WATER QUALITY OF COAL CREEK TRIBUTARIES
DRAINING AN EAGLE-PICHER SMELTER SITE
OKMULGEE COUNTY,
OKLAHOMA

By

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Thesis Approved:

Thesis Adviser

Dean of the Graduate College

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CHAPTER I

INTRODUCTION

Statement of the Problem

The objective of this investigation was to explore the effects of runoff from an abandoned Eagle-Picher smelter site on the water quality of the two unnamed tributaries (the northern and southern tributaries) of Coal Creek draining the smelter site. The effects of the runoff were evaluated as follows:

1. Results of this study were compared to historical laboratory analytical data from corresponding surface-water sample locations to determine whether significant changes occurred over approximately a ten-year period.

2. Measurements of pH, specific conductance, and total dissolved solids were evaluated for surface-water samples collected within the study area.

3. Potential chemical reactions and trends for major and minor constituents and trace constituents for both the southern and northern tributaries were evaluated.

Location

The abandoned Eagle-Picher zinc smelter site located between the cities of Henryetta and Dewar, Okmulgee County, Oklahoma (Figure 1) is drained by two unnamed tributaries of Coal Creek that flow south and north from the site. The study area is covered by a portion of the United States Geological Survey (USGS) 7.5-minute series Henryetta Quadrangle. More specifically, the southern portion of the study area is in the north half of Section 5 of Township 11 North, Range 13 East. The northern portion of the study area is situated in the west half of Section 32 and the southwest quarter of Section 29 of Township 12 North, Range 13 East (Figure 2).

The southern tributary flows southward from the smelter site and then east and adjacent to the north side of United States (U. S.) Highway 266. The confluence of the southern tributary with Coal Creek is approximately 3,000 feet east of the intersection of U. S. Highways 266 and 62 and 300 feet north of U. S. Highway 266 (Figure 2). The northern tributary flows northward from the smelter site and adjacent to the east side of U. S. Highway 62. The confluence of the northern tributary with Coal Creek is approximately 7,500 feet north of the highway intersection and 1,500 feet east of U. S. Highway 62 (Figure 2).

Tri-State Mining District

The Tri-State Mining District encompasses northeastern Oklahoma, southeastern Kansas, and southwestern Missouri. In 1933, the Tri-State District

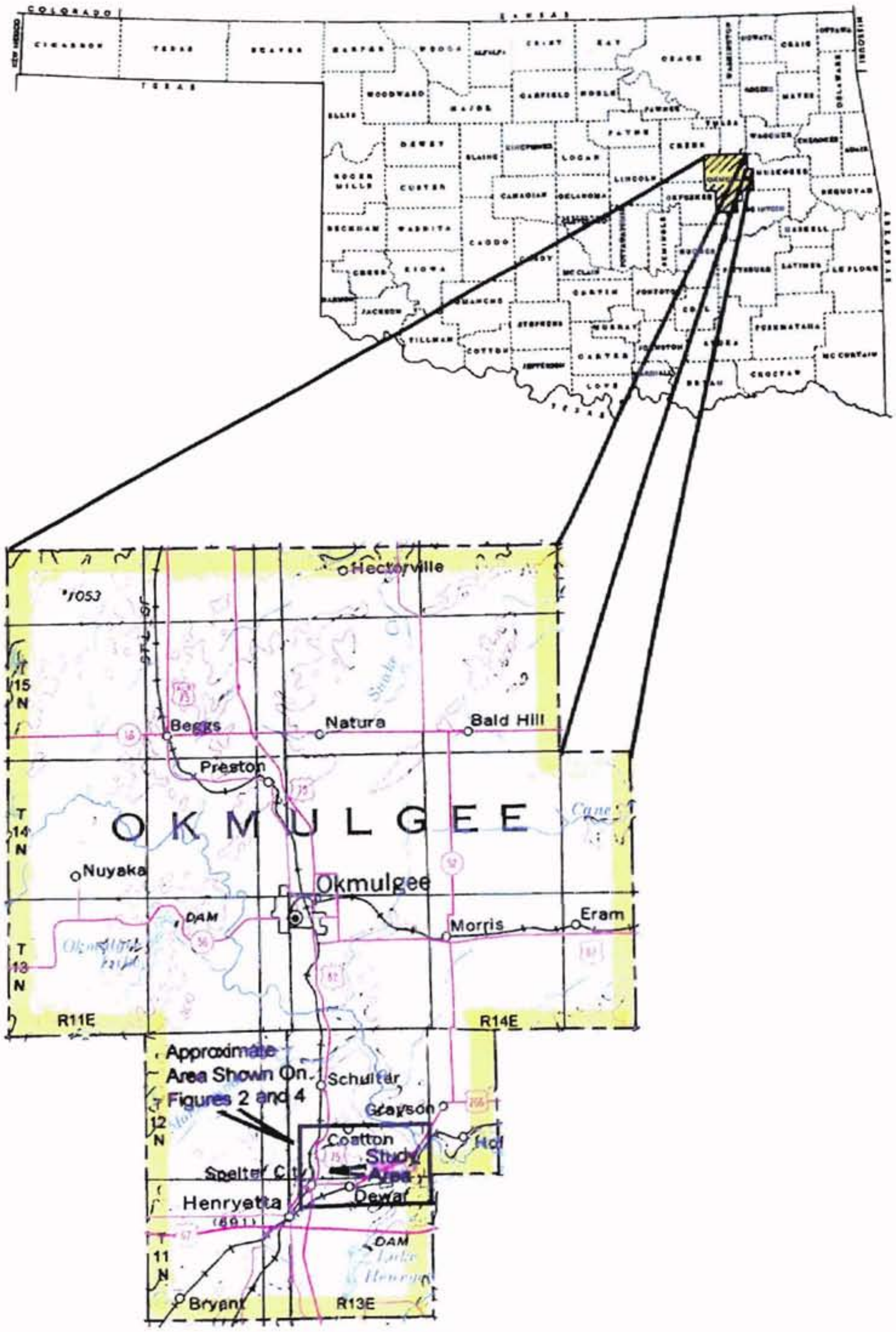


Figure 1. Regional Location Map (after U.S.G.S., State Map of Oklahoma, 1972)

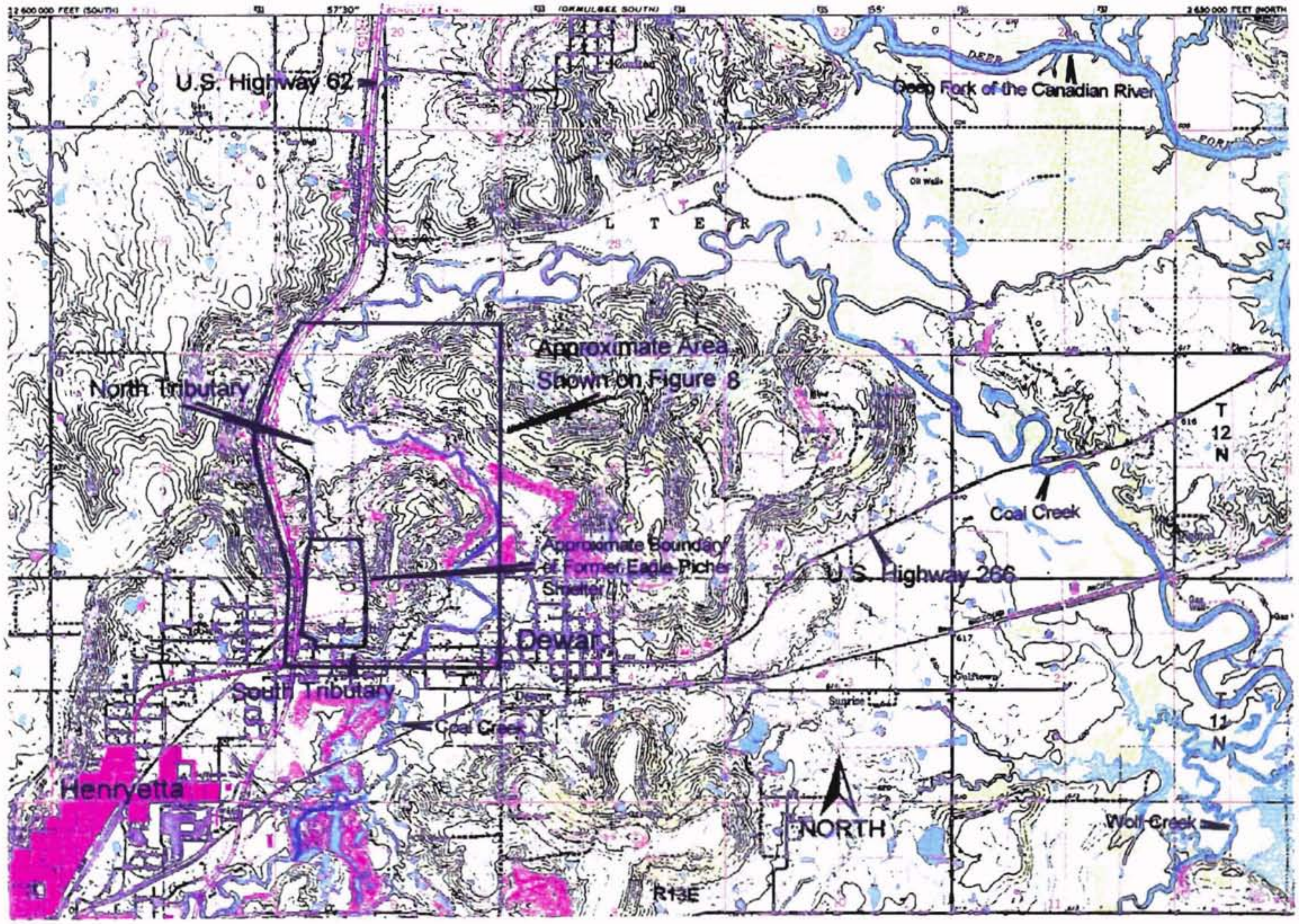


Figure 2. Study Area and Topographic Map (After U.S.G.S. Henryetta 7.5 Minute Quadrangle)

produced more than 40 percent of the zinc and 12 percent of the lead mined in the United States (Harbaugh, 1933). Practically all of the zinc and lead concentrates produced were processed in plants in Oklahoma, Kansas, Arkansas, Illinois, Indiana, Pennsylvania, and West Virginia (Harbaugh, 1933). In Oklahoma, three plants were constructed between 1907 and 1908, and 11 plants were constructed between 1910 and 1917 (Mower, 1959). By 1959, only three of the 14 plants were in operation. These were located in Blackwell, Bartlesville, and at the Eagle-Picher plant in Henryetta, Oklahoma (Figure 3). The Eagle-Picher plant in Henryetta was operated from 1916 (Mower, 1959) through 1968 (EPA, 1988).

The following is a partial list of minerals associated with ores in the Tri-State Mining District:

Anglesite	$PbSO_4$	Aragonite	$CaCO_3$
Barite	$BaSO_4$	Calamine	$(ZnOH)_2 SiO_3$
Calcite	$CaCO_3$	Chalcopyrite	$CuFeS_2$
Dolomite	$(Ca,Mg)CO_3$	Enargite	Cu_3AsS_4
Galena	PbS	Greenockite	CdS
Marcasite	FeS_2	Melanterite	$FeSO_4 + 7H_2O$
Pyrite	FeS_2	Quartz	SiO_2
Smithsonite	$ZnCO_3$	Sphalerite	ZnS

The partial list is compiled from work published by Samuel Wiedman (1932) and Edwin T. McKnight and Richard P. Fisher (1970).

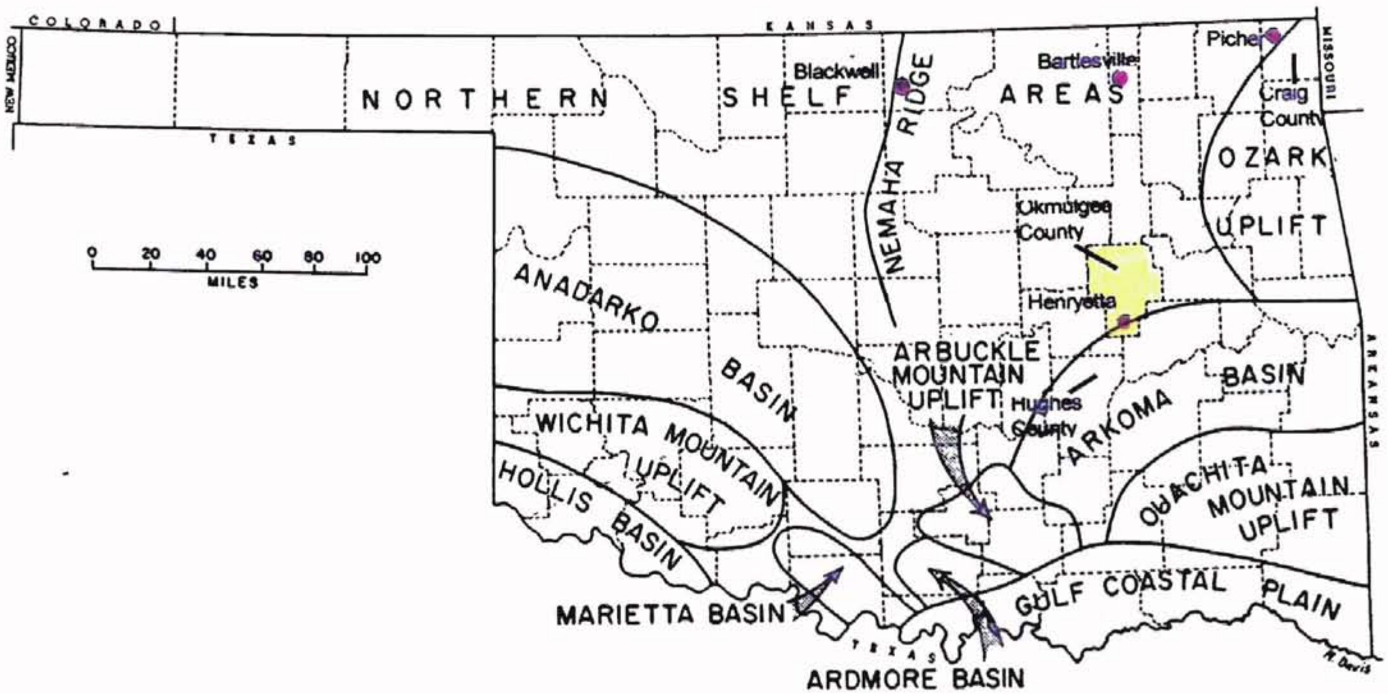


Figure 3. Map Showing Geologic Provinces of Oklahoma
(After Johnson and Denison, 1973)

Marcasite specimens were reported to contain from 0.06% to 0.09% nickel (Barrett, 1940). Pyrite specimens had nickel concentrations of as much as 0.18% (McKnight and Fisher, 1970). Sphalerite specimens reportedly had cadmium concentrations that ranged from 0.035% (Weidman, 1932) to 1.4% (McKnight and Fisher, 1970). Additionally, trace concentrations of iron, copper, lead, titanium, manganese, silver, gallium, cobalt, barium, and indium were associated with shell boundaries of sphalerite species (McKnight and Fisher, 1970). The minerals listed above are assumed to be the source, in part, for concentrations of 13 dissolved metals and 16 total metals detected in surface-water samples collected from the northern and southern unnamed tributaries draining the smelter site.

Site Background

The Henryetta Zinc Smelter, owned by the Picher Lead Company, was brought on line in 1916. The Picher Lead Company, and the Eagle White Lead Company merged on June 1, 1916 to form the Eagle-Picher Lead Company. In 1945, the name was changed to the Eagle-Picher Company (Mower, 1959).

Smelting activities at the Henryetta plant included the roasting, sintering, and distillation processes from 1916 through 1955 (Mower, 1959). During the roasting process, ore concentrate (predominately sphalerite) was heated in furnaces in the presence of oxygen to form zinc oxide called calcine and sulfur dioxide gas (Mower, 1959). Next, the calcine powder was mixed with about 10%

coal. During the sintering process, the mixture was placed on slowly moving pallets, passed through a combustion area to ignite the coal, and then fed into an oven where the heat from the burning coal caused the fine calcine particles to fuse forming sinter cake (Mower, 1959). The sinter cake was then ground to the proper size, and mixed with about 20% coal with a small amount of water, and 0.5% salt. This mixture was then placed in retorts (clay cylinders approximately 60 inches in length with an internal diameter of 9 inches) within a furnace (Mower, 1959). Each furnace contained several hundred retorts. During the distillation process, the temperature within the furnace was increased to approximately 1,400 degrees centigrade. Zinc vapor produced at this high temperature passed from the retort to a condenser where liquid zinc was collected. By 1955, the Henryetta plant had furnaces for approximately 8,800 retorts (Mower, 1959).

Gases produced during the roasting and sintering processes typically contained concentrations of sulfur dioxide, cadmium, arsenic, antimony, bismuth, and lead. These gases generally were discharged to the atmosphere (Mower, 1959), and resulted in a particulate plume that generally extended northeast from the smelter. The roasting and sintering processes, along with the sulfuric acid production and cadmium recovery, were transferred to a Galena, Kansas plant in 1955 (Mower, 1959). Slag, residue from the smelting process, was removed from the retorts and either processed for precious metals or discarded on the smelter property.

Slag, mixed with retort shards and fire-brick, now covers approximately 30 acres on the former Eagle-Picher property. The slag ranges in thickness from less than one foot on the east side of the site to greater than 15 feet on the west side of the site near U. S. Highway 62 (Figure 2). The slag pile is porous and allows for rapid percolation of storm-water to the underlying soil or to Pennsylvanian strata. Water that has percolated through the slag discharges at the margins of the slag pile to two unnamed tributaries of Coal Creek.

During operation of the Eagle-Picher Smelter, several companies were mining the Croweburg Coal (Henryetta Coal) beneath the smelter property and beneath surrounding properties. The larger mines included the Dewar Coal Company, Big Four Coal Company, Blackstone Coal and Mining Company, Starr Coal Company, and the Cado Coal Company. The Croweburg Coal was accessed by shafts ranging in depths from approximately 110 to 133 feet (Dunham and Trumbull, 1955).

The Dewar Coal Company mined in the northern half of Section 5, Township 11 North, Range 13 East and the southern half of Section 32, Township 12 North, Range 13 East (Dunham and Trumbull, 1955; and State of Oklahoma Department of Mines, 1992). The Big Four and Blackstone Coal and Mining Company were active in the eastern half of Section 30 and the western half of the western half of Section 32, Township 12 North, Range 13 East (Dunham and Trumbull, 1955). The Starr Coal Company was active in the southwestern quarter of Section 29 and the northern half of Section 32, Township 12 North, Range 13 East (Dunham and Trumbull, 1955). The Cado Coal Company mined in the eastern half of Section 6 and the northwestern quarter of Section 5, Township 11 North, Range 13 East (Dunham and Trumbull, 1955; and State of Oklahoma Department of Mines, 1992). Approximate locations of the mines are shown in Figure 4.

