG/L)	DIS-SOLVED NITRITE PLUS NITRATE (N) (MG/L)	DIS-SOLVED AMMONIA NITRO-GEN (N) (MG/L)	DIS-SOLVED AMMONIA (NH4) (MG/L)	TOTAL ALUM-INUM (AL) (UG/L)	DIS-SOLVED ALUM-INUM (AL) (UG/L)	TOTAL ARSENIC (AS) (UG/L)	DIS-SOLVED ARSENIC (AS) (UG/L)	TOTAL BARIUM (BA) (UG/L)	DIS-SOLVED BARIUM (BA) (UG/L)	TOTAL BORON (B) (UG/L)	DIS-SOLVED BORON (B) (UG/L)
APR , 1976												
20...	.00	.26	.02	.03	90	10	0	0	100	100	60	30
21...	.00	.24	.00	.00	90	20	1	1	100	0	170	100
21...	.03	.01	.28	.36	7300	7700	3	2	100	100	180	150
21...	.00	.01	.28	.36	12000	10000	2	1	0	0	190	120
AUG												
25...	--	--	--	--	60	30	--	--	--	--	120	40
25...	--	--	--	--	15000	5000	--	--	--	--	90	100
OCT												
19...	.00	.22	.00	.00	150	0	1	0	0	0	70	40
19...	--	--	--	--	--	--	--	--	--	--	--	--
19...	.00	.42	.27	.35	10000	5000	10	10	0	0	240	170
DEC												
07...	--	--	--	--	40	0	--	--	--	--	60	60
07...	--	--	--	--	10000	5000	--	--	--	--	240	190
FEB , 1977												
17...	--	--	--	--	40	0	--	--	--	--	70	40
17...	--	--	--	--	4500	1400	--	--	--	--	270	170
APR												
21...	--	--	--	--	40	10	--	--	--	--	50	30
21...	--	--	--	--	4500	4500	--	--	--	--	240	140
JUN												
07...	.00	.21	.00	.00	60	20	0	0	100	100	60	30
07...	.03	.03	.27	.35	200	200	5	6	200	200	280	170

DATE	TOTAL CAD-MIUM (CD) (UG/L)	DIS-SOLVED CAD-MIUM (CD) (UG/L)	TOTAL CHRO-MIUM (CR) (UG/L)	DIS-SOLVED CHRO-MIUM (CR) (UG/L)	TOTAL COBALT (CO) (UG/L)	DIS-SOLVED COBALT (CO) (UG/L)	TOTAL COPPER (CU) (UG/L)	DIS-SOLVED COPPER (CU) (UG/L)	TOTAL IRON (FE) (UG/L)	DIS-SOLVED IRON (FE) (UG/L)	TOTAL LEAD (PB) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)
APR , 1976												
20...	80	90	10	0	<50	0	10	4	650	0	<100	2
21...	100	100	10	0	<50	3	<10	7	800	670	<100	2
21...	780	780	30	20	800	53	60	70	250000	130000	300	200
21...	950	930	40	30	850	56	100	100	510000	130000	500	400
AUG												
25...	110	110	--	--	--	--	--	--	120	80	<100	10
25...	620	360	--	--	--	--	--	--	290000	210000	400	200
OCT												
19...	90	80	10	0	<50	4	<10	3	140	40	100	3
19...	570	540	20	10	750	61	30	33	300000	310000	300	300
DEC												
07...	90	70	--	--	--	--	--	--	70	40	<100	3
07...	540	540	--	--	--	--	--	--	300000	290000	300	350
FEB , 1977												
17...	60	65	--	--	--	--	--	--	120	0	<100	1
17...	580	600	--	--	--	--	--	--	310000	300000	400	450
APR												
21...	70	75	--	--	--	--	--	--	480	40	100	50
21...	580	610	--	--	--	--	--	--	280000	270000	400	400
JUN												
07...	70	80	10	10	<50	2	<10	1	300	70	0	0
07...	530	550	20	30	750	800	30	13	350000	53000	400	350