Previous Investigations

Geological investigations into the coal resources of the area were conducted by Chance (1890), Drake (1896) and Dunham and Trumbull (1955). Culp (1955) reported on the roadside geology of Okmulgee County. Logan (1957) reported on oil and gas production in Okmulgee County.

Oakes (1963), Marcher (1969) and Bingham (1975) conducted investigations into the geology and water resources of the area. These investigations contained limited climatological and water-quality data.

Mower (1959) investigated the zinc-smelting industry of Oklahoma, which included the Eagle-Picher smelter located in Henryetta. Investigations into the toxicity of the sediment, soil and surface-water of the abandoned Eagle-Picher smelter property were conducted by the Oklahoma Water Resources Board (1989) and the Environmental Protection Agency (1983, 1987, 1988, and 1990).

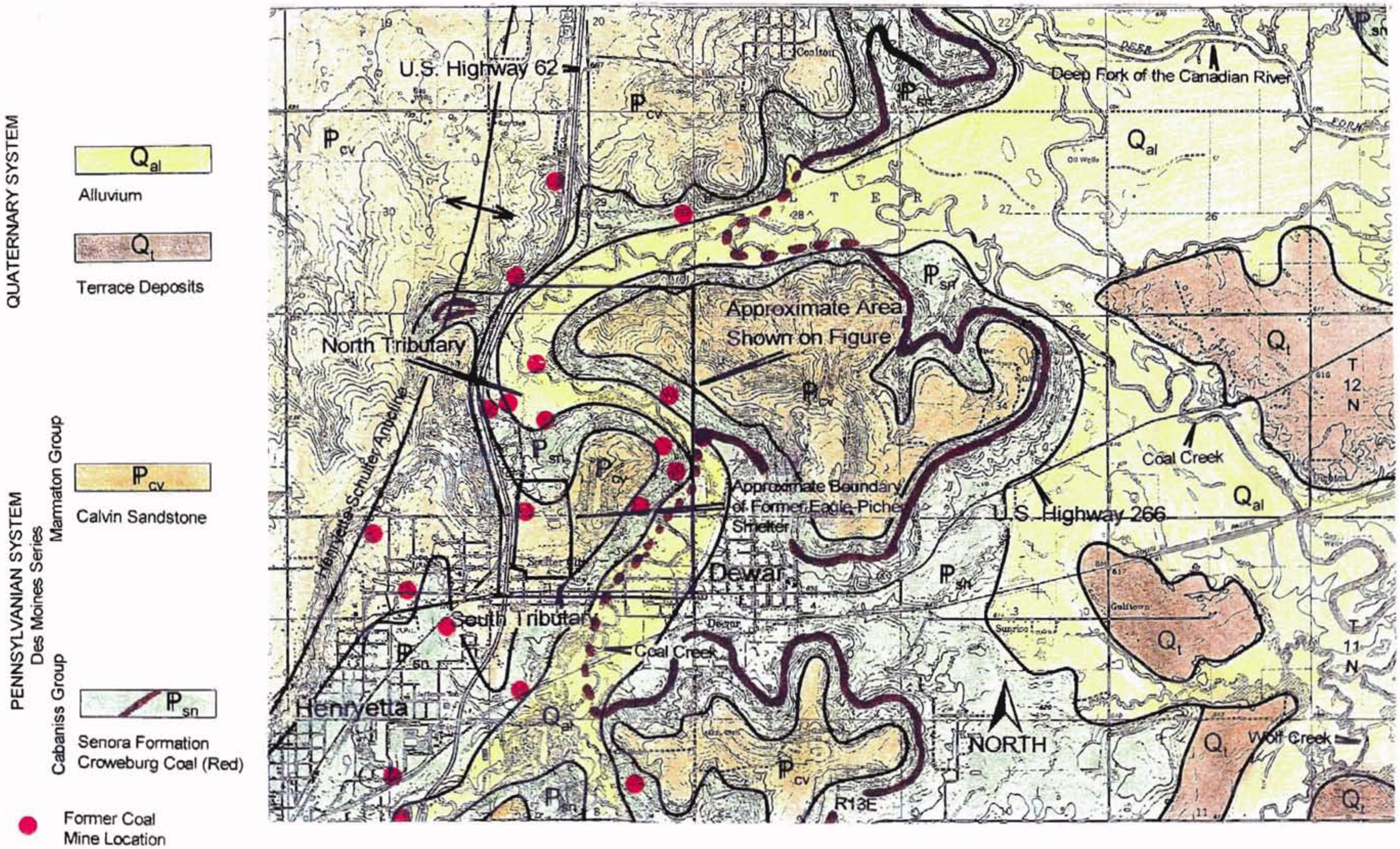


Figure 4. Geologic and Topographic Map (After Dunham and Trumbull, 1955, and Oakes and Motts, 1963)

CHAPTER II

PHYSIOGRAPHY AND GEOLOGY

Topography

The southernmost portion Okmulgee County, Townships 11 and 12 North, Ranges 12 and 13 East where the study area is located, is within the drainage basin of the Deep Fork of the Canadian River (Figure 2). The Deep Fork occupies an alluvial valley that is approximately two miles wide and flows in a southeasterly direction through Township 12 North, Range 13 East. Tributaries of the Deep Fork in this area generally flow in a northeasterly direction to the confluence with the Deep Fork. The tributaries and their branches form a dendritic to sub-rectangular drainage pattern.

This area of Okmulgee County is characterized by cuestas that trend North 30° East, separated by valleys that are one-half mile to one mile wide. The cuestas are capped with erosion-resistant sandstones overlying less resistant shales. Sandstones and shales generally dip North 60° West at an average of about 60 feet per mile.

Topographic relief in the study area is approximately 250 feet, measured from the top of a sandstone-capped butte on the east side of the northern unnamed tributary (860 feet above mean sea level (AMSL)) in the southeast quarter of

Section 32, Township 12 North, Range 13 East to the confluence of the northern unnamed tributary and Coal Creek (610 feet AMSL) in the southwest quarter of Section 29, Township 12 North, Range 13 East. The maximum topographic relief in the four townships surrounding the study area is approximately 390 feet. The elevations range from approximately 600 feet AMSL on the alluvial plain of the Deep Fork of the Canadian River in Township 12 North, Range 13 East to 990 feet AMSL in Section 34, Township 12 North, Range 12 East.

Soils

Soils of the study area are comprised of the Bates-Collinsville fine sandy loam, Collinsville-Talihina complex, Dennis silt loam, Hector complex, and Lightning silt loam. The soil in the central portion of the study area, denuded of vegetation by of fumes and toxic residues from smelter operations, is classified as Smelter-waste land (Sparwasser, 1968).

The Bates-Collinsville fine sandy loam is in the extreme southwestern portion of the study area. This complex consist of 40 to 60 percent Bates fine sandy loam, 30 to 50 percent Collinsville fine sandy loam, and 5 to 10 percent Bates loam. The soil is 10 to 20 inches deep, gently sloping, and formed from weathered sandstone. The Bates-Collinsville fine sandy loam is porous, moderately acidic, and is moderately fertile. Water-holding capacity is limited due to the shallow depth to bedrock (about 38 inches).

Collinsville-Talihina complex is along the southern unnamed tributary in the study area. This complex consist of 60 to 70 percent Collinsville fine sandy loam and 30 to 40 percent Talihina clay with slopes of 10 to 30 percent. Soil of this series is very stony.

Denis silt loam is in the extreme southeastern portion of the study area, adjacent to Coal Creek. Dennis silt loam is deep and moderately acidic (pH of 5.6 to 6.0). The soil is grayish brown silt loam approximately 12 inches thick, brown heavy silt loam four inches thick and mottled light yellowish brown to brownish yellow clay loam to a depth of 36 inches. Slopes range from one to three percent.

Hector complex is on the butte in the eastern and northern portion of the site. Hector soil is thin (five to six inches) and consists of grayish brown stony sandy loam and light yellowish brown fine sandy loam, with fragments of sandstone. The soil forms from the detritus of weathered sandstones. Slopes range from five to 30 percent.

Lightning silt loam is in the extreme northern portion of the study area, adjacent to Coal Creek. This soil type is in bottom lands that are occasionally flooded. The soil consists of approximately 11 inches of gray silt loam, nine inches of gray silty clay loam, 16 inches of gray clay and dark gray clay below 36 inches. Slopes range from zero to one percent.

Stratigraphy

Rocks exposed in the area of study are included in the Des Moines Series of the Pennsylvanian System. The Des Moines Series is further divided into the Krebs, Cabaniss and the Marmaton Groups in ascending order.

The Cabaniss Group, which consists of the Thurman Sandstone, Stuart Shale and Senora Formation in ascending order, is conformable with the overlying Marmaton Group and unconformable with the underlying Krebs Group. The oldest formation outcropping in the area of study is the Senora Formation (Figure 4).

The Senora Formation crops out in a band that extends from the northeastern border of Oklahoma in Craig County to Hughes County in southeastern Oklahoma (Figure 3). This exposure of Senora Formation extends from the area of study, east for 12 miles to the Okmulgee County line, and then three miles east into Muskogee County. The maximum thickness in the area of study is approximately 800 feet (Oakes and Motts, 1963). The Senora Formation in southern Okmulgee County generally strikes North 30° East and dips North 60° West at an average of about 60 feet per mile.

The Senora Formation is divided by the Croweburg Coal (Henryetta Coal) into an upper portion approximately 220 feet thick and a lower portion approximately 580 feet thick. The Croweburg Coal is generally 30 to 36 inches thick and has been mined extensively in the Henryetta area (Oakes and Motts, 1963). Outcrop of the Croweburg Coal is shown in Figure 4. The lower portion of the Senora consists of silty-sandy shale, fine-grained sandstone and limestone. The upper portion consists of shale with lenses of silty sandstone. In the study area, shale of the upper portion of the Senora formation is exposed in the steam beds of the northern and southern unnamed tributaries of Coal Creek.

The Senora Formation is overlain by the Calvin Sandstone of the Marmaton Group. The contact is irregular, characterized by an interfingering of the discontinuous sandstones and shale. The Calvin Sandstone consists of silty shale inter-bedded with sandstone. The maximum thickness in southern Okmulgee County is 440 feet. Cuestas bounding the northern portion of the study area on the east and west are capped by resistant Calvin Sandstone (Marcher, 1988) as shown in Figure 4.

Structural Geology

The study area is situated 30 miles east of the Seminole arch, 55 miles southwest of the Ozark Uplift and approximately 15 miles northwest of the Arkoma Basin as shown in Figure 3. The most prominent structural feature in southern Okmulgee County is the Henryetta-Schulter Anticline. The anticline is approximately ten miles long and is one half to three fourths mile wide. The anticline extends from four miles south of Henryetta, through Henryetta to Schulter, Oklahoma (Figure 4). The anticline strikes North 30° East south of Henryetta and strikes North 15° East north of Henryetta. Strata are reported to dip one degree on the western flank and ten to 20 degrees on the eastern flank. The study area is one half mile east of the anticline.

CHAPTER III

HYDROGEOLOGY

Climate

The climate of Okmulgee County is warm and temperate. The National Oceanic and Atmospheric Administration (NOAA) reports a mean temperature of 59.4° Fahrenheit (F) for the years 1961 through 1990. During this same period of time, the normal maximum temperature was 71.9° F. and the normal minimum temperature was 46.6° F. The average annual precipitation was 39.46 inches, with the heaviest precipitation generally occurring during the months of April, May, and June. The data cited above was for the Okmulgee Water Works Station (0700 LT), Okmulgee, Oklahoma and is considered typical for Okmulgee County (NOAA, 1990).

The Oklahoma Climatological Survey (OCS) compiles precipitation data reported by the Dewar, Oklahoma station (station index 34-2485-6). This station is close to the study area. A summary of monthly precipitation data from January 1985 through August, 1992 (OCS, 1992), presented on Table 1, includes annual precipitation for years 1985 through 1991 and average monthly precipitation (eight year average from January through August and seven year average from

TABLE 1

SUMMARY OF MONTHLY PRECIPITATION FOR 1985 THROUGH 1992
STATION NAME : DEWAR, 2 NE
STATION INDEX NO: 34-2485-6

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1985	2.87	2.83	7.88	7.01	3.30	6.32	0.87	1.35	4.42	10.87	3.60	4.02	55.35
1986	0.00	1.91	2.45	5.89	7.28	2.83	0.59	3.32	7.53	11.05	3.58	0.99	47.43
1987	2.84	4.14	3.01	0.20	7.03	3.74	3.15	6.58	3.10	1.52	4.86	7.28	47.45
1988	1.21	1.19	6.38	3.42	0.88	1.62	9.57	0.79	4.98	1.57	4.13	1.91	37.65
1989	1.61	4.92	2.46	0.23	7.92	3.43	4.34	1.27	5.74	2.25	0.06	0.32	34.55
1990	4.76	3.79	8.82	9.18	10.37	0.50	4.35	2.85	6.87	1.96	3.35	3.05	59.85
1991	1.56	0.39	1.86	1.61	5.23	5.71	2.65	4.50	5.52	7.36	4.44	6.48	47.31
1992	1.06	0.67	2.23	4.70	4.19	5.61	6.89	5.28					
MONTHLY AVERAGE	1.99	2.48	4.39	4.03	5.78	3.72	4.05	3.24	5.45	5.23	3.43	3.44	

NOTE:
1. EIGHT -YEAR MONTHLY AVERAGE FROM JANUARY THROUGH AUGUST AND SEVEN-YEAR MONTHLY AVERAGE FROM SEPTEMBER THROUGH DECEMBER

September through December). Annual precipitation ranged from 34.55 (1989) to 59.85 (1990) inches. Average monthly precipitation ranged from 1.99 (January) to 5.78 (May) inches and is presented graphically on Figure 5. Monthly precipitation for years 1985 through 1988 is shown graphically in Figure 6 and the monthly precipitation for years 1989 through August, 1992 in Figure 7.

Surface-water

The study area is drained by two unnamed tributaries of Coal Creek. The confluence of the southern tributary with Coal Creek is approximately 3,000 feet east of the intersection of U. S. Highways 266 and 62 and 300 feet north of U. S. Highway 266. The northern tributary flows north from the smelter site and adjacent to the east side of U. S. Highway 62 as shown in Figures 2 and 8. The natural courses of the northern unnamed tributary and Coal Creek were modified during surface reclamation conducted during 1979 or 1980 as shown in Figure 8.

A canal was constructed from a point on Coal Creek approximately 500 feet east of the original confluence of the northern unnamed tributary and Coal Creek (approximately the center of the east half of the northwest quarter of Section 32, Township 12 North, Range 13 East), north approximately 1,900 feet to a point on Coal Creek near the center of the southeast quarter of the southwest quarter of Section 29, Township 12 North, Range 13 East (Figure 2). After the canal was completed, approximately 1,200 feet of Coal Creek channel was abandoned.

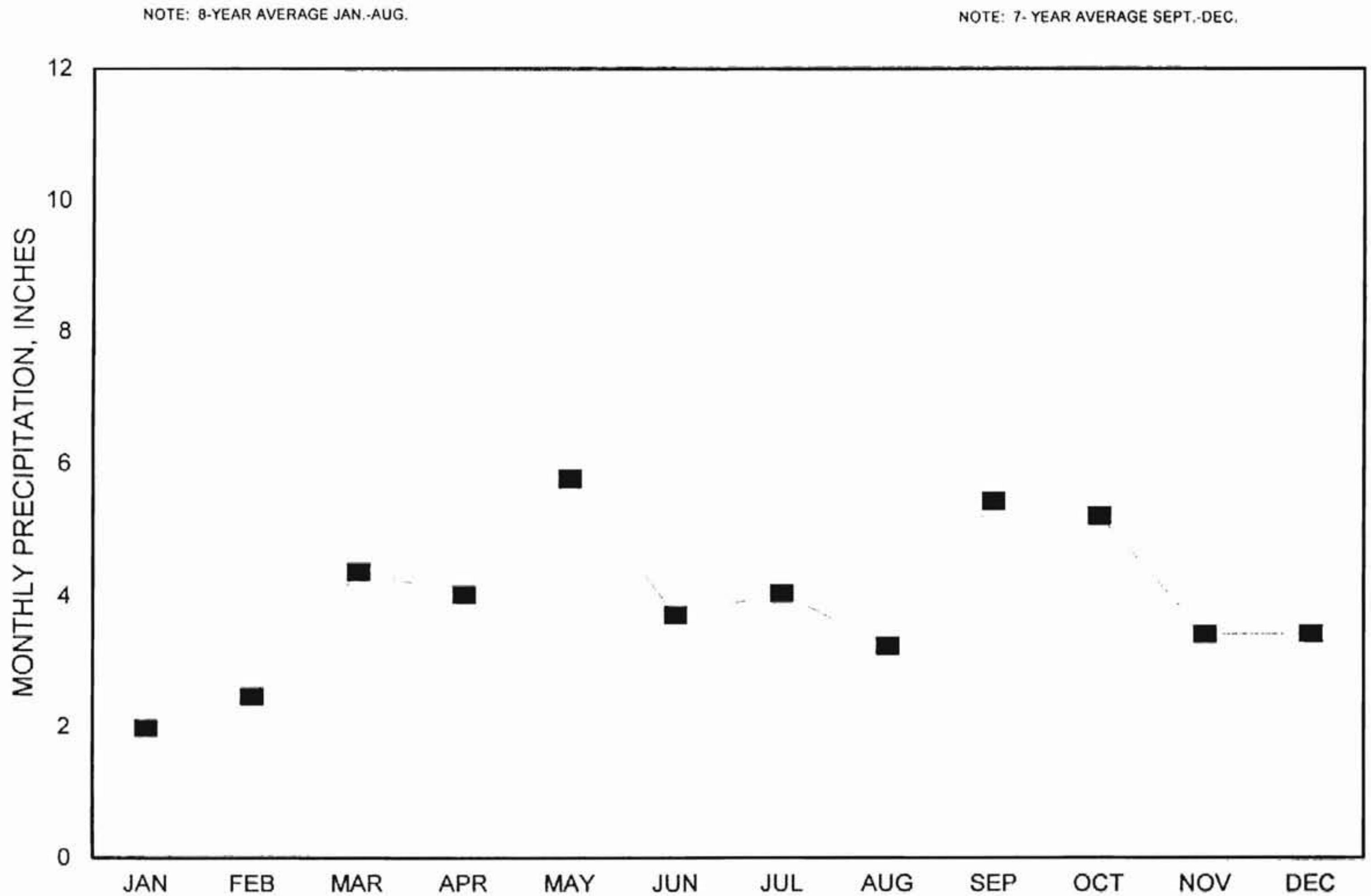


Figure 5. Average Monthly Precipitation, 1985-1992

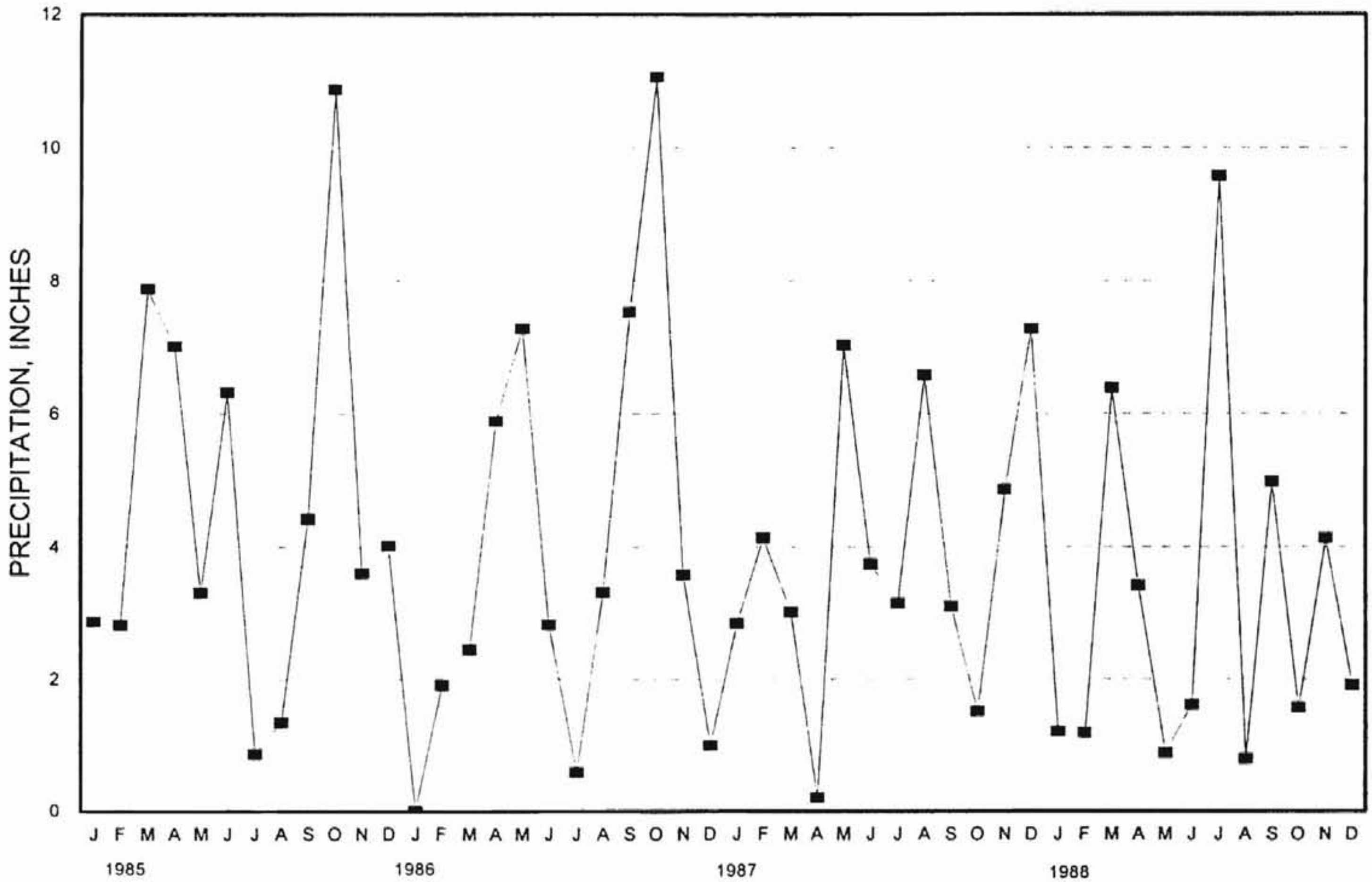


Figure 6. Precipitation, 1985-1989

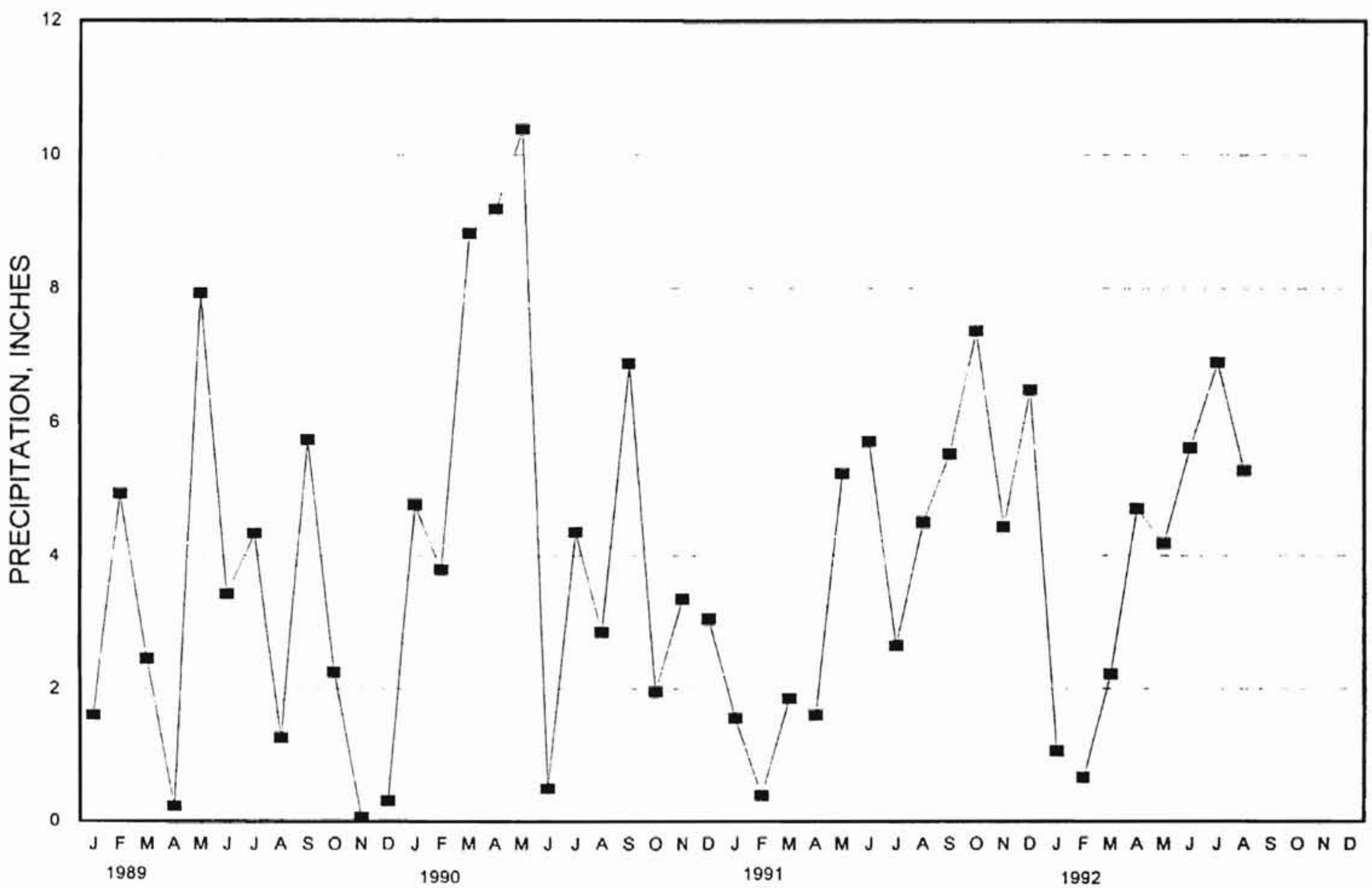


Figure 7. Precipitation, 1989-1992

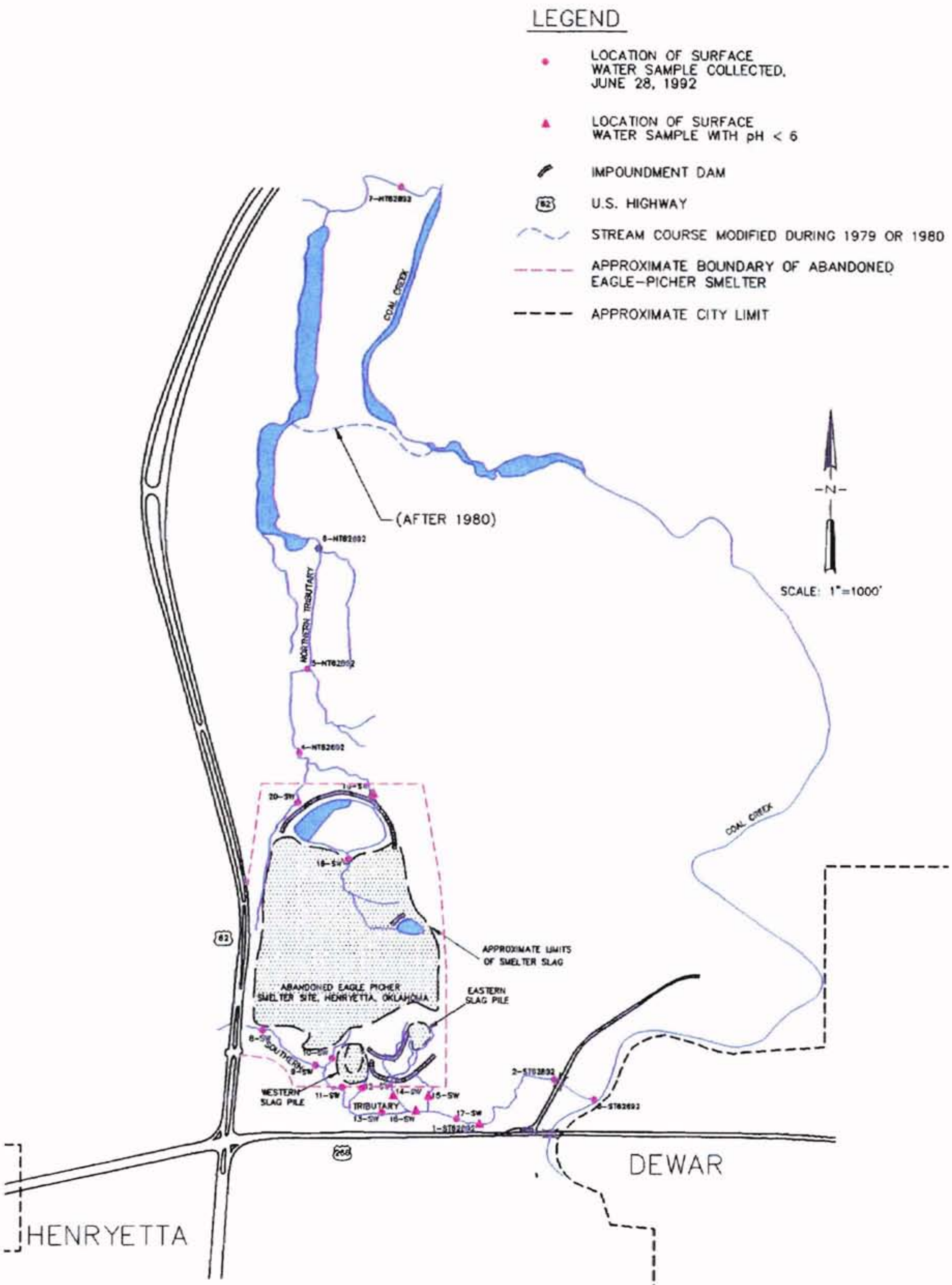


Figure 8. Study Area with Surface-Water Sample Locations

The northern unnamed tributary now occupies approximately 2,900 feet of the former Coal Creek channel. The new confluence of the northern tributary with Coal Creek is approximately 7,500 feet north of the intersection of U. S. Highways 62 and 266 and 1,500 feet east of U. S. Highway 62.

A dam was constructed on the northern unnamed tributary approximately 1,200 feet upstream from the new confluence. The resulting impoundment measures 150 feet from east to west and 2,050 feet from north to south (Figure 8). The surface reclamation is not shown on the Henryetta Quadrangle, photorevised in 1979. However, the surface reclamation is shown on a high-altitude aerial photograph dated April, 1980.

Perennial seeps and springs occur along the northern and southern margins of the smelter slag, and in each of the unnamed tributaries where sands and gravels thin, exposing the underlying shale of the Senora Formation. Alluvial fans, on the west side of a butte on the east side of the northern tributary (Figure 2), extend west to the northern tributary. During periods of heavy precipitation, springs flow in steep washes on the alluvial fans, and flow from the base of the fans to the northern tributary (between sample locations 5-NT62892 and 6-NT62892 shown in Figure 8). During periods of heavy precipitation, springs discharge from mixed alluvium and slag on the west side of the northern tributary (near sample location 4-NT62892) to the northern tributary. One spring emanates from the base of a dam of an impoundment (measuring 400 feet from north to south and 800 feet from east to west) along the northern limit of the smelter slag. The runoff from this spring flows into the northern unnamed tributary. Subsurface flow occurs in both unnamed tributaries where sands and gravels thicken along their courses.

The drainage area of Coal Creek is estimated to be 22.2 square miles at the point 2,000 feet south of the study area where the Union Pacific Railroad crosses Coal Creek (Federal Emergency Management Agency (FEMA), 1991). The peak discharges for 10-, 50-, and 100-year floods are estimated to be 9,300 cubic feet per second (cfs), 12,800 cfs, and 14,500 cfs, respectively (FEMA, 1991).

Coal Creek bifurcates approximately 2.5 miles northeast of the study area in Section 27 of Township 12 North, Range 13 East. Most of the steam flow from the bifurcation is toward the confluence with Wolf Creek approximately three miles to the south in Section 1, Township 11 North, Range 13 East. The confluence of Wolf Creek and Deep Fork of the Canadian River is in Section 32, Township 12 North, Range 14 East.

A smaller portion of the steam flow from the bifurcation is towards the confluence with Deep Fork approximately one mile to the north in Section 22, Township 12 North, Range 13 East.

Groundwater

Groundwater present in alluvium deposited along the Deep Fork of the Canadian River drainage and associated tributaries, and in Pennsylvanian bedrock throughout Okmulgee County. Groundwater resources in Okmulgee County generally support stock and some domestic uses (Oakes and Motts, 1963).

Total dissolved solids range from 1,000 ppm to 2,000 ppm in alluvial aquifers associated with the Deep Fork. Yields range from 1 gpm to 25 gpm (Oakes and Motts, 1963). Groundwater quality of the younger Deep Fork alluvial aquifers is variable, influenced in part, by recharge from poorer quality surface-water of the Deep Fork (Oakes and Motts, 1963). Older alluvial terrace deposits of the Deep Fork, occupy a higher topographic position than the younger alluvial deposits. The older alluvial terrace aquifers have groundwater of better quality because recharge is by direct infiltration of rainfall as opposed to recharge from the Deep Fork. Groundwater quality in alluvial aquifers associated with the tributaries of Deep Fork is variable with total dissolved solids reported to be as low as 250 ppm. However, groundwater quality of the tributary alluvial aquifers may be influenced by recharge from underlying, highly mineralized bedrock aquifers. Yields from the tributary alluvial aquifers have been reported as high as 17 gpm (Oakes and Motts, 1963). Within the study area, the alluvial deposits of Coal Creek are considered to be an alluvial aquifer (Johnson, 1993).

Pennsylvanian sandstones comprise most of the bedrock aquifers in Okmulgee County. Generally, each thickly bedded sandstone is a potable aquifer over part of its outcrop area where recharge is from infiltration of rainfall. Potable groundwater has been reported to mix with highly mineralized groundwater under confined conditions down dip in the sandstones. Total dissolved solids have been reported for groundwater produced from bedrock aquifers as ranging from 670 ppm east of Henryetta (Bingham and Moore, 1991) to 5,000 ppm north of Okmulgee (Marcher, 1988).

CHAPTER IV

METHODS AND MATERIALS

Data Sources

Water quality data of surface-water samples collected on the Eagle-Picher smelter site and two unnamed tributaries that drain the smelter site were obtained from the U. S. Environmental Protection Agency (EPA) and the Oklahoma Water Resources Board (OWRB). These samples were collected from December 2, 1982 through December 7, 1988. A summary of the EPA and OWRB analyses is presented on Table 2.

Water-quality data for the two unnamed tributaries of Coal Creek were obtained from laboratory analyses of surface-water (from three locations on the southern tributary and four locations on the northern tributary). These seven samples were collected by the writer on June 28, 1992 and submitted to the Oklahoma State Environmental Laboratory for analysis on June 29, 1992.