TABLE 8.—WATER-QUALITY DATA FROM CONSOLIDATED NO. 2 MINE SHAFT, APRIL 1976–JUNE 1977—*Continued*

DATE	DIS-SOLVED LITHIUM (LI) (UG/L)	TOTAL MAN-GANESE (MN) (UG/L)	DIS-SOLVED MAN-GANESE (MN) (UG/L)	TOTAL MERCURY (HG) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	TOTAL MOLYB-DENUM (MO) (UG/L)	DIS-SOLVED MOLYB-DENUM (MO) (UG/L)	TOTAL NICKEL (NI) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)	TOTAL SELE-NIUM (SE) (UG/L)	DIS-SOLVED SELE-NIUM (SE) (UG/L)	DIS-SOLVED VANA-DIUM (V) (UG/L)
APR , 1976												
20...	30	100	80	.8	.7	3	0	50	3	1	1	.1
21...	40	80	80	.2	.2	2	0	50	32	1	1	.1
21...	210	5800	5700	.4	.4	0	0	3300	3400	0	0	150
21...	220	6600	5900	.5	.6	0	0	3800	47	0	0	150
AUG												
25...	20	90	100	--	--	--	--	<50	10	--	--	.5
25...	120	6000	4200	--	--	--	--	3500	1500	--	--	--
OCT												
19...	30	40	30	.2	.4	0	0	50	39	1	1	1.0
19...	200	5500	5400	.2	.3	0	0	3500	3400	1	1	130
DEC												
07...	30	50	40	--	--	--	--	900	37	--	--	.0
07...	190	6000	50	--	--	--	--	6000	3300	--	--	60
FEB , 1977												
17...	40	60	60	--	--	--	--	50	36	--	--	.0
17...	200	5600	5500	--	--	--	--	3400	3600	--	--	200
APR												
21...	40	100	100	--	--	--	--	50	55	--	--	.0
21...	190	5600	5100	--	--	--	--	3200	3200	--	--	110
JUN												
07...	20	160	160	.2	.0	1	0	<50	14	1	0	.0
07...	300	5400	5600	.1	.2	0	0	3500	3400	0	0	160

DATE	SAMP-LING DEPTH (FT)	TOTAL ZINC (ZN) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)	TOTAL ORGANIC CARBON (C) (MG/L)	METHY-LENE BLUE ACTIVE SUB-STANCE (MG/L)
APR , 1976					
20...	191	3000	3200	5.4	.10
21...	227	4900	4000	4.7	.00
21...	229	280000	310000	4.7	.10
21...	234	360000	380000	4.8	.10
AUG					
25...	165	2200	2200	--	--
25...	230	300000	150000	--	--
OCT					
19...	165	3900	3900	1.7	.00
19...	230	290000	290000	.9	.00
DEC					
07...	165	30000	3500	--	--
07...	230	280000	280000	--	--
FEB , 1977					
17...	165	3300	3300	--	--
17...	230	300000	300000	--	--
APR					
21...	165	--	4200	--	--
21...	230	--	292000	--	--
JUN					
07...	165	2100	2100	.7	.00
07...	230	310000	310000	1.0	.00

TABLE 9.—CHEMICAL AND PHYSICAL PROPERTIES OF MINE-SHAFT WATER DETERMINED AND MAXIMUM, MINIMUM, MEAN, AND 50TH PERCENTILE VALUES