Field Procedures

Surface-water samples (1-ST62892 through 7-NT62892) were collected the morning of June 28, 1992. Approximately 0.23 inches of precipitation

TABLE 2

SUMMARY OF LABORATORY ANALYTICAL RESULTS OF SURFACE WATER SAMPLES COLLECTED BY THE EPA AND OWRB

AGENCY	EPA	EPA	EPA	EPA	EPA	EPA	EPA	EPA	EPA	EPA	OWRB
DATE COLLECTED	12/2/82	12/2/82	12/2/82	12/2/82	12/7/88	12/7/88	12/7/88	12/7/88	12/7/88	12/7/88	9/28/88
SAMPLE #	4588-A	4589-A	4593-A	4594-A	MFF 777	MFF 778	MFF779	MFF 780	MFF 787	MFF 788	0107
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L
ALUMINUM	---	---	---	---	118.00	5,530.00	1,310.00	1,110.00	6,210.00	158.00	---
ANTIMONY	6	<5	<5	<5	27.40	27.40	27.40	27.40	27.40	27.40	---
ARSENIC	83	<5	<5	<5	5.40	5.40	5.40	5.40	5.40	5.40	---
BARIUM	---	---	---	---	20.00	19.80	20.80	19.10	16.80	23.10	---
BERYLLIUM	<20	<20	<20	<20	0.10	1.00	1.30	0.56	2.40	0.14	---
CADMIUM	70	270	462	436	237.00	541.00	226.00	572.00	742.00	584.00	0.38
CALCIUM	---	---	---	---	127,000.00	218,000.00	96,000.00	221,000.00	319,000.00	212,000.00	---
CHROMIUM	<20	<20	<20	<20	3.30	3.30	3.30	3.30	3.30	3.30	---
COBALT	---	---	---	---	18.60	92.70	254.00	86.80	376.00	19.30	---
COPPER	265	22	793	<20	650.00	9,030.00	11,800.00	5,490.00	30,800.00	24.00	58.2
IRON	---	---	---	---	80.80	734.00	431.00	199.00	187.00	153.00	1.1
LEAD	2,580	110	154	<30	8.70	65.30	76.90	32.70	105.00	16.90	0.54
MAGNESIUM	---	---	---	---	29,300.00	64,900.00	25,600.00	70,000.00	60,300.00	79,100.00	102.76
MANGANESE	---	---	---	---	1,050.00	5,070.00	6,880.00	51.90	11,900.00	4,990.00	1.41
MERCURY	84 00	0.97	<0 2	<0.2	---	---	---	---	---	---	---
NICKEL	64	164	19,600	1,310	169.00	699.00	1,490.00	607.00	1,940.00	303.00	---
POTASSIUM	---	---	---	---	3,680.00	10,200.00	7,430.00	10,700.00	9,630.00	12,300.00	---
SELENIUM	<10	<10	13	<10	4.20	4.20	4.20	4.20	4.20	4.20	---
SILVER	<20	<20	<20	<20	4.10	4.10	4.10	4.10	7.50	4.10	---
SODIUM	---	---	---	---	41,100.00	82,700.00	43,000.00	89,200.00	85,500.00	97,900.00	---
THALLIUM	<6	<6	<6	<6	5.20	5.20	5.20	5.20	5.20	5.20	---
VANADIUM	---	---	---	---	5.00	5.00	5.00	5.00	5.00	5.00	---
ZINC	21,200	78,500	290,000	83,800	69,900.00	166,000.00	83,900.00	176,000.00	210,000.00	186,000.00	151.38
TEMPERATURE	60¦ F	59¦ F.	58¦ F.	59¦ F.	---	---	---	---	---	---	---
pH	6	6	5	6	---	---	---	---	---	---	4.57
SULFIDE	<0.1	<0.1	<0.1	<0.1	---	---	---	---	---	---	---
CHLORIDE	---	---	---	---	---	---	---	---	---	---	23.9
HARDNESS	---	---	---	---	---	---	---	---	---	---	4270
SOLIDES, DISSOLVED	---	---	---	---	---	---	---	---	---	---	3498
SULFATE	---	---	---	---	---	---	---	---	---	---	123
NH3-N	---	---	---	---	---	---	---	---	---	---	0.058
NO2-N	---	---	---	---	---	---	---	---	---	---	2.2
PHOSPHORUS, TOTAL	---	---	---	---	---	---	---	---	---	---	0.48

NOTE:
1 --- ANALYSIS NOT PERFORMED
2. < LESS THAN DETECTION LIMIT
3. TOTAL METAL CONCENTRATIONS REPORTED

accumulated the two hours prior to sampling (Oklahoma Climatological Survey).

Surface-water samples for laboratory analysis were collected at locations downstream from the smelter property on each of the two unnamed tributaries. The first sample collected on each tributary was a few feet upstream from the confluence with Coal Creek. Subsequent samples were collected at progressively upstream locations. Surface-water samples 1-ST62892 through 3-ST62-892 were collected on the southern tributary and surface-water samples 4-NT62892 through 7-NT62892 were collected on the northern tributary (Figure 8).

Samples submitted for laboratory analyses were collected in three one-liter and one 500-milliliter, precleaned laboratory containers provided by the Oklahoma State Environmental Laboratory (OSEL). An attempt was made to collect a representative water sample at each location by minimizing the amount of sediment in each sample. Each sample container was labeled and stored immediately on ice. Specific conductance, pH, and temperature of each sample were measured in the field. Results of the field measurements are in Table 3.

Thirteen surface-water samples (8-SW through 20-SW) were collected for field measurements of pH, specific conductance, and temperature. Ten surface-water samples were collected from the southern portion of the study area and three from the northern portion of the study area. Results of these field measurements are in Table 3.

One surface-water sample was collected from each of four arroyos (10-SW, 12-SW, 14-SW, and 15-SW) that drain the southern portion of the smelter site.

TABLE 3

SUMMARY OF FIELD MEASUREMENTS OF SURFACE WATER SAMPLES

FIELD SAMPLE NO.	1-ST62892	2-ST62892	3-ST62892	4-NT62892	5-NT62892	6-NT62892	7-NT62892	8-SW	9-SW	10-SW
SPECIFIC CONDUCTANCE	1830.0	1340.0	1280.0	1980.0	2020.0	1810.0	490.0	1120.0	870.0	3730.0
pH	4.3	6.6	6.6	6.7	6.8	7.3	7.2	6.7	7.1	6.6
TEMPERATURE	23.6	23.8	24.0	23.8	23.6	23.0	24.0	22.6	23.1	23.6

FIELD SAMPLE NO.	11-SW	12-SW	13-SW	14-SW	15-SW	16-SW	17-SW	18-SW	19-SW	20-SW
SPECIFIC CONDUCTANCE	1530.0	3950.0	1990.0	2010.0	590.0	1910.0	1870.0	2340.0	1900.0	4640.0
pH	6.9	6.5	6.8	3.9	5.7	5.2	6.0	6.6	3.8	6.1
TEMPERATURE	23.1	23.7	23.7	23.1	23.9	24.0	23.8	29.7	31.1	25.9

NOTE:
1. SPECIFIC CONDUCTANCE IN MICROMHOS PER CENTIMETER
2. pH IN STANDARD UNITS
3. TEMPERATURE IN DEGREES CENTIGRADE

Six surface-water samples (8-SW, 9-SW, 11-SW, 13-SW, 16-SW, and 17-SW) were collected at locations above and below the confluences of the four arroyos with the southern unnamed tributary. These ten surface-water sample locations were upstream from surface-water sample location 1-ST62892.

Surface-water sample SW-18 was collected from runoff above a settling pond on the north side of the smelter site. Sample SW-19 was collected from water flowing over the spillway of the settling pond, and sample SW-20 was collected from a seep at the base of the west end of the settling pond dike. Field measurements of specific conductance, pH, and temperature were performed on these samples.

Sample Preparation

Samples placed in 500-milliliter containers were labeled "total metals" and preserved with approximately one milliliter of reagent grade nitric acid to achieve a pH less than two. The reagent grade nitric acid was provided by the OSEL. A portion of the water from one of the one-liter containers from each sample location was filtered into a second 500-milliliter container and labeled "dissolved metals". The water was pumped from the one-liter container into the 500-milliliter container using a peristaltic pump, disposable inert tubing and a 0.45-micron high-capacity disposable filter. After each sample was filtered, the filter and tubing were replaced. The filtered sample was then preserved with approximately one milliliter of reagent-grade nitric acid, to achieve a pH less than two. The remainder of water in each of the one-liter containers was used for field measurements of pH, specific conductance, and temperature. A field filter blank was prepared utilizing distilled, deionized water provided by the OSEL. The distilled, deionized water was pumped from a one-liter container into a 500-milliliter container by the method discussed above. The container was marked "filter blank" and submitted to the OSEL for quality control.

Sample Analysis

Four sample containers from each sample location and one filter blank were retained by the writer and submitted to the OSEL on June 29, 1992 under chain-of-custody control. The surface-water samples were analyzed for total and dissolved metals (aluminum, arsenic, barium, cadmium, calcium, cobalt, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, sodium and zinc). Results of analyses are in Tables 4 and 5, respectively. The samples were also analyzed for chloride, sulfate, nitrate, alkalinity (carbonate and bicarbonate), pH, specific conductance and total dissolved solids. These results are in Table 6. The filter-blank sample was analyzed for dissolved metals only.

Method 3010, digestion procedure for the preparation of aqueous samples, was used by the OSEL prior to the total and dissolved metal analyses by Method 6010, inductively coupled plasma atomic emission spectroscopy. These methods were used to analyze for the metals listed above, with the exception of

TABLE 4

SUMMARY OF ANALYTICAL RESULTS (TOTAL METALS) OF AQUEOUS SAMPLES COLLECTED ON JUNE 28, 1992 DOWN STREAM FROM THE EAGLE-PICHER SMELTER SITE, HENRYETTA, OKLAHOMA.

OSDH LAB SAMPLE NO. FIELD SAMPLE NO.	215447 1-ST62892 µg/L	215448 2-ST62892 µg/L	215449 3-ST62892 µg/L	215450 4-NT62892 µg/L	215451 5-NT62892 µg/L	215452 6-NT62892 µg/L	215453 7-NT62892 µg/L
ALUMINUM	30,080	518	2,154	1,325	1,576	355	1,996
ARSENIC	203	<60	<60	<60	<60	<60	<60
BARIUM	224	33	45	43	56	48	46
CADMIUM	426	263	211	432	331	22	5
CALCIUM	221,000	159,000	142,000	201,000	196,000	110,000	32,000
COBALT	105	<100	<100	<100	<100	<100	<100
COPPER	14,060	527	272	85	31	<10	38
IRON	102,400	780	3,094	625	1,528	966	3,912
LEAD	2,193	<45	61	<45	<45	<45	<45
MAGNESIUM	40,000	30,000	33,000	159,000	63,000	51,000	15,000
MANGANESE	4,881	360	1,558	4,391	3,868	3,347	1,130
MERCURY	2	<.5	<.5	<.5	<.5	<.5	<.5
NICKEL	800	334	336	939	783	75	77
POTASSIUM	11,900	13,500	13,400	27,100	23,500	15,200	6,500
SODIUM	83,000	60,000	57,000	116,000	104,000	159,000	29,000
ZINC	108,100	55,480	49,540	91,190	71,750	5,555	1,254

NOTE:
1. < LESS THAN DETECTION LIMIT

TABLE 5

SUMMARY OF ANALYTICAL RESULTS (DISSOLVED METALS) OF AQUEOUS SAMPLES COLLECTED ON JUNE 28, 1992, DOWN STREAM FROM THE EAGLE-PICHER SMELTER SITE, HENRYETTA, OKLAHOMA.

OSDH LAB SAMPLE NO.	215454	215455	215456	215457	215458	215459	215460	215446
FIELD SAMPLE NO.	1-ST62892	2-ST62892	3-ST62892	4-NT62892	5-NT62892	6-NT62892	7-NT62892	FILTER BLANK
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
ALUMINUM	10,950	<300	<300	<300	<300	<300	<300	<300
ARSENIC	<60	<60	<60	<60	<60	<60	<60	<60
BARIUM	42	28	33	44	55	45	32	<10
CADMIUM	412	255	215	431	355	10	<5	<5
CALCIUM	222,000	159,000	147,000	203,000	214,000	111,000	32,000	<1000
COBALT	<100	<100	<100	<100	<100	<100	<100	<100
COPPER	13,230	195	137	46	12	<10	<10	10
IRON	3,248	55	132	90	196	146	110	64
LEAD	333	<45	<45	<45	<45	<45	<45	<45
MAGNESIUM	38,000	32,000	35,000	62,000	71,000	53,000	16,000	<1000
MANGANESE	4,749	359	1,589	4,484	4,221	3,365	1,071	<10
MERCURY	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
NICKEL	768	335	322	949	848	74	<25	<25
POTASSIUM	14,200	16,100	15,500	27,900	23,700	17,500	6,600	<100
SODIUM	84,000	61,000	60,000	120,000	116,000	163,000	28,000	<10000
ZINC	103,600	53,850	49,910	89,580	74,970	4,054	268	32

NOTE:
1. < LESS THAN DETECTION LIMIT

TABLE 6

SUMMARY OF ANALYTICAL RESULTS (GENERAL CHEMISTRY) OF AQUEOUS SAMPLES COLLECTED ON JUNE 28, 1992, DOWN STREAM FROM THE EAGLE-PICHER SMELTER SITE, HENRYETTA, OKLAHOMA.

OSDH LAB SAMPLE NO. FIELD SAMPLE NO.	215447 1-ST62892	215448 2-ST62892	215449 3-ST62892	215450 4-NT62892	215451 5-NT62892	215452 6-NT62892	215453 7-NT62892
CHLORIDE	<10	<10	10	35	39	96	16
pH	3.8	6	6.3	6.4	6.5	7.4	7.5
SULFATE	693	466	415	664	723	413	132
ALKALINITY, BICARBONATE	<15	24	35	46	43	246	89
ALKALINITY, TOTAL	<15	24	35	46	43	246	89
ALKALINITY, CARBONATE	0	0	0	0	0	0	0
NITRATE/NITRITE AS N	0.7	0.9	0.9	0.6	0.5	<.5	<.5
SPECIFIC CONDUCTANCE	1,716	1,262	1,211	1,867	1,918	1,716	439
TOTAL DISSOLVED SOLIDS	1,660	1,135	1,062	1,766	1,754	1,300	306

NOTE:
1. CONCENTRATIONS IN MILLIGRAMS PER LITER; pH IN STANDARD UNITS
2. SPECIFIC CONDUCTANCE IN MICROMHOS PER CENTIMETER
3. < LESS THAN DETECTION LIMIT

mercury. Method 7470, a cold-vapor atomic absorption technique, was used to analyze for mercury (EPA Test Methods For Evaluating Solid Waste Physical/Chemical Methods, 1986).

Methods of Data Evaluation

Laboratory analytical data from this study are discussed in Chapter V. The discussion includes: data validation; a comparison of historical analytical data to data from this study; pH, specific conductance, and total-dissolved-solids measurements of samples collected in the study area; and chemical trends and reactions.

The data validation includes results of the filter blank analysis, a comparison of total versus dissolved metal concentrations, and a comparison of field versus laboratory measurements of pH and specific conductance.

Comparisons of historical analytical data (reported by the EPA and the OWRB) to data from this study, are included in sections for both the southern and northern tributaries. The purpose of this comparison is to determine whether significant changes in total metals concentrations have occurred over approximately a ten year period. It is assumed that any significant changes in total metal concentrations would be reflected by similar changes in dissolved metal concentrations.

Specific conductance, pH, and total-dissolved-solids values for sample locations in the study area are used to assess the general water quality of the two unnamed tributaries and their branches. Field measurements of specific conductance and pH were used to evaluate samples 8-SW through 18-NT. Laboratory measurements of specific conductance, pH, and total dissolved solids were used to evaluate samples 1-ST62892 through 7-NT62892.

Chemical trends and reactions were evaluated using Eh-Ph diagrams (Brookins, 1988; and Garrels and Christ, 1965). The computer program WATEVAL (Hounslow and Goff, 1995) was utilized for calculation of anion-cation balance, analytical reliability, element ratios, and mass balance. WATEVAL was also used to generate Piper (Piper, 1944) and Stiff (Stiff, 1951) diagrams for graphical presentation of analytical data. WATEVAL printouts for dissolved metal samples 1-ST62892 through 7-NT62892 are in Appendix A. The computer program WATEQ4F (Ball, Nordstrom, and Zachmann, 1987) was utilized for the calculation of equilibrium distribution (activities) of inorganic aqueous species and saturations indices for solid phase minerals, for samples collected during this investigation. Portions of each of the WATEQ4F printouts for each of the samples are in Appendix B.

CHAPTER V

RESULTS AND DISCUSSION

This chapter is presented in four sections: Data Validation; Comparison of Historical Data to Data from This Study; Results of Specific Conductance, pH, and TDS Measurements; and Chemical Trends and Reactions. In the first section, results from seven sample analyses, one laboratory control sample (field-filter blank), and field measurements are compared for the purpose of identifying anomalies in the study data, if anomalies are present. In the second section, historical laboratory analytical data from the study area are compared to analytical data from corresponding surface-water sample locations of this study, to determine whether significant changes occurred over approximately a ten-year period. In the third section, pH, specific conductance, and total-dissolved-solids (TDS) measurements are evaluated for anomalies or trends. In the fourth section, chemical trends and potential chemical reactions are evaluated for the surface-water in the southern and northern tributaries that drain the smelter site.

Data Validation

Sample containers, distilled deionized water, and nitric acid were provided by the OSEL. Inert tubing, 0.45-micron single-use filters, and a peristaltic pump were provided by Roberts/Schornick & Associates, Inc., an environmental consulting firm.

A field-filter blank was prepared using the materials listed above. The filter blank was submitted to the OSEL for analysis of dissolved metals. Copper, iron, and zinc were detected in the filter blank at concentrations of 10, 64, and 32 µg/L, respectively (Table 5). The director of the OSEL indicated in conversation that plumbing repairs had been made to the distilled-deionized-water supply system, which possibly resulted in the detected concentrations.

Total metal concentrations are generally expected to be equal to, or greater than the dissolved metal concentrations, due to dissolution of metals from particulates (if present) in the sample, when the sample is preserved with nitric acid. A comparison of 112 (seven samples, 16 metal analyses per sample) total metal to dissolved metal analyses showed 35 analyses (nine metals) where dissolved metal concentrations exceeded total metal concentrations.

The percent differences in cation and anion balances calculated with WATEVAL ranged from -3.95 (7-NT62892) to 16.34 (3-ST62892). The percent differences in input cation and anion balances calculated with WATEQ4F ranged from -6.82 (7-NT62892) to 47.79 (1-ST62892). WATEVAL input parameters are generally limited to major and minor constituent concentrations. The constituent concentrations are used in balance calculations totally as aqueous species with ionic charge. WATEQ4F input parameters include major, minor, and trace constituents. Neutrally charged aqueous species are not used in WATEQ4F for calculation of balances. Thus, calculated percent differences in cation and anion balances are greater with WATEQ4F. High percent differences may indicate error in laboratory analyses.

Field measurements of pH and specific conductance were conducted on seven samples submitted for laboratory analysis (1-ST62892 through 7-NT62892), and thirteen additional samples (8-SW through 20-SW) collected from branches of the northern and southern tributaries. Field measurements are in Table 3 and laboratory measurements (1-ST62892 through 7-NT62892) are in Table 6. Generally, field and laboratory measurements of pH differed by less than 0.5 standard units (SU). Field and laboratory measurements of specific conductance differed by less than 115 micromhos per centimeter (µmhos/cm). Laboratory measurements will be used in the following discussion.

Comparison of Historical Data with Data from This Study

Southern Tributary

The southern portion of the smelter site is drained by several branches of the southern unnamed tributary. Each of the branches emanates from springs along the southern portion of the smelter slag, including the western and eastern slag piles (shown in Figure 9).