Chemical or physical property	Number of analyses	Values			
		Maximum	Minimum	Mean	50th Percentile
Acidity (as $CaCO_3$) (mg/L)	66	1,340	0	465	320
Alkalinity (as $CaCO_3$) (mg/L)	77	308	0	61	23
Aluminum, dissolved (ug/L)	77	42,000	0	4,880	460
Aluminum, total (ug/L)	77	280,000	10	9,040	1,700
Ammonia, dissolved, as N (mg/L)	44	.65	.00	.21	.18
Arsenic, dissolved (ug/L)	44	11	0	2.2	1.0
Arsenic, total (ug/L)	44	14	0	2.8	1.6
Barium, dissolved (ug/L)	44	600	0	55	0
Barium, total (ug/L)	44	600	0	50	0
Bicarbonate (mg/L)	77	375	0	75	33
Boron, dissolved (ug/L)	77	560	30	150	140
Boron, total (ug/L)	77	1,700	50	280	200
Cadmium, dissolved (ug/L)	77	1,200	1	240	80
Cadmium, total (ug/L)	77	1,100	10	310	180
Calcium, dissolved (mg/L)	77	600	120	395	480
Carbon, total organic (mg/L)	44	8.0	.0	2.6	2.1
Carbonate (mg/L)	77	0	0	0	0
Chloride, dissolved (mg/L)	77	85	.5	11.8	6.3
Chromium, dissolved (ug/L)	44	140	0	20	16
Chromium, total (ug/L)	44	150	0	22	17
Cobalt, dissolved (ug/L)	44	800	0	160	50
Cobalt, total (ug/L)	44	850	50	340	200

TABLE 9.—CHEMICAL AND PHYSICAL PROPERTIES OF MINE-SHAFT WATER DETERMINED AND MAXIMUM, MINIMUM, MEAN, AND 50TH PERCENTILE VALUES—*Continued*

Chemical or physical property	Number of analyses	Values			
		Maximum	Minimum	Mean	50th Percentile
Copper, dissolved (ug/L)	44	260	1	40	8
Copper, total (ug/L)	44	240	10	45	20
Detergents (MBAS) (mg/L)	44	.80	.00	.06	.00
Dissolved Solids, residue at 180°C (mg/L)	74	5,920	622	4,000	3,410
Fluoride, dissolved (mg/L)	77	15	.1	3.3	1.9
Hardness, noncarbonate (mg/L)	77	2,500	250	1,480	1,800
Hardness, total (mg/L)	77	2,500	410	1,540	1,800
Iron, dissolved (ug/L)	77	330,000	0	88,000	39,000
Iron, total (ug/L)	77	150,000	0	110,000	52,000
Lead, dissolved (ug/L)	77	500	0	135	63
Lead, total (ug/L)	77	500	0	220	310
Lithium, dissolved (ug/L)	77	300	20	123	130
Magnesium, dissolved (mg/L)	77	290	13	133	134
Manganese, dissolved (ug/L)	77	14,000	10	3,000	1,870
Manganese, total (ug/L)	77	15,000	10	3,370	2,400
Mercury, dissolved (ug/L)	44	1.30	.0	.31	.22
Mercury, total (ug/L)	44	1.40	.0	.33	.20
Molybdenum, dissolved (ug/L)	44	2	0	0	0
Molybdenum, total (ug/L)	44	3	0	0	0
Nickel, dissolved (ug/L)	77	5,000	3	1,510	600
Nickel, total (ug/L)	77	8,000	50	1,800	1,000

TABLE 9.—*Continued*

Chemical or physical property	Number of analyses	Values			
		Maximum	Minimum	Mean	50th Percentile
Nitrate, dissolved, as N (mg/L)	44	0.42	0.00	0.08	0.04
Nitrite, dissolved, as N (mg/L)	44	.04	.00	.00	.00
pH (field measured) (units)	147	8.6	3.4	--	6.4
Potassium, dissolved (mg/L)	77	9.2	1.3	4.0	3.8
Selenium, dissolved (ug/L)	44	3	0	1	1
Selenium, total (ug/L)	44	3	0	1	1
Silica, dissolved (mg/L)	77	22	4.9	11.7	11.7
Sodium adsorption ratio	77	25	.1	.6	.5
Sodium, dissolved (mg/L)	77	200	7.1	54	44
Sodium, percent	77	26	1.0	7.4	6.0
Specific conductance (field measured) (umhos/cm at 25°C)	139	4,950	740	2,680	2,800
Sulfate, dissolved (mg/L)	77	3,500	320	1,950	2,070
Suspended solids, residue at 110°C (mg/L)	76	216	0	61	20
Turbidity (NTU)	77	400	0	65	23
Vanadium, dissolved (ug/L)	74	200	.0	34	1.0
Water temperature (field measured) (degrees Celsius)	149	18,0	13.0	15.5	15.0
Zinc, dissolved (ug/L)	77	490,000	640	175,000	103,000
Zinc, total (ug/L)	74	490,000	730	108,000	106,000