EPA sample locations MFF778 through MFF788 are on various branches of the southern tributary. Sample location 1-ST62892 (this study) is below the confluences of the several branches of the southern tributary (Figure 9). A

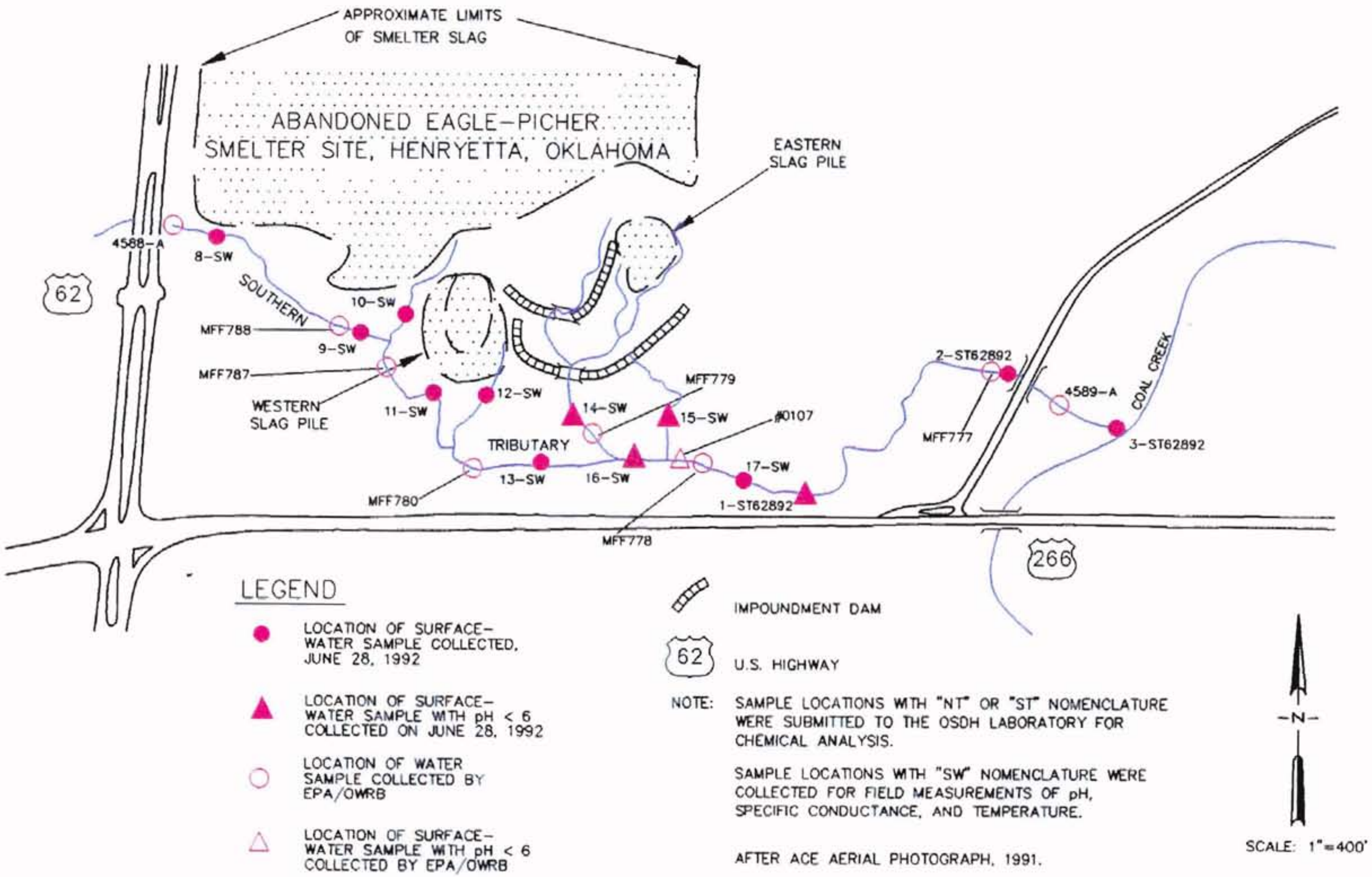


Figure 9. Sample Locations on the Southern Tributary

comparison the analytical results of EPA sample locations MFF778 through MFF788 (1988) to sample location 1-ST62892 shows total metal concentrations of similar magnitude.

EPA sample location MFF777 corresponds with this study's sample location 2-ST62892. Results of analyses for total metals for both samples MFF777 and 2-ST62892 are similar. The total metal concentrations were generally higher in sample 2-ST62892, with the exception of copper and manganese. Based on these comparisons of total metal concentrations, it is assumed that dissolved metal concentrations similarly have remained about the same since 1988.

Northern Tributary

The EPA collected samples from two locations on the northern tributary. One EPA sample location (4593-A) corresponds with this study's sample location 18-SW. Sample locations along the northern tributary are shown in Figure 10. Sample 18-SW was collected for field measurements of pH and specific conductance. The pH of samples 4593-A and 18-SW were 5 and 6.6 SU, respectively. Specific conductance was not reported for EPA sample 4593-A. The second sample collected by the EPA (4594-A) corresponds with sample location 4-NT62892. EPA sample 4594-A was analyzed for seven total metals (arsenic, cadmium, copper, lead, mercury, nickel, and zinc) of which three were detected as being above the laboratory's reporting limit. Comparison of total

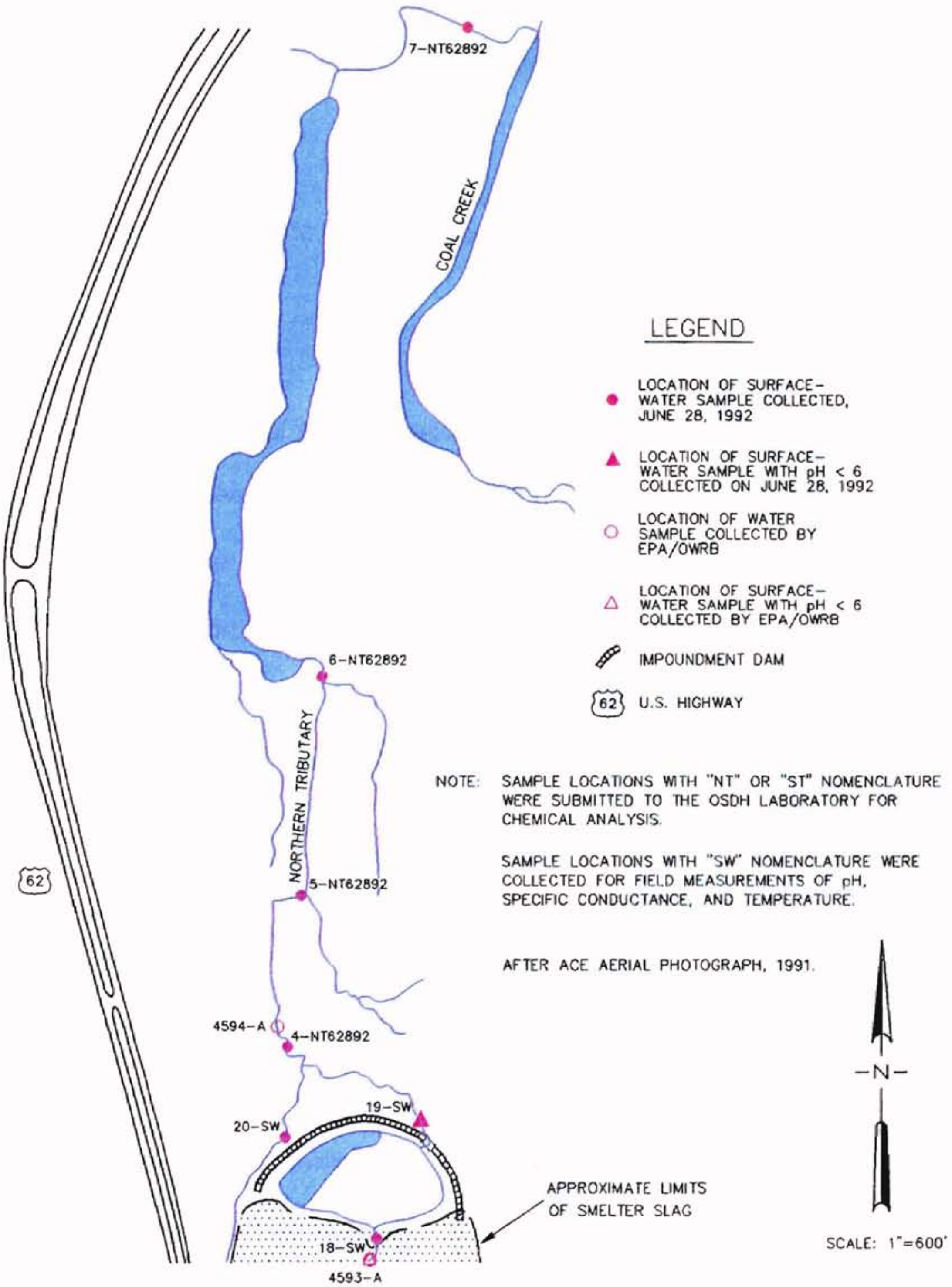


Figure 10. Sample Locations on the Northern Tributary

metals analysis of sample 4594-A (Table 2) with sample 4-NT62892 (Table 4) shows similar concentrations between 1982 to 1992. Based on this comparison, it appears that dissolved-metal concentrations have remained about the same since 1982.

Results of Specific Conductance, pH, and TDS Measurements

Southern Tributary

Field measurements of pH and specific conductance were conducted on surface-water samples 8-SW through 17-SW (see Table 3) for the purpose of identifying anomalous areas (Figure 9). Generally, surface-water originating from the southern portion of the smelter slag and from the western slag pile had pH typical for stream waters. Measured pH for branches draining the southern portion of the smelter slag and the western slag pile ranged from 6.5 (12-SW) to 7.1 SU (10-SW). Specific conductance ranged from 870 to 3950 µmhos/cm. No trend was apparent between pH and specific conductance. However, surface-water from branches draining the eastern slag pile showed lower pH, ranging from 3.9 (14-SW) to 5.7 SU (15-SW), with specific conductance ranging from 590 to 2010 µmhos/cm for samples 14-SW through 16-SW. Approximately 200 feet downstream from the confluence of the most easterly branch of the southern tributary, pH was measured at 6.0 SU (17-SW).

Samples 1-ST62892 through 3-ST62892 (Figure 9) were submitted for laboratory analysis of pH, specific conductance, and TDS (see Table 6). The pH was measured at 3.8 SU for sample location 1-ST62892, approximately 150 feet downstream from location 17-SW. The low pH of this sample and of water draining form the eastern slag pile may be the result of pyrite oxidation. Pyrite was a gangue mineral with ores from the Tri-State District. Additionally, the low pH may be associated with acid-water drainage from former coal mines operated in this area. The recorded pH of samples 2-ST62892 and 3-ST62892 was 6 and 6.3 SU, respectively. Specific conductance of samples 1-ST62892, 2-ST62892, and 3-ST62892 was 1716, 1262, and 1211 µmhos/cm, respectively, with TDS of 1660, 1135, and 1062 mg/L, respectively.

Northern Tributary

Generally, water samples from the northern tributary showed pH that ranged from weakly acidic (3.8 SU) for water draining from the settling impoundment (19-SW) to weakly alkaline (7.5 SU) near the confluence with Coal Creek. Specific conductance and total dissolved solids generally decrease in a downstream direction.

Water samples were collected for field measurements of pH and specific conductance at locations 18-SW, 19-SW, and 20-SW (see Figure 10). Field measurements of pH ranged from 3.8 (19-SW) to 6.6 SU (18-SW). Specific conductance ranged from 1900 (19-SW) to 4640 µmhos/cm (20-SW). No trend was apparent between pH and specific conductance.

Samples 4-NT62892 through 7-NT62892 were submitted for laboratory analysis of pH, specific conductance, and TDS. The reported pH increased at progressively downstream locations from 6.4 (4-NT62892) to 7.5 SU (7-NT62892) (see Figure 10). Specific conductance for samples submitted for laboratory analysis ranged from 490 (7-NT62892) to 2020 µmhos/cm (5-NT62892). TDS ranged from 306 (7-NT62892) to 1766 mg/L (4-NT62892).

Chemical Trends and Reactions

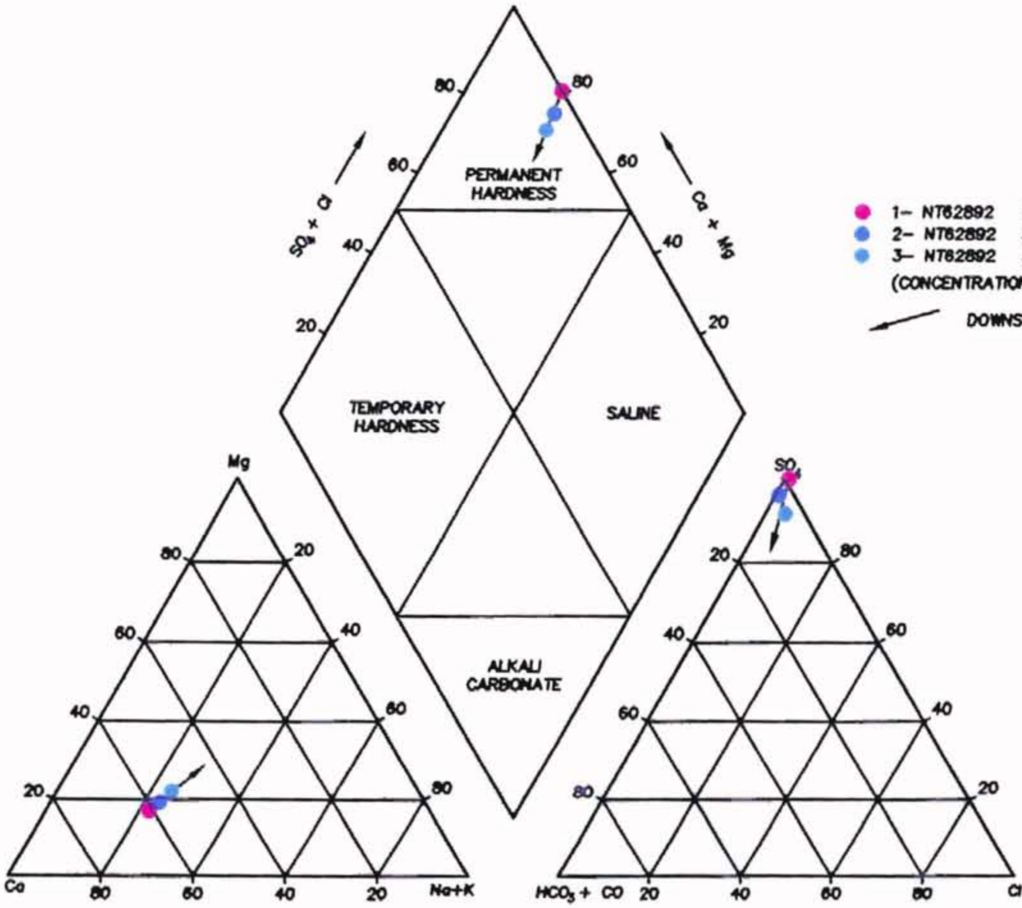
The chemical trends and reactions generally are based on analyses, calculated activities, and calculated mineral species for solutions in equilibria. However, chemical reactions probably do not approach equilibria for water within the southern and northern tributaries because of highly variable stream velocity, commingling of runoff originating from different areas outside the smelter site, variable groundwater discharge, and seasonal changes in temperature, evaporation, and biological activity.

Southern Tributary

The southern portion of the smelter site is drained by several branches of the southern unnamed tributary. Each of the branches emanates from springs along the southern portion of the smelter slag, including the western and eastern slag piles (see Figure 9). Downstream from the confluences of the of the several branches of the southern tributary, flow is generally over a uniform substrate of silts, sands, gravels, and slag transported from the smelter site. Very little aquatic life is present.

Major and Minor Constituents. Samples 1-ST62892 through 3-ST62892 were analyzed for the following major constituents: sodium, calcium, magnesium, chloride, sulfate, and bicarbonate. Additionally, the samples were analyzed for the minor constituents potassium and iron.

Cations (calcium, magnesium, and sodium plus potassium) and anions (bicarbonate, sulfate, and chloride) are graphically presented in Figure 11 (Piper diagram). The three water analyses (1-ST62892 through 3-ST62892) lie on straight lines. The lines, when extrapolated, pass near the calcium apex of the cation triangle and through the sulfate apex of the anion triangle. As illustrated, magnesium and potassium concentrations remain relatively constant. However, calcium and sulfate ions are removed from solution between each successive downstream sample location. This trend is characteristic of gypsum ($CaSO_4$) precipitation. However, the calculated (WATEQ4F) saturation indices shows that each of the samples are slightly under saturated with respect to gypsum. However, high percent differences in the cation and anion balances (sum of cations greater than the sum of anions for each of the samples) may indicate that sulfate concentrations should be higher than reported. Higher sulfate concentrations could result in higher calculated saturation indices. Dissolved $CaSO_4$ in each of the samples is further evident from the Stiff diagrams presented in Figure 12. Stiff diagrams illustrate major and minor cation and



	Ca	Mg	Na+K	HCO_3	SO_4	Cl
1– NT62892	60.4	17.0	21.9	0.0	99.9	0.0
2– NT62892	58.2	19.3	22.5	3.9	96.0	0.0
3– NT62892	55.5	21.8	22.7	6.0	90.9	3.0

(CONCENTRATIONS IN % meq/L)

DOWNSTREAM DIRECTION

Figure 11. Piper Diagram of Sample Analyses, Southern Tributary

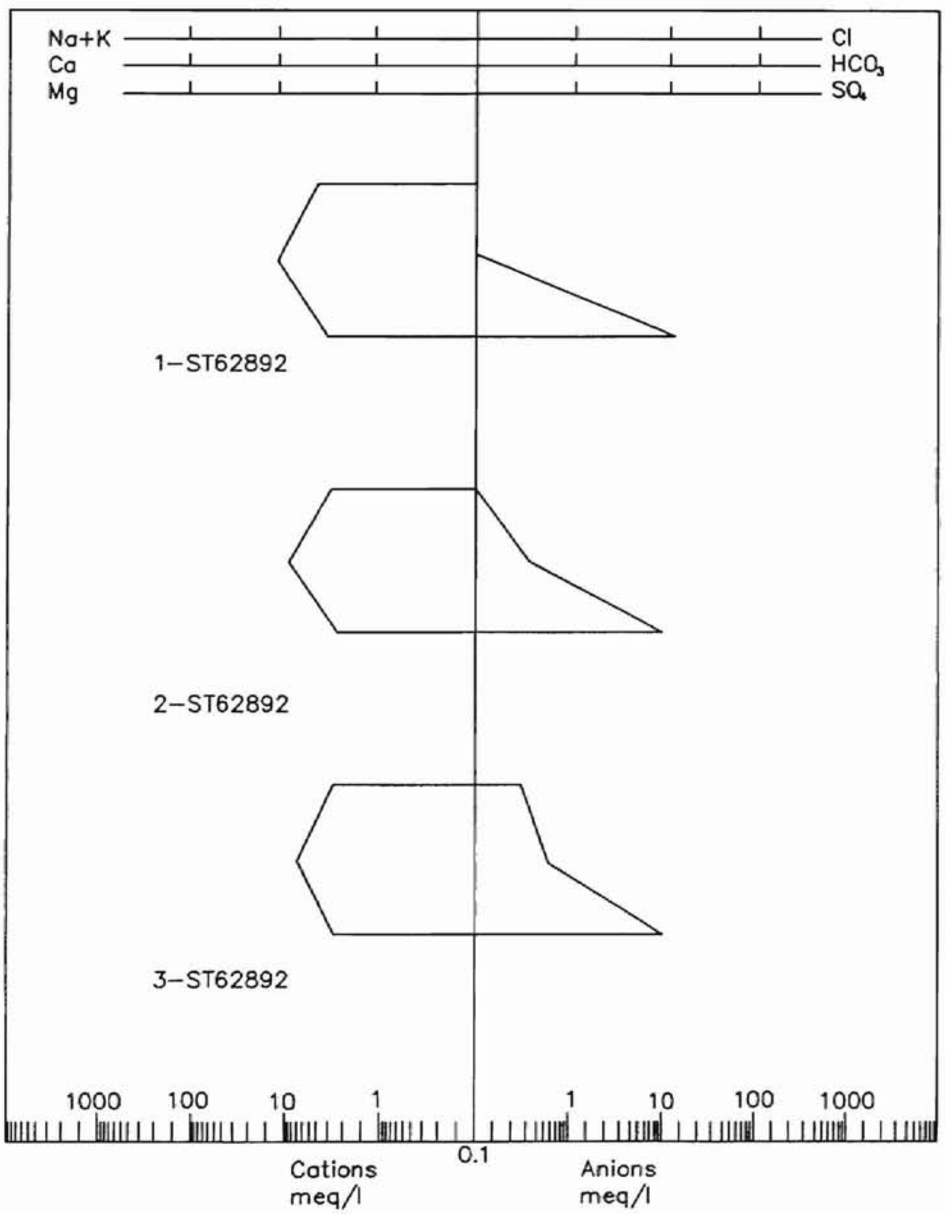


Figure 12. Stiff Diagrams of Sample Analyses, Southern Tributary

anion concentrations. As shown in Figure 12, the Stiff diagram for each of the samples exhibits the shape (calcium greater than sodium plus potassium and greater than magnesium, with high sulfate) characteristic of water with aqueous $CaSO_4$ species.