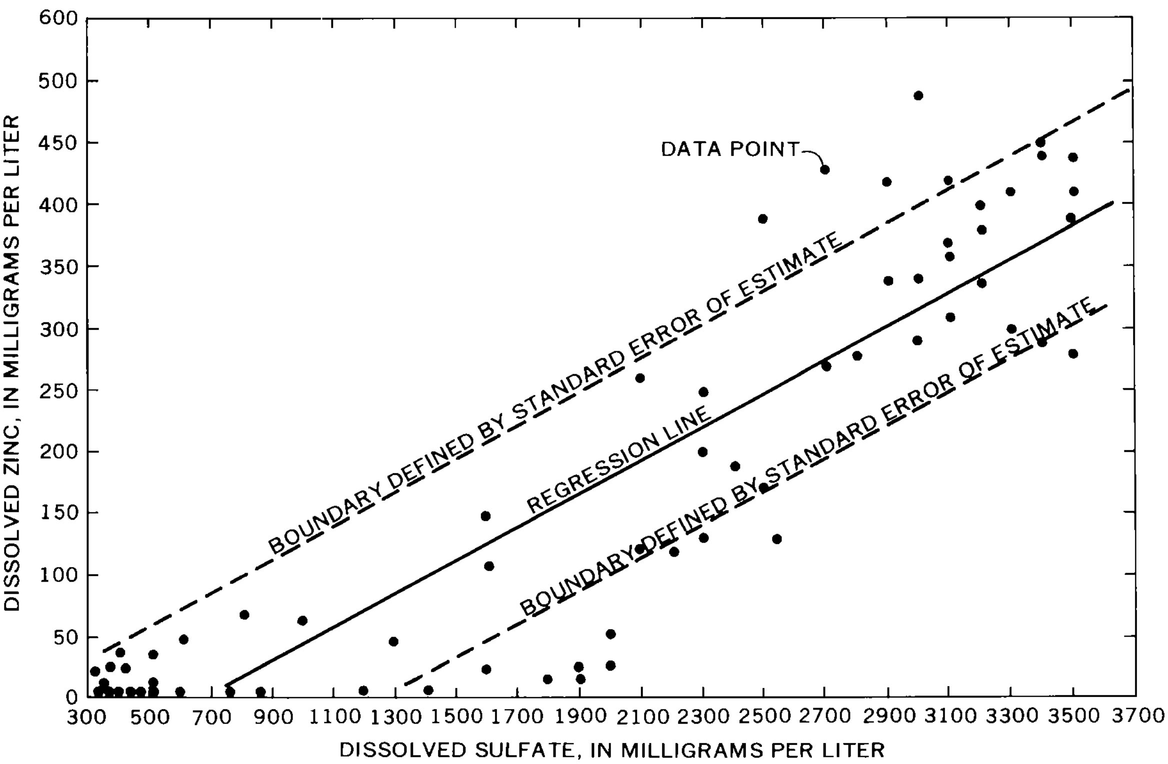


Figure 12. Graph showing relationship of dissolved zinc concentration to dissolved sulfate concentration of mine-shaft water.

TABLE 10.—CHEMICAL AND PHYSICAL PROPERTIES OF MINE-SHAFT WATER ANALYZED FOR LINEAR RELATIONSHIP WITH SPECIFIC CONDUCTANCE, AND REGRESSION SUMMARY, INCLUDING CORRELATION COEFFICENTS, INTERCEPTS, SLOPES, AND STANDARD ERRORS OF ESTIMATE