As calcium and sulfate ions are removed from solution in a downstream direction, the bicarbonate concentration increases. This trend of the data may be attributed to pyrite oxidation, the reaction of carbonic acid (CO_2) with calcite to form bicarbonate, the removal of calcium by precipitation of gypsum, and the removal of sulfate by precipitation of gypsum and of other sulfate minerals.

Pyrite oxidation is described by the following reaction to form iron hydroxide, sulfate, and hydrogen ions :

$$FeS_2 + 6O + 5H_2O \Rightarrow Fe(OH)_3 + 2SO_4^{2-} + 7H^+$$

The hydrogen ions react with available calcite in stream sediment to form calcium ions, water, and carbon dioxide:

$$2CaCO_3 + 4H^+ \Rightarrow 2Ca^{2+} + 2H_2O + 2CO_2$$

The oxidation of pyrite, resulting in low pH along with high sulfate, calcium, and iron concentrations, is consistent with the analyses of sample 1-ST62892. Additionally, pyrite oxidation is indicated by the $Ca/(Ca+SO_4)$ ratio for sample 1-ST62892. A ratio of less than 0.5 along with low pH indicates pyrite oxidation. Further downstream, carbon dioxide dissolves to form carbonic acid, likely reacting with more calcite to form calcium and bicarbonate ions:

$$2CaCO_3 + 2H_2O + 2CO_2 \Rightarrow 2Ca^{2+} + 4HCO_3^-$$

This is consistent with the increase in bicarbonate concentrations at both sample locations 2-ST62892 and 3-ST62892.

Calcium is removed from solution between each successive, downstream sample location. Similarly, TDS is lower at each successive, downstream location. The greatest change is between sample locations 1-ST62892 and 2-ST62892. Removal of calcium from solution probably is due to the precipitation of gypsum even though the calculated (WATEQ4F) saturation indices shows that each of the samples are slightly under-saturated with respect to gypsum. It is unlikely that calcium is removed by either by Ca-Mg exchange during dedolomitization or by Ca-Na exchange in clays. Calcium exchange with sodium in clays would likely result in higher sodium concentrations. However, sodium concentrations decrease from sample locations 1-ST62892 to 3-ST62892. Dedolomitization would likely result in higher magnesium concentrations. It is unlikely that dedolomitization occurs because magnesium concentrations are relatively constant between the three sample locations.

Sulfate is removed from solution between each successive, downstream sample location. The greatest change is between sample locations 1-ST62892 and 2-ST62892. Removal of sulfate from solution probably is due to precipitation of gypsum (this assumption is based on the discussion above regarding the removal of calcium from solution). Additional sulfate probably is removed from solution by the precipitation of other sulfate minerals. The calculated (WATEQ4F) saturation indices show that water at each of the three sample locations is over-saturated with respect to barite (BaSO4) and that water at sample location 1-ST62892 is over-saturated with respect to basaluminite ($Al_4(OH)_{10}SO_4 \cdot 5H_2O$). This probably would result in precipitation of these minerals. It is also assumed that anglesite ($PbSO_4$) is precipitated even though the calculated saturation index shows evidence of under-saturation. Eh-pH diagrams for the Pb-S-C-O-H system show that lead would likely precipitate as anglesite above pH of 5 SU (Brookins, 1988, and Garrels and Christ, 1965). Additionally, analytical results show that lead (in the presence of sulfate) is removed from solution by location 2-ST62892.

Sulfate probably is not removed from solution by replacement of calcite with gypsum in the presence of sulfate, because of the limited amount of calcite available in stream sediment. Neither limestones or dolomites, which would provide a continuing source of calcite in stream sediments, are exposed in the study area.

Trace constituents. Surface-water samples 1-ST62892 through 3-ST62892 were submitted for the analysis of 11 trace metals (aluminum, arsenic, barium, cadmium, cobalt, copper, lead, manganese, mercury, nickel, and zinc). Trace metals generally are defined by concentrations of less than 0.1 mg/L. The concentrations of three metals (arsenic, cobalt, and mercury) were less than the laboratory reporting limit in each of the samples. Six of the eight trace metals detected (lead, cadmium, nickel, zinc, copper, and barium) are associated with minerals contained in ore from the Tri-State Mining District. The presence of these trace metals in samples from this study area is consistent with metals reported in stream waters of the Picher Mining Area, northeastern Oklahoma, and southeastern Kansas (portion of the Tri-State Mining District) (Parkhurst, 1987).

Jenne (1968), Elder (1988), Horowitz (1985, and McLean and Bledsoe (1992) have discussed the importance of metal-partitioning in natural waters. Methods of metal-partitioning include complexation, sorption, precipitation, and biological uptake. However, complexes formed with organic matter and biologic uptake of the trace metals probably are less important, due to absence of observable aquatic life in the southern tributary.

Results of analyses made during this study were used to calculate (WATEQ4F) activities and saturation indices (Appendix B). The activities and saturation indices were used to evaluate which ions were likely to form complexes in the aqueous phase or were likely to precipitate, respectively. Availability of hydrous oxides of aluminum, iron, and manganese for sorption sites was evaluated. Additionally, the results analyses of trace metals detected in water samples from this study were compared to Eh-pH diagrams (Brookins, 1988, and Garrels and Christ, 1965) to determine which species (aqueous or solid phase) probably would exist for a given sample pH. The Eh for the samples were assumed to range from 0.4 to 0.6 volts (V). This range includes stream waters (0.4 V) to acid mine drainage (0.6 V) (Brookins, 1988).

Aluminum (10950 µg/L) was reported in only one sample, 1-ST62892 (pH of 3.8). The Eh-ph diagram for aluminum (Al-O-H system) shows that Al^{3+} may be in solution at pH than approximately 3.7 SU (Brookins, 1988, and Garrels and Christ, 1965). At pH greater than approximately 3.7 SU, aluminum precipitates as gibbsite ($Al(OH)_3$). However, the calculated (WATEQ4F) saturation indices for basaluminite ($Al_4(OH)_{10}SO_4 \cdot 5H_2O$) and diaspore ($AlO(OH)$) show that these species are slightly over-saturated and probably would precipitate. This is consistent with the calculated activities. The highest activities in the aqueous phase are $AlOH^{+2}$ and $AlSO_4^{+1}$ species. Precipitation of aluminum is consistent with analytical results. Aluminum was removed from solution by sample location 2-ST62892 (pH of 6.0 SU). Sample location 2-ST62892 is approximately 700 feet downstream from sample location 1-ST62892.

Lead was reported in one sample only, 1-ST62892 (333 µg/L). The Eh-pH diagram for lead (Pb-S-C-O-H system) shows that Pb^{2+} may be in solution at pH less than approximately 0.5 SU. Above a pH of 0.5 SU, anglesite ($PbSO_4$) probably would precipitate (Brookins, 1988, and Garrels and Christ, 1965). This is consistent with the activities. The highest activity in the aqueous phase is the $PbSO_4$ species. Precipitation of lead is consistent with results of analyses, which show that lead was removed from solution by sample location 2-ST62892. However, the saturation index shows that sample 1-ST62892 is under-saturated with respect to anglesite.

The Eh-pH diagram for barium indicates that barium (Ba-S-O-H-C system) precipitates as barite ($BaSO_4$) at pH greater than 1 SU (Brookins, 1988, and Garrels and Christ, 1965). This is consistent with the calculated saturation indices, which show that barite is slightly over-saturated in each of the three samples. However, precipitation of barite may not occur. Barium concentrations are about the same among each of the three sample locations. The activities for each of the samples show that barium forms a complex with sulfate ($BaSO_4$) in the aqueous phase.

Eh-pH diagrams are similar for cadmium (Cd-C-S-O-H system), copper (Cu-C-S-O-H system), nickel (Ni-O-H system), manganese (Mn-O-H system), and zinc (Zn-O-H-S-C system) (Brookins, 1988, and Garrels and Christ, 1965). The diagrams indicate that each of these metals should be in an aqueous phase below pH of about 7 or 8 SU, as hydrated free ions having the general formula $M(H_2O)_x^{n+}$ where M is the ion and n+ is the ionic charge (Elder, 1988). This is consistent with results discussed below.

Concentrations of cadmium (412 µg/L), copper (13230 µg/L), nickel (768 µg/L), manganese (38000 µg/L), and zinc (103600 µg/L) were high at sample location 1-ST62892, where the pH was 3.8 SU. These metals were in solution at sample locations 2-ST62892 (700 feet downstream from location 1-ST62892) and 3-ST62892 (300 feet downstream from location 2-ST62892) where pH measurements were 6.0 and 6.3, respectively. However, concentrations of cadmium, nickel, and zinc were reduced by approximately 50%, manganese by

93%, and copper by approximately 99% of the amounts reported for sample 1-ST62892. These significant changes coincide with precipitation of hydrous oxides of aluminum and iron. Presumably, the most important mechanism for removal of cadmium, copper, manganese, nickel, and zinc ions between sample locations 1-ST62892 and 2-ST62892 is sorption to hydrous oxides of aluminum and iron. This is consistent with the calculated saturation indices, which show that the samples are under-saturated with respect to cadmium, nickel, manganese, and zinc solid-phase minerals, with the exception of otavite ($CdCO_3$) in sample 3-ST62892. As discussed above, Eh-pH diagrams show that the aqueous/solid phase boundaries are at pH of approximately 7 to 8 SU for cadmium, nickel, manganese, and zinc.

As discussed previously, iron hydroxide is precipitated as a product of pyrite oxidation and aluminum hydroxide is precipitated as a result of change in pH. Both iron and aluminum hydroxides would be available as sorption sites or sorption edges for cadmium, copper, manganese, nickel, and zinc ions. The low pH and high dissolved aluminum and iron concentrations at sample location 1-ST62892 indicate a continuing source for precipitation of iron and aluminum hydroxides. Additionally, amorphous hydrous oxides of iron (and manganese) tend to precipitate, forming coatings on clay particles. This increases their surface area and efficiency as sorption edges (Jenne, 1968).

Eh-pH diagrams for copper show that precipitation of malachite ($Cu_2CO_3(OH)_2$), or tenorite (CuO) is likely at pH of approximately 6.3 SU, with a

Cu^{2+} activity of 10^{-7} (sample location 3-ST62892). Elder (1988) points out that copper species are dominated by malachite below pH of 7 and tenorite above pH of 7 SU (depending on the ratio of activity of copper species to the activity of the copper ions). However, the saturation indices show that samples 2-ST62892 and 3-ST62892 are under-saturated for copper solid-phase minerals.

The saturation indices show under saturation for manganese minerals in each of the three samples.

<u>Northern Tributary</u>

Water emanates from springs along a channel cut through the slag immediately upstream from a settling impoundment along the northern limit of the smelter slag. Runoff and water from springs discharge into the settling impoundment. Water flows from a spring on the west side of a settling-impoundment dam and from the impoundment spillway across silts, sands, gravels, and slag to sample location 4-NT62892. Additionally, stormwater runoff from the east side of U. S. Highway flows in washes to a western branch of the northern tributary (along the northwestern side of the smelter slag).

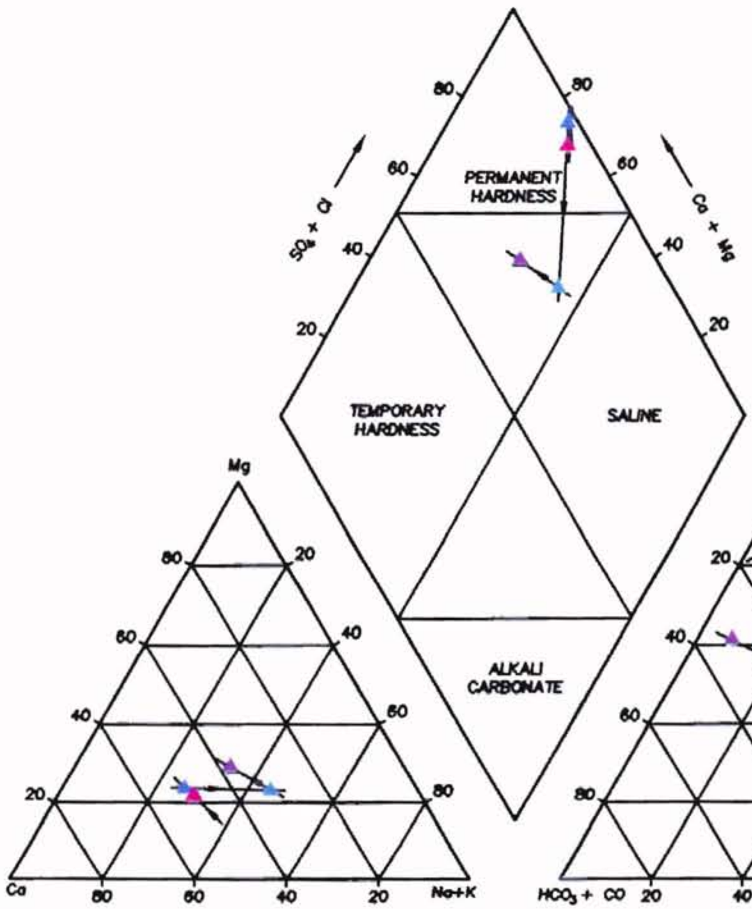
During periods of heavy precipitation, springs discharge from mixed alluvium and slag on the west side of the northern tributary (near sample location 4-NT62892) to the northern tributary. Water flows from sample location 4-NT62892 across exposed Senora shale, and then flows beneath silts, sands, gravels, and slag within the channel before discharging from springs at sample location 5-NT62892 (a distance of about 600 feet between sample locations).

Alluvial fans, on the west side of a butte on the east side of the northern tributary (Figure 2), extend west to the northern tributary. During periods of heavy precipitation, springs flow in steep washes on the alluvial fans, and flow from the base of the fans to the northern tributary (between sample locations 5-NT62892 and 6-NT62892 shown in Figure 8). Flow from sample location 5-NT62892 to 6-NT62892 is through a wetlands covered with reeds and willows for a distance of approximately 770 feet. The water then flows north into an impoundment that is approximately 2050 feet (south-to-north direction) by 150 feet wide. Sample location 7-NT62892 is approximately 3200 feet downstream from sample location 6-NT62892 (650 feet downstream from the impoundment). Sample locations along the northern tributary are shown in Figure 10.

Major and Minor Constituents. Samples 4-NT62892 through 7-NT62892 were analyzed for the major constituents: sodium, calcium, magnesium, chloride, sulfate, and bicarbonate. Additionally, the samples were analyzed for the minor constituents, potassium and iron.

Cations (calcium, magnesium, and sodium plus potassium) and anions (bicarbonate, sulfate, and chloride) are shown in Figure 13 (Piper diagram), and these constituents show distinctive trends.

Stream flow from sample locations 4-NT62892 to 5-NT62892 is over exposed Senora shale, subsurface flow through sands and gravels within the channel,



	Ca	Mg	Na+K	HCO_3	SO_4	Cl
4– NT62892	47.9	24.1	28.1	4.8	88.8	6.3
5– NT62892	48.1	26.3	25.4	4.2	89.3	6.5
6– NT62892	31.8	25.0	43.2	26.3	56.1	17.7
7– NT62892	37.1	30.6	32.2	31.3	59.0	9.7

(CONCENTRATIONS IN % meq/L)

DOWNSTREAM DIRECTION

Figure 13. Piper Diagram of Sample Analyses, Northern Tributary

and flow from springs at sample location 5-NT62892 (approximate distance of 600 feet). The analysis of sample 4-NT62892, compared to the analysis of 5-NT62892, shows slight increases in calcium, iron, magnesium, sulfate, and chloride, with slight decreases in sodium plus potassium and bicarbonate. This trend is shown by the Piper diagram (Figure 13). Lines connecting the two data points in both the cation and anion portions of the Piper diagram illustrate a trend toward the calcium-magnesium and sulfate-chloride baselines, respectively. This trend could be attributed to oxidation of minor amounts of pyrite (increases in iron and sulfate) buffered by dissolution of dolomite (increases in calcium and magnesium). However, bicarbonate concentrations decreased, unlike the bicarbonate trend of the southern tributary. As discussed previously (Southern Tributary, Major and Minor Constituents), increase in bicarbonate is anticipated as an indirect product of pyrite oxidation.

Stream flow from sample locations 5-NT62892 to 6-NT62892 is through the wetlands environment (approximate distance of 770 feet). The analysis of sample 5-NT62892 compared to the analysis of sample 6-NT62892 shows significant increases in sodium plus potassium (33%), bicarbonate (472%), and chloride (146%) and significant decreases in calcium (48%), magnesium (25%), and sulfate (43%). This trend is illustrated by the Piper diagram (Figure 13). Lines connecting the two data points on both the cation and anion portions of the diagram show a trend toward the sodium plus potassium and bicarbonate regions, respectively.

Changes in composition from location 5-NT62892 to 6-NT62892 are accompanied by increase in pH from 6.5 to 7.4 SU. Increase in pH, along with increases in sodium plus potassium, bicarbonate, and chloride, probably are the result of commingling of runoff originating outside the smelter site. Analyses of water samples collected by the OWRB at locations both above and below confluences of the southern and northern unnamed tributaries on Coal Creek (Grimshaw, Shapiro, Powell, and Black, 1986) reported pH as high as 7.4 SU. Analyses of water samples collected from Lake Henryetta (approximately 3.5 miles southeast of the smelter site) reported pH as high as 7.4 SU, sodium plus potassium as high as 405 ppm, bicarbonate as high as 270 ppm, and chloride as high as 740 ppm (Smith, Dott, and Warkentin, 1942). Lake Henryetta is on Wolf Creek, in an area of similar geological setting. Therefore, pH, sodium plus potassium, bicarbonate, and chloride reported at sample location 6-NT62892 are consistent with natural surface-water in the area.

The change in water chemistry at sample location 6-NT62892 is illustrated by Stiff diagrams in Figure 14. Samples 4-NT62892 and 5-NT62892 have shapes similar to those of samples 1-ST62892 through 3-ST62892 from the southern tributary. The similarity is indicative of water with aqueous $CaSO_4$ species. This is assumed to be the result of pyrite oxidation and dissolution of calcite. However, the Stiff diagram for sample 6-NT62892 has a shape suggestive of water associated with shale, reflecting the possible influence of commingling of runoff from the smelter site with natural water from springs along the base of

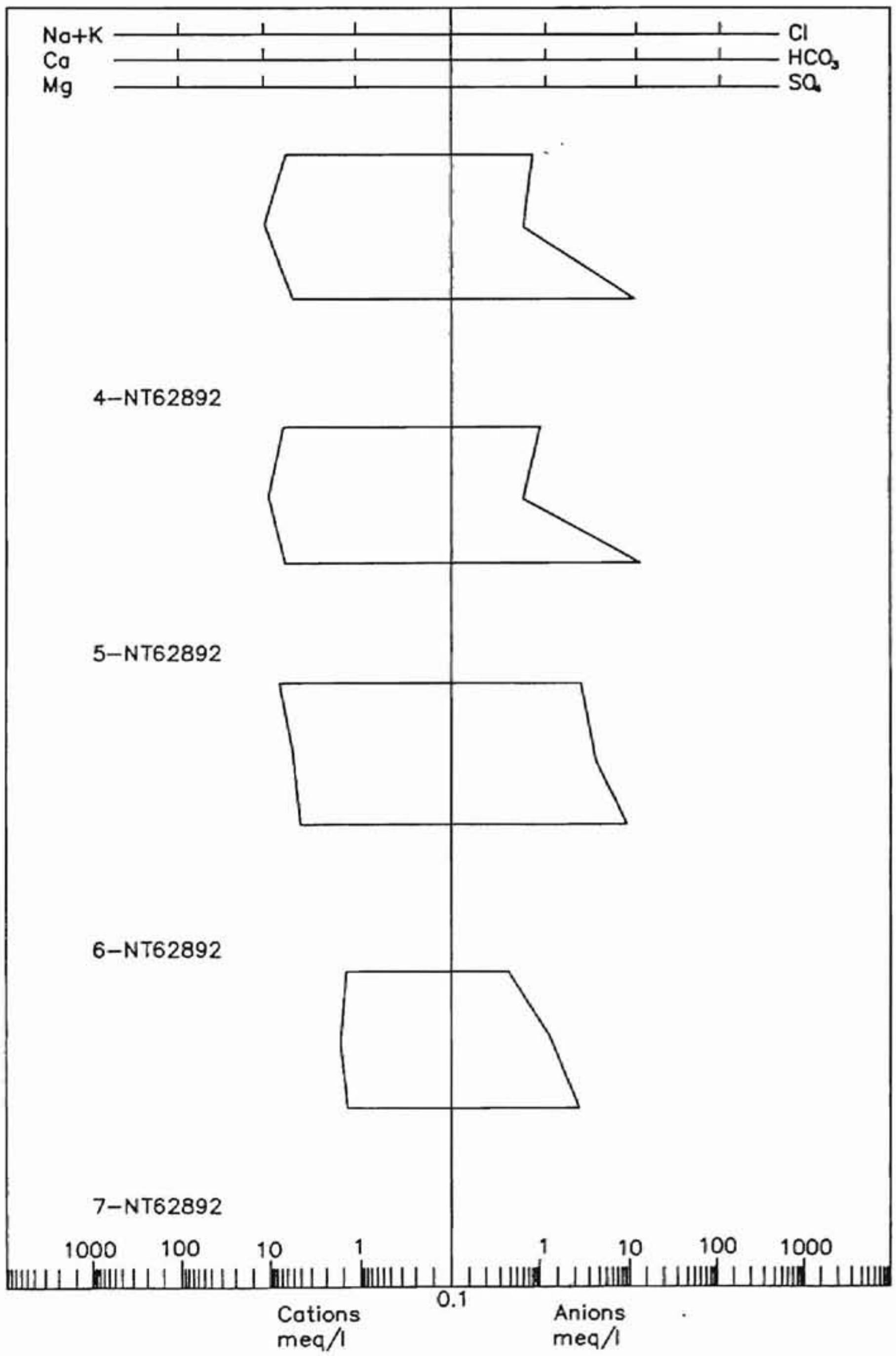


Figure 14. Stiff Diagrams of Sample Analyses, Northern Tributary

alluvial fans on the east side of the northern tributary, and groundwater discharge from outcropping fractured shale of the Senora Formation.

The significant reduction of calcium, magnesium, and sulfate probably is the result of precipitation of sulfate and carbonate minerals. Commingling of runoff from the smelter site (pH of 6.3 to 6.4 SU) with natural surface-water (pH of 7.4 SU) probably would result in a pH boundary. This is consistent with the analyses. The calculated saturation indices show that sample 6-NT62892 is over-saturated with respect to calcite ($CaCO_3$), dolomite (CaMg $(CaCO_3)_2$), rhodochrosite ($MnCO_3$), $ZnCO_3 \cdot H_2O$, and otavite ($CdCO_3$). Additionally, gypsum ($CaSO_4$) may precipitate even though the calculated saturation indices is under-saturated with respect to gypsum. High percent differences in the cation and anion balances (sum of cations greater than the sum of anions for each of the samples) may indicate that sulfate concentrations should be higher than reported. Higher sulfate concentrations could result in higher calculated saturation indices.

Water from sample location 6-NT62892 to 7-NT62892 passes through the impoundment (total distance between the locations is approximately 3245 feet). Comparison of analyses of samples 6-NT62892 to 7-NT62892 shows overall decrease in concentrations of major and minor constituents, which probably is due to dilution from stormwater runoff. However, the percent milliequivalent concentrations of calcium, magnesium, bicarbonate, and sulfate increase, but concentrations of sodium and chloride decrease. This trend is illustrated by the

Piper diagram (Figure 13). Lines connecting the two data points on the cation and anion portions of the diagram show a trend toward the calcium-magnesium and bicarbonate-sulfate baselines, respectively. Changes in composition (percent milliequivalent concentrations) between sample locations 6-NT62892 and 7-NT62892 are reflected in the Stiff diagram in Figure 14. The shape of the Stiff diagram for sample 7-NT62892 is indicative of water associated with dissolution of limestone. However, as illustrated by the shape of the Stiff diagram, magnesium and sulfate concentrations are higher than shown in literature (Hounslow, 1995); they may be the result of dissolution of minor amounts of dolomite along with sulfate from pyrite oxidation.

Trace Constituents. Surface-water samples 4-NT62892 through 7-NT62892 were submitted for analysis of 11 trace metals (aluminum, arsenic, barium, cadmium, cobalt, copper, lead, manganese, mercury, nickel, and zinc). Trace metals, as discussed previously, generally are defined by concentrations of less than 0.1 mg/L. Concentrations of aluminum, arsenic, cobalt, lead, and mercury were less than the laboratory reporting-limit in each of the samples. Five of the six trace metals (barium, cadmium, copper, nickel, and zinc) are associated with minerals contained in ore from the Tri-State Mining District. As discussed previously, the presence of these trace metals in samples from this study area are consistent with metals reported in stream waters of the Picher Mining Area, northeastern Oklahoma, and southeastern Kansas (Parkhurst, 1987).

Methods of metal-partitioning discussed previously (Southern Tributary, Trace Constituents) include complexation, sorption, precipitation, and biologic uptake. Each of these methods probably is important in varying degrees along the northern tributary.

Calculated activities and saturation indices, as for samples from the southern tributary, were used to evaluate which ions were likely to form complexes in the aqueous phase and which were likely to precipitate. Availability of hydrous oxides of aluminum, iron, and manganese for sorption sites was evaluated. Analyses of the trace metals detected in water samples from this study were compared to Eh-pH diagrams (Brookins, 1988, and Garrels and Christ, 1965), to determine which species (aqueous or solid phase) probably would exist for a given pH. Eh values of the samples were assumed to range from 0.4 to 0.6 volts (V), as was assumed for samples from the southern tributary.

Precipitation is assumed to be the most important mechanism for reducing concentrations of cadmium, manganese, and zinc. As discussed earlier, a significant difference in pH occurs between sample location 5-NT62892 (6.5 SU) and 6-NT62892 (7.4 SU). This difference in pH would likely result in a pH boundary.

Eh-pH diagrams show that the aqueous/solid phase boundaries are at pH of approximately 7 to 8 SU for cadmium, manganese, and zinc (Brookins, 1988, and Garrels and Christ, 1965). This is consistent with the calculated saturation indices. Saturation indices show that the samples 4-NT62892 (pH of 6.4 SU) and 5-NT62892 (pH of 6.5 SU) are over-saturated with respect to otavite ($CdCO_3$). However, at sample location 6-NT62892 (pH of 7.4 SU), water is over-saturated with respect to rhodochrosite ($MnCO_3$), $ZnCO_3 \cdot H_2O$, and otavite ($CdCO_3$) and likely results in precipitation of these minerals. This is consistent with the analyses which show the most significant reduction in concentrations occur at sample location 6-NT62892.

The Eh-pH diagram for barium indicates that barium (Ba-S-O-H-C system) precipitates as barite ($BaSO_4$) at pH greater than 1 SU (Brookins, 1988, and Garrels and Christ, 1965). This is consistent with the calculated saturation indices which show that barite is slightly over-saturated in each of the four samples. However, barite may not be precipitated. Barium concentrations are about the same between sample locations 4-NT62892 and 7-NT62892.

Sorption is assumed to be the most important mechanism for reducing concentrations of copper and nickel. As shown on the southern tributary, concentrations of dissolved aluminum and iron are high in low-pH water (location 1-ST62892). Likewise, it is assumed that low-pH water (3.8 SU) contained in the holding impoundment located on the north side of the slag pile would have similar concentrations of dissolved aluminum and iron, which would provide a continuing source for precipitation of iron and aluminum hydroxides. Iron and aluminum hydroxides then would be available as sorption sites for ions of cadmium, copper, manganese, nickel, and zinc. Further, the reduction in copper, zinc, cadmium, and nickel could be due, in part, to sorption by calcium carbonate (McLean and Bledsoe, 1992), which is over-saturated at location 6-NT62892 and likely precipitates.

Eh-pH diagrams show that copper precipitation as malachite ($Cu_2CO_3(OH)_2$), and/or tenorite (CuO) is likely at a pH of approximately 6.3 SU (Brookins, 1988, and Garrels and Christ, 1965). Copper is removed from solution by sample location 5-NT62892 (pH of 6.5 SU). However, calculated saturation indices show that tenorite and malachite are under-saturated in samples 4-NT62892 and 5-NT62892. Therefore, sorption is the likely mechanism for removal of copper from solution.

The most significant reduction in concentrations of nickel occur between locations 5-NT62892 and 6-NT62892. Eh-pH diagrams for nickel show that the aqueous-Ni^{2+} and solid phase boundary is approximately at 8.8 SU (with an activity of 10^{-6}), which is well above reported pH for samples from the northern tributary (Brookins, 1988, and Garrels and Christ, 1965). Therefore, sorption is the likely mechanism for removal of nickel from solution.

Lower concentrations of trace metals could also result from uptake by vegetation and sorption by humic materials present in water, from sample location 5-NT62892 through 7-NT62892. Mildly reducing or gley water resulting from decaying organic matter, present in water between sample locations 5-NT62892 and 6-NT62892, is not indicated. Between sample locations 5-NT62892 and 6-NT62892, iron and trace metal concentrations decrease. In gley water, dissolved oxygen, hydrogen sulfide, and ferric oxides and hydroxides are absent. Ferrous iron is present, and generally trace metal concentrations increase because of the absence of ferric oxides and hydroxides (Hounslow, 1995).

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are based on the results of this study:

1. Comparison of historical analytical date to data from this study indicates that total metal and probably dissolved metal concentrations in water draining from the smelter slag have not changed significantly since the 1982 and 1988 EPA sampling events.

2. Generally, pH was slightly acidic to slightly alkaline for samples collected in the study area. Three anomalous areas (pH less than 4 SU) were identified. One area included branches of the southern tributary draining the eastern slag pile. A second area was at sample location 1-ST62892 on the southern tributary. The third area was water flowing from the settling impoundment at the northern margin of the smelter slag. These pH anomalies probably are due to pyrite oxidation and/or acid mine drainage from former coal mines operated in the study area.

3. Water flows over a substrate of mixed silts, sands, gravels, and slag in the southern tributary. The data trends of water analyses from the southern tributary are generally described as follows:

a. The trend of major and minor constituents, as shown on a Piper diagram, is characteristic of gypsum precipitation. This is illustrated as removal of calcium and sulfate between successive, downstream sample locations.

b. The trend of minor and trace constituents is precipitation of aluminum and iron hydroxides, anglesite, basaluminite, and diaspore along with the sorption of cadmium, copper, nickel, manganese, and zinc to aluminum and iron hydroxides between each successive downstream sample locations.

4. Unlike flow in the southern tributary, flow in the northern tributary is through three environments: over and through silts, sands, gravels, and slag; through a wetlands; and through an elongated impoundment. Each of the three environments exhibits different data trends for major and minor constituents and trace constituents as described below:

a. The major and minor constituent trends, as illustrated on a Piper diagram, are as follows:

1. Flow over and through silts, sands, gravels, and slag is characterized by a trend toward the calcium-magnesium and sulfate-chloride baselines of the Piper diagram. This trend reflects slight increases in calcium, magnesium, sulfate, and chloride with decreases in sodium plus potassium and bicarbonate. This trend could be attributed to oxidation of minor amounts of pyrite buffered by dissolution of dolomite.

2. Flow through the wetlands is characterized by a trend toward the sodium plus potassium and bicarbonate regions of the Piper diagram. This

trend is likely due to the commingling of runoff from the smelter site with natural water (significant increases in sodium plus potassium, bicarbonate, and chloride) from springs along the base of alluvial fans on the east side of the northern tributary, and groundwater discharge from outcropping fractured shale of the Senora Formation, resulting in a higher pH (pH boundary) at sample location 6-NT62892 and precipitation calcite, dolomite (decreases in calcium and magnesium), and sulfate minerals (possibly gypsum). Gypsum ($CaSO_4$) may precipitate even though the calculated saturation indices is under-saturated with respect to gypsum. High percent differences in the cation and anion balances (sum of cations greater than the sum of anions for each of the samples) may indicate that sulfate concentrations should be higher than reported. Higher sulfate concentrations could result in higher calculated saturation indices.

3. Flow through the impoundment is characterized by a trend towards the calcium-magnesium and bicarbonate-sulfate baselines of the Piper diagram. This trend reflects slight increases in the percent milliequivalent concentrations of calcium, magnesium, bicarbonate, and sulfate with decreases in sodium plus potassium and chloride. This trend may be the result of dissolution of minor amounts of dolomite, sulfate from pyrite oxidation, and bicarbonate as an indirect product of pyrite oxidation.

b. The trace constituent trends are as follows:

1. Precipitation is assumed to be the most important mechanism for reducing concentrations of cadmium, manganese, and zinc by the

precipitation of otavite, rhodochrosite, and $ZnCO_3 \cdot H_2O$, respectively. Precipitation probably is in response to a pH boundary at sample location 6-NT62892.

2. Saturation indices shows that barite is over-saturated in each of the four samples. However, barium concentrations remain about the same among the sample locations. Therefore, barite probably does not precipitate.

3. Sorption of copper and nickel to aluminum and iron hydroxides, calcite, and humic material is assumed to be the most important mechanism for removal of copper and nickel from solution. Calculated saturation indices show that samples with detectable levels of copper and nickel are under-saturated with respect to solid phase minerals.

Recommendations

The following are the author's recommendations for further study:

1. Conduct a second surface-water sampling, using existing sample locations; the analyses could be used for comparison with data from the June 28, 1992.
2. A systematic study to determine the source of low pH waters.
3. Field measurements of Eh and dissolved oxygen in addition to pH.
4. Collect water samples from Coal Creek, upstream and downstream from confluences of the southern and northern tributaries, to assess the impact of tributaries on the water quality of Coal Creek.