Chemical or physical property	Units	Correlation coefficient	Intercept	Slope	Standard error of estimate
Boron, dissolved	ug/L	0.35	69	0.03	103
Calcium, dissolved	mg/L	.88	119	.09	69
Chloride, dissolved	mg/L	.16	5.3	.002	19
Dissolved Solids	mg/L	.98	-633	1.31	327
Fluoride, dissolved	mg/L	.61	-1.3	.002	2.8
Hardness, total	mg/L	.94	110	.49	245
Lithium, dissolved	ug/L	.86	-22	.05	39
Magnesium, dissolved	mg/L	.92	-47	.06	36
pH	units	.64	7.6	.0005	.8
Potassium, dissolved	mg/L	.27	3.0	.0004	1.7
Silica, dissolved	mg/L	.13	13	.0004	3.7
Sodium, dissolved	mg/L	.39	17	.01	.39
Sulfate, dissolved	mg/L	.95	-362	.80	336

TABLE 11.—CHEMICAL AND PHYSICAL PROPERTIES OF MINE-SHAFT WATER ANALYZED FOR LINEAR RELATIONSHIP WITH pH, AND REGRESSION SUMMARY, INCLUDING CORRELATION COEFFICIENTS, INTERCEPTS, SLOPES, AND STANDARD ERRORS OF ESTIMATE

Chemical or physical property	Units	Correlation coefficient	Intercept	Slope	Standard error of estimate
Aluminum, dissolved	ug/L	-0.69	35,300	-5,060	6,099
Bicarbonate	mg/L	.60	-234	51	78
Boron, dissolved	ug/L	-.08	198	-7.28	110
Fluoride, dissolved	mg/L	-.57	13.8	-1.75	2.85
Hardness, total	mg/L	-.60	3,744	-367	562
Iron, dissolved	ug/L	-.44	337,143	-41,485	95,533
Lithium, dissolved	ug/L	-.64	383	-43	59
Manganese, dissolved	ug/L	-.48	11,023	-1,335	2,816
Nickel, dissolved	ug/L	-.55	6,182	-776	1,326
Specific conductance	umhos/cm at 25°C	-.64	7,425	-770	989
Sulfate, dissolved	mg/L	-.66	5,838	-647	835
Zinc, dissolved	ug/L	-.64	759,476	-97,270	132,913

TABLE 12.—CHEMICAL CONSTITUENTS OF MINE-SHAFT WATER ANALYZED FOR LOGARITHMIC RELATIONSHIP WITH pH, AND REGRESSION SUMMARY, INCLUDING CORRELATION COEFFICIENTS, INTERCEPTS, SLOPES, AND STANDARD ERRORS OF ESTIMATE

Constituent	Correlation coefficient	Intercept	Slope	Standard error of estimate
Aluminum, dissolved	-0.86	19.66	-2.199	1.396
Iron, dissolved	-.65	21.64	-2.174	2.889
Manganese, dissolved	-.67	14.24	-1.238	1.535
Nickel, dissolved	-.75	14.56	-1.420	1.420
Zinc, dissolved	-.81	19.39	-1.406	1.153

TABLE 13.—CHEMICAL CONSTITUENTS OF MINE-SHAFT WATER ANALYZED FOR LINEAR RELATIONSHIP WITH DISSOLVED SULFATE CONCENTRATION, AND REGRESSION SUMMARY, INCLUDING CORRELATION COEFFICIENTS, INTERCEPTS, SLOPES, AND STANDARD ERRORS OF ESTIMATE

Constituent	Units	Correlation coefficient	Intercept	Slope	Standard error of estimate
Aluminum, dissolved	ug/L	0.44	-1,514	3.279	7,556
Iron, dissolved	ug/L	.79	-58,787	75.13	66,020
Manganese, dissolved	ug/L	.76	-1,281	2.192	2,069
Zinc, dissolved	ug/L	.88	-92,278	136.89	81,846

TABLE 14.—CHEMICAL CONSTITUENTS OF MINE-SHAFT WATER ANALYZED FOR LOGARITHMIC RELATIONSHIP WITH DISSOLVED SULFATE CONCENTRATION, AND REGRESSION SUMMARY, INCLUDING CORRELATION COEFFICIENTS, INTERCEPTS, SLOPES, AND STANDARD ERRORS OF ESTIMATE

Constituent	Correlation coefficient	Intercept	Slope	Standard error of estimate
Aluminum, dissolved	0.76	2.367	0.0020	1.8121
Iron, dissolved	.79	3.288	.0027	2.3380
Manganese, dissolved	.83	3.773	.0016	1.1648
Zinc, dissolved	.86	7.963	.0015	1.0006

in the mined areas of Joplin were contaminated by mine water. After equilibrium water-level conditions are reached, the same possibility for stream contamination by mine water exists in the study area of this report.

At this time the quantity of water and the direction of water movement in the mined area of the Boone Formation in northeastern Oklahoma and southeastern Kansas can only be speculated. The possible directions of movement of the mine water after equilibrium water-level conditions are reached are not fully understood, although, regionally, the drainage is toward the southeast and southwest. Because of the possibilities of contamination of presently used water supplies by highly mineralized mine water, further study of the movement of water within the Boone Formation throughout the mined areas is warranted.

SUMMARY

This study was undertaken to determine the suitability for selected uses of water stored in abandoned zinc mines in northeastern Oklahoma and southeastern Kansas. Phase I consisted of a reconnaissance sampling survey of the water in selected mine shafts, and has been reported by Playton and Davis (1977). Phase II consisted of bimonthly sampling of the water in selected

TABLE 15.—CHEMICAL AND PHYSICAL PROPERTIES OF MINE-SHAFT WATER WITH OBSERVED VALUES EXCEEDING RECOMMENDED LIMITS FOR PUBLIC WATER SUPPLY, AND PERCENTAGE OF SAMPLES WITH EXCESSIVE VALUES

Chemical or physical property	Recommended maximum value	Percent of samples with excessive values
Ammonia, dissolved, as N	0.5 mg/L[1]	11
Cadmium, dissolved	10 ug/L[2]	77
Chromium, total	50 ug/L[2]	11
Detergents (MBAS)	0.5 mg/L[3]	2
Fluoride, dissolved	2.0 mg/L for temp=15-18°C[2] 2.2 mg/L for temp=13-14°C[2]	
Iron, dissolved	300 ug/L[3]	62
Lead, dissolved	50 ug/L[2]	55
Manganese, dissolved	50 ug/L[3]	84
pH	5.0-9.0 units[4]	16
Sulfate, dissolved	250 mg/L[5]	100
Zinc, dissolved	5,000 ug/L[3]	83

1 — Limit set because constituent is indicative of pollution.
2 — Limit set because constituent causes adverse physiological effects.
3 — Limit set because constituent causes undesirable aesthetic or taste effects.
4 — Limits set because standard treatment practices become uneconomical outside stated range.
5 — Limit set, where water sources with lower sulfate concentrations are or can be made available, because of taste and laxative effects.

mine shafts over a period of 1 year in order to detect short-term variations of water quality.

The results indicate that, generally, the mine-shaft water is stratified. Specific conductance, water temperature, dissolved solids, total and dissolved metal concentrations, and dissolved sulfate tend to increase with sampling depths, while pH tends to decrease with increasing sampling depth. No areal trend or significant seasonal variations in water quality were detected.

Some chemical constituents and properties of the mine-shaft water—such as dissolved solids, total hardness, and dissolved sulfate, calcium, magnesium, and lithium—are significantly linearly correlated to specific conductance. No chemical constituent or property of mine-shaft water showed significant linear correlation to pH. However, dissolved aluminum, zinc, and nickel values, when transformed to natural or Napierian logarithms, are significantly linearly correlated to pH.

Water in the mine shafts is judged unsuitable for domestic supply, irrigation, and industrial cooling without treatment. Because of the presence of metals, such as cadmium and lead, in concentrations exceeding the limits recommended by the National Academy of Sciences and the National Academy of Engineering (1972), the water should not be considered as a source of public supply.

TABLE 16.—CHEMICAL AND PHYSICAL PROPERTIES OF MINE-SHAFT WATER WITH OBSERVED VALUES EXCEEDING RECOMMENDED LIMITS FOR FRESH, ONCE-THROUGH, INDUSTRIAL COOLING WATER, AND PERCENTAGE OF SAMPLES WITH EXCESSIVE VALUES

Chemical or physical property	Recommended maximum value	Percent of samples with excessive values
Acidity, total, as $CaCO_3$	0 mg/L	97
Aluminum, dissolved	3,000 ug/L	40
Calcium, dissolved	500 mg/L	23
Dissolved Solids, residue at 180°C	1,000 mg/L	78
Hardness, total, as $CaCO_3$	850 mg/L	73
Iron, dissolved	14,000 ug/L	56
Manganese, dissolved	2,500 ug/l	43
pH	5.0-8.9 units	16
Sulfate, dissolved	680 mg/L	75

TABLE 17.—CHEMICAL CONSTITUENTS AND PROPERTIES OF MINE-SHAFT WATER WITH OBSERVED VALUES EXCEEDING RECOMMENDED LIMITS FOR FRESH, MAKEUP-RECYCLE, INDUSTRIAL COOLING WATER, AND PERCENTAGE OF SAMPLES WITH EXCESSIVE VALUES

Chemical constituent or property	Recommended maximum value	Percent of samples with excessive values
Acidity, total, as $CaCO_3$	200 mg/L	55
Aluminum, dissolved	3,000 ug/L	40
Calcium, dissolved	500 mg/L	23
Dissolved Solids, residue at 180°C	1,000 mg/L	78
Hardness, total, as $CaCO_3$	850 mg/L	73
Iron, dissolved	80,000 ug/L	39
Manganese, dissolved	10,000 ug/L	3
Sulfate, dissolved	680 mg/L	75

TABLE 18.—CHEMICAL AND PHYSICAL PROPERTIES OF MINE-SHAFT WATER WITH OBSERVED VALUES EXCEEDING RECOMMENDED LIMITS FOR BRACKISH INDUSTRIAL COOLING WATER, AND PERCENTAGE OF SAMPLES WITH EXCESSIVE VALUES

Constituent or property	Recommended maximum value	Percent of samples with excessive values
Acidity, total, as $CaCO_3$	0 mg/L	97
Alkalinity, total, as $CaCO_3$	150 mg/L	14
Bicarbonate	180 mg/L	14
Iron, dissolved	1,000 ug/L	58
Manganese, dissolved	20 ug/L	95
pH	5.0-8.4 units	17
Sulfate, dissolved	2,700 mg/L	32

TABLE 19.—CHEMICAL CONSTITUENTS AND PROPERTIES OF MINE-SHAFT WATER WITH OBSERVED VALUES EXCEEDING RECOMMENDED LIMITS FOR IRRIGATION WATER, AND PERCENTAGE OF SAMPLES WITH EXCESSIVE VALUES

Constituent or property	Recommended maximum value	Percent of samples with excessive values
Aluminum, total	5,000 ug/L[1]	36
Boron, total	750 ug/L[1]	6
Cadmium, total	10 ug/L[1]	88
Chromium, total	100 ug/L[1]	5
Cobalt, total	50 ug/L[1]	68
Copper, total	200 ug/L[1]	2
Dissolved Solids, residue at 180°C	2,560 mg/L[2]	58
Fluoride, dissolved	1.0 mg/L[1]	69
Iron, total	5,000 ug/L[1]	60
Manganese, total	200 ug/L[1]	74
Nickel, total	200 ug/L[1]	69
Vanadium, dissolved	100 ug/L[1]	18
Zinc, total	2,000 ug/L[1]	97

1 — For water used continuously on all soils.
2 — Recommended limit for moderately salt-tolerant crops with an average of 3 irrigations between leaching rains.

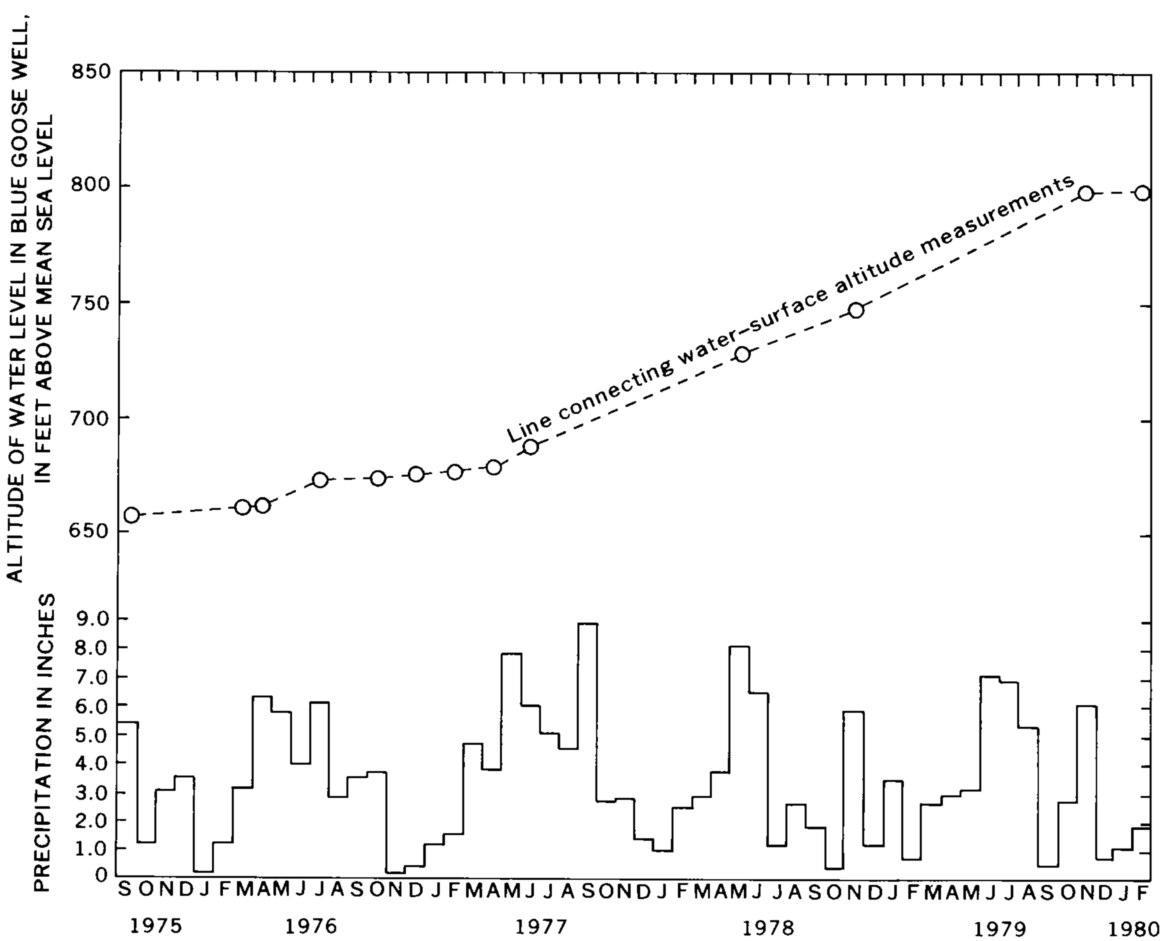


Figure 13. Graph showing measured water-surface altitude at Blue Goose well and monthly precipitation at Quapaw, Oklahoma, September 1976–February 1980.

Water levels within the mined areas have risen since cessation of mining and accompanying dewatering in the late 1950's. In the Blue Goose well the water level rose at an average rate of 2.6 ft per month from September 1975 to February 1980, but it rose at a rate greater than average after periods of heavy rainfall and after the major mine workings were filled with water. The water level in the mines and the surrounding Boone Formation should be near the static or equilibrium level—probably the same level as before mining and dewatering. Highly mineralized mine water could possibly migrate into and contaminate the Roubidoux Formation, shallow aquifers, or surface water.

Further study of movement of water in the Boone Formation through the mined area is warranted, so that the quantity of mine water, the directions of its flow, and the consequences resulting from its movement can be adequately assessed.

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