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APPENDIXES

APPENDIX A

WATEVAL PRINTOUTS

Sample 1-ST62892

TempC	=	25.0	pH	=	3.8
TDS	=	1660.0	COND	=	1716.0
HARD	=	0.0	DENS	=	0.0
x-cor	=	0.0	y-cor	=	0.0
Units	=	mg/L	rock	=	0.0

	mg/L	mmole/L	meq/L	% meq/L
Na+	84.0	3.6536	3.6536	19.9
K +	14.2	0.3632	0.3632	2.0
Ca++	222.0	5.5389	11.0778	60.4
Mg++	38.0	1.5630	3.1260	17.0
Cl-	0.0	0.0000	0.0000	0.0
SO4--	693.0	7.2142	14.4285	99.9
HCO3-	0.0	0.0000	0.0000	0.0
CO3--	0.0	0.0000	0.0000	0.0
SiO2	0.0	0.0000	0.0000	0.0
Li+	0.0	0.0000	0.0000	0.0
Sr++	0.0	0.0000	0.0000	0.0
Ba++	0.0	0.0003	0.0006	0.0
Fe++	3.2	0.0582	0.1163	0.6
NO3-	0.7	0.0113	0.0113	0.1
F-	0.0	0.0000	0.0000	0.0
Br-	0.0	0.0000	0.0000	0.0
B	0.0	0.0000	0.0000	0.0

LANGELIER INDEX = 0.00 SAR = 1.4
Conductivity = 1716 umho Est. Cond. = 1834 umho

Analytical checks and comparisons

Sum cations = 18.3376 Sum anions = 14.4398
BALANCE = 11.89 %

TDS entered = 1660 mg/L
TDS calc = 1055 mg/L TDS(180) calc = 1055 mg/L
Entered TDS - TDS(calc) diff= 36.4 % Entered TDS - TDS(180) diff= 36.4 %

Conductivity = 1716 umho
TDS(entered)/Cond ratio = 0.97 Usual range = 0.55 to 0.75
TDS(calc)/Cond = 0.61 Usual range = 0.55 to 0.75
Conductivity/Sum-cations = 94 Usual range = 90 - 110

Entered and calculated density
Meas. Density = 0.0000 Calc. Density = 1.0011

Entered and calculated hardness
Meas. hardness= 0.0 mg/L CaCO3 Calc. hardness= 710.8 mg/L CaCO3

Element ratios
Na/(Na+Cl) = 100.0 % Usually > 50%

Ca/(Ca + SO4) = 43.4 % Usually > 50%
K/(Na + K) = 9.0 % Usually < 20%

Mg/(Mg+Ca) = 22.0 % Usually < 40%

Carbonate/bicarbonate at pH = 3.8
Meas HCO3 = 0.0 mg/L Meas CO3 = 0.0 mg/L
Calc HCO3 = 0.0 mg/L Calc CO3 = 0.0 mg/L

Sample 1-ST62892
SOURCE ROCK ESTIMATE

SiO2 (mmol/L)	=		SiO2 not analysed
HCO3/SiO2	=		SiO2 not analysed
			HCO3 not analysed
SiO2/(Na+K-Cl)	=		SiO2 not analysed
(Na+K-Cl)/(Na+K-Cl+Ca)	=	0.42	Plagioclase weathering possible
Na/(Na + Cl)	=	1.00	Albite or ion exchange
Mg/(Mg+Ca)	=	0.22	Granitic weathering
Ca/(Ca + SO4)	=	0.43	Pyrite oxidation
(Ca + Mg)/SO4	=	1.0	Dedolomitization likely
TDS calculated	=	1055 mg/L	Carbonate weathering, brine, evaporites or sea water
Cl/sum anions	=	0.00	Silicate or carbonate weathering
HCO3/sum anions	=	0.00	Sea water, brine, or evaporites
Langelier Index	=		

Mass Balance Calculation

Carbonate option

Mineral	Dissolves	Precipitates
HALITE	0.000	
CALCITE		-1.412
DOLOMITE	1.563	
GYPSUM	7.214	
ION EXCH	1.827	
CO2 GAS		-1.714

Silicate option

Mineral	Dissolves	Precipitates
HALITE	0.000	
ALBITE(K)	3.654	
ANORTHIT(K)		-3.238
DIOPSIDE	1.563	
GYPSUM	7.214	
CO2 GAS		-3.429

Analysed silica = 0 Silica from albite and diopside = 407 - 627

TEMPERATURE ESTIMATES IN DEGREES C

Good for temperatures 20 - 350 C

Mg-Li	-->	0
Na-Li	-->	0
Na-K-Ca (Mg corrected)	-->	57

Good for low temperatures 30 - 70 C

Chalcedony	-->	0

Good for temperatures > 70 C

Quartz-no steam loss	-->	0
Quartz-maximum steam loss	-->	0

Do not use for oil-field waters
May not be useful below 150 C

Na-K (Fournier)	-->	267
Na-K (Truesdell)	-->	271
Na-K-Ca (t < 100 C)	-->	57
Na-K-Ca (t > 100 C)	-->	175

Sample 2-ST62892

TempC	= 25.0		pH	=	6.0
TDS	= 1135.0		COND	=	1262.0
HARD	= 0.0		DENS	=	0.0
x-cor	= 0.0		y-cor	=	0.0
Units	= mg/L		rock	=	0.0

	mg/L	mmole/L	meq/L	% meq/L
Na+	61.0	2.6532	2.6532	19.5
K +	16.1	0.4117	0.4117	3.0
Ca++	159.0	3.9671	7.9341	58.2
Mg++	32.0	1.3162	2.6324	19.3
Cl-	0.0	0.0000	0.0000	0.0
SO4--	466.0	4.8511	9.7023	96.0
HCO3-	24.0	0.3933	0.3933	3.9
CO3--	0.0	0.0000	0.0000	0.0
SiO2	0.0	0.0000	0.0000	0.0
Li+	0.0	0.0000	0.0000	0.0
Sr++	0.0	0.0000	0.0000	0.0
Ba++	0.0	0.0002	0.0004	0.0
Fe++	0.1	0.0010	0.0020	0.0
NO3-	0.9	0.0145	0.0145	0.1
F-	0.0	0.0000	0.0000	0.0
Br-	0.0	0.0000	0.0000	0.0
B	0.0	0.0000	0.0000	0.0

LANGELIER INDEX = -1.95 SAR = 1.2
Conductivity = 1262 umho Est. Cond. = 1363 umho

Analytical checks and comparisons

Sum cations = 13.6339 Sum anions = 10.1101
BALANCE = 14.84 %
TDS entered = 1135 mg/L
TDS calc = 759 mg/L TDS(180) calc = 747 mg/L
Entered TDS - TDS(calc) diff= 33.1 % Entered TDS - TDS(180) diff= 34.2 %

Conductivity = 1262 umho
TDS(entered)/Cond ratio = 0.90 Usual range = 0.55 to 0.75
TDS(calc)/Cond = 0.60 Usual range = 0.55 to 0.75
Conductivity/Sum-cations = 93 Usual range = 90 - 110

Entered and calculated density
Meas. Density = 0.0000 Calc. Density = 1.0008

Entered and calculated hardness
Meas. hardness= 0.0 mg/L CaCO3 Calc. hardness= 528.8 mg/L CaCO3

Element ratios
Na/(Na+Cl) = 100.0 % Usually > 50%

Ca/(Ca + SO4) = 45.0 % Usually > 50%
K/(Na + K) = 13.4 % Usually < 20%

Mg/(Mg+Ca) = 24.9 % Usually < 40%

Carbonate/bicarbonate at pH = 6
Meas HCO3 = 24.0 mg/L Meas CO3 = 0.0 mg/L
Calc HCO3 = 24.0 mg/L Calc CO3 = 0.0 mg/L

Sample 2-ST62892

SOURCE ROCK ESTIMATE

SiO2 (mmol/L)	=		SiO2 not analysed
HCO3/SiO2	=		SiO2 not analysed
SiO2/(Na+K-Cl)	=		SiO2 not analysed
(Na+K-Cl)/(Na+K-Cl+Ca)	=	0.44	Plagioclase weathering possible
Na/(Na + Cl)	=	1.00	Albite or ion exchange
Mg/(Mg+Ca)	=	0.25	Granitic weathering
Ca/(Ca + SO4)	=	0.45	Ca removal ion exchange or calcite precipitation
(Ca + Mg)/SO4	=	1.1	Dedolomitization likely
TDS calculated	=	759 mg/L	Carbonate weathering, brine, evaporites or sea water
Cl/sum anions	=	0.00	Silicate or carbonate weathering
HCO3/sum anions	=	0.04	Sea water, brine, or evaporites
Langelier Index	=	-1.95	Undersaturated with respect to calcite

Mass Balance Calculation

Carbonate option

Mineral	Dissolves	Precipitates
HALITE	0.000	
CALCITE		-0.874
DOLOMITE	1.316	
GYPSUM	4.851	
ION EXCH	1.327	
CO2 GAS		-1.365

Silicate option

Mineral	Dissolves	Precipitates
HALITE	0.000	
ALBITE(K)	2.653	
ANORTHIT(K)		-2.200
DIOPSIDE	1.316	
GYPSUM	4.851	
CO2 GAS		-3.124

Analysed silica = 0 Silica from albite and diopside = 318 - 477

TEMPERATURE ESTIMATES IN DEGREES C

Good for temperatures 20 - 350 C

Mg-Li --> 0
Na-Li --> 0
Na-K-Ca (Mg corrected) --> 64

Good for low temperatures 30 - 70 C

Chalcedony --> 0

Good for temperatures > 70 C

Quartz-no steam loss --> 0
Quartz-maximum steam loss --> 0

Do not use for oil-field waters
May not be useful below 150 C

Na-K (Fournier) --> 317
Na-K (Truesdell) --> 344
Na-K-Ca (t < 100 C) --> 64
Na-K-Ca (t > 100 C) --> 197

Sample 3-ST62892

TempC =	25.0	pH =	6.3
TDS =	1062.0	COND =	1211.0
HARD =	0.0	DENS =	0.0
x-cor =	0.0	y-cor =	0.0
Units =	mg/L	rock =	0.0

	mg/L	mmole/L	meq/L	% meq/L
Na+	60.0	2.6097	2.6097	19.7
K +	15.5	0.3964	0.3964	3.0
Ca++	147.0	3.6677	7.3353	55.5
Mg++	35.0	1.4396	2.8792	21.8
Cl-	10.0	0.2821	0.2821	3.0
SO4--	415.0	4.3202	8.6404	90.9
HCO3-	35.0	0.5736	0.5736	6.0
CO3--	0.0	0.0000	0.0000	0.0
SiO2	0.0	0.0000	0.0000	0.0
Li+	0.0	0.0000	0.0000	0.0
Sr++	0.0	0.0000	0.0000	0.0
Ba++	0.0	0.0002	0.0005	0.0
Fe++	0.1	0.0024	0.0047	0.0
NO3-	0.9	0.0145	0.0145	0.2
F-	0.0	0.0000	0.0000	0.0
Br-	0.0	0.0000	0.0000	0.0
B	0.0	0.0000	0.0000	0.0

LANGELIER INDEX = -1.52 SAR = 1.2
Conductivity = 1211 umho Est. Cond. = 1323 umho

Analytical checks and comparisons

Sum cations = 13.2259 Sum anions = 9.5106
BALANCE = 16.34 %

TDS entered = 1062 mg/L
TDS calc = 719 mg/L TDS(180) calc = 701 mg/L
Entered TDS - TDS(calc) diff= 32.3 % Entered TDS - TDS(180) diff= 34.0 %

Conductivity = 1211 umho
TDS(entered)/Cond ratio = 0.88 Usual range = 0.55 to 0.75
TDS(calc)/Cond = 0.59 Usual range = 0.55 to 0.75
Conductivity/Sum-cations = 92 Usual range = 90 - 110

Entered and calculated density
Meas. Density = 0.0000 Calc. Density = 1.0007

Entered and calculated hardness
Meas. hardness= 0.0 mg/L CaCO3 Calc. hardness= 511.2 mg/L CaCO3

Element ratios
Na/(Na+Cl) = 90.2 % Usually > 50%

Ca/(Ca + SO4) = 45.9 % Usually > 50%
K/(Na + K) = 13.2 % Usually < 20%

Mg/(Mg+Ca) = 28.2 % Usually < 40%

Carbonate/bicarbonate at pH = 6.3
Meas HCO3 = 35.0 mg/L Meas CO3 = 0.0 mg/L
Calc HCO3 = 35.0 mg/L Calc CO3 = 0.0 mg/L

Sample 3-ST62892
SOURCE ROCK ESTIMATE

SiO2 (mmol/L)	=		SiO2 not analysed
HCO3/SiO2	=		SiO2 not analysed
SiO2/(Na+K-Cl)	=		SiO2 not analysed
(Na+K-Cl)/(Na+K-Cl+Ca)	=	0.43	Plagioclase weathering possible
Na/(Na + Cl)	=	0.90	Albite or ion exchange
Mg/(Mg+Ca)	=	0.28	Granitic weathering
Ca/(Ca + SO4)	=	0.46	Gypsum dissolution
(Ca + Mg)/SO4	=	1.2	Dedolomitization likely
TDS calculated	=	719 mg/L	Carbonate weathering, brine, evaporites or sea water
Cl/sum anions	=	0.03	Silicate or carbonate weathering
HCO3/sum anions	=	0.06	Sea water, brine, or evaporites
Langelier Index	=	-1.52	Undersaturated with respect to calcite

Mass Balance Calculation

Carbonate option

Mineral	Dissolves	Precipitates
HALITE	0.282	
CALCITE		-0.928
DOLOMITE	1.440	
GYPSUM	4.320	
ION EXCH	1.164	
CO2 GAS		-1.377

Silicate option

Mineral	Dissolves	Precipitates
HALITE	0.282	
ALBITE(K)	2.328	
ANORTHIT(K)		-2.092
DIOPSIDE	1.440	
GYPSUM	4.320	
CO2 GAS		-3.328

Analysed silica = 0 Silica from albite and diopside = 313 - 453

TEMPERATURE ESTIMATES IN DEGREES C

Good for temperatures 20 - 350 C

Mg-Li --> 0
Na-Li --> 0
Na-K-Ca (Mg corrected) --> 65

Good for low temperatures 30 - 70 C

Chalcedony --> 0

Good for temperatures > 70 C

Quartz-no steam loss --> 0
Quartz-maximum steam loss --> 0

Do not use for oil-field waters
May not be useful below 150 C

Na-K (Fournier) --> 315
Na-K (Truesdell) --> 340
Na-K-Ca (t < 100 C) --> 65
Na-K-Ca (t > 100 C) --> 196

Sample 4-NT62892

TempC	=	25.0	pH	=	6.4
TDS	=	1766.0	COND	=	1867.0
HARD	=	0.0	DENS	=	0.0
x-cor	=	0.0	y-cor	=	0.0
Units	=	mg/L	rock	=	0.0

	mg/L	mmole/L	meq/L	% meq/L
Na+	120.0	5.2194	5.2194	24.7
K +	27.9	0.7135	0.7135	3.4
Ca++	203.0	5.0649	10.1297	47.9
Mg++	62.0	2.5502	5.1004	24.1
Cl-	35.0	0.9872	0.9872	6.3
SO4--	664.0	6.9123	13.8247	88.8
HCO3-	46.0	0.7539	0.7539	4.8
CO3--	0.0	0.0000	0.0000	0.0
SiO2	0.0	0.0000	0.0000	0.0
Li+	0.0	0.0000	0.0000	0.0
Sr++	0.0	0.0000	0.0000	0.0
Ba++	0.0	0.0003	0.0006	0.0
Fe++	0.1	0.0016	0.0032	0.0
NO3-	0.6	0.0097	0.0097	0.1
F-	0.0	0.0000	0.0000	0.0
Br-	0.0	0.0000	0.0000	0.0
B	0.0	0.0000	0.0000	0.0

LANGELIER INDEX = -1.21 SAR = 1.9
Conductivity = 1867 umho Est. Cond. = 2117 umho

Analytical checks and comparisons

Sum cations = 21.1669 Sum anions = 15.5755
BALANCE = 15.22 %

TDS entered = 1766 mg/L
TDS calc = 1159 mg/L TDS(180) calc = 1135 mg/L
Entered TDS - TDS(calc) diff= 34.4 % Entered TDS - TDS(180) diff= 35.7 %

Conductivity = 1867 umho
TDS(entered)/Cond ratio = 0.95 Usual range = 0.55 to 0.75
TDS(calc)/Cond = 0.62 Usual range = 0.55 to 0.75
Conductivity/Sum-cations = 88 Usual range = 90 - 110

Entered and calculated density
Meas. Density = 0.0000 Calc. Density = 1.0012

Entered and calculated hardness
Meas. hardness= 0.0 mg/L CaCO3 Calc. hardness= 762.2 mg/L CaCO3

Element ratios
Na/(Na+Cl) = 84.1 % Usually > 50%

Ca/(Ca + SO4) = 42.3 % Usually > 50%
K/(Na + K) = 12.0 % Usually < 20%

Mg/(Mg+Ca) = 33.5 % Usually < 40%

Carbonate/bicarbonate at pH = 6.4
Meas HCO3 = 46.0 mg/L Meas CO3 = 0.0 mg/L
Calc HCO3 = 46.0 mg/L Calc CO3 = 0.0 mg/L

Sample 4-NT62892

SOURCE ROCK ESTIMATE

SiO2 (mmol/L)	=		SiO2 not analysed
HCO3/SiO2	=		SiO2 not analysed
SiO2/(Na+K-Cl)	=		SiO2 not analysed
(Na+K-Cl)/(Na+K-Cl+Ca)	=	0.49	Plagioclase weathering possible
Na/(Na + Cl)	=	0.84	Albite or ion exchange
Mg/(Mg+Ca)	=	0.33	Granitic weathering
Ca/(Ca + SO4)	=	0.42	Ca removal ion exchange or calcite precipitation
(Ca + Mg)/SO4	=	1.1	Dedolomitization likely
TDS calculated	=	1159 mg/L	Carbonate weathering, brine, evaporites or sea water
Cl/sum anions	=	0.06	Silicate or carbonate weathering
HCO3/sum anions	=	0.05	Sea water, brine, or evaporites
Langelier Index	=	-1.21	Undersaturated with respect to calcite

Mass Balance Calculation

Carbonate option

Mineral	Dissolves	Precipitates
HALITE	0.987	
CALCITE		-2.282
DOLOMITE	2.550	
GYPSUM	6.912	
ION EXCH	2.116	
CO2 GAS		-2.065

Silicate option

Mineral	Dissolves	Precipitates
HALITE	0.987	
ALBITE(K)	4.232	
ANORTHIT(K)		-4.398
DIOPSIDE	2.550	
GYPSUM	6.912	
CO2 GAS		-4.884

Analysed silica = 0 Silica from albite and diopside = 561 - 815

TEMPERATURE ESTIMATES IN DEGREES C

Good for temperatures 20 - 350 C

Mg-Li	-->	0
Na-Li	-->	0
Na-K-Ca (Mg corrected)	-->	62

Good for low temperatures 30 - 70 C

Chalcedony	-->	0

Good for temperatures > 70 C

Quartz-no steam loss	-->	0
Quartz-maximum steam loss	-->	0

Do not use for oil-field waters

Sample 5-NT62892

TempC =	25.0	pH =	6.5
TDS =	1754.0	COND =	1918.0
HARD =	0.0	DENS =	0.0
x-cor =	0.0	y-cor =	0.0
Units =	mg/L	rock =	0.0

	mg/L	mmole/L	meq/L	% meq/L
Na+	116.0	5.0455	5.0455	22.7
K +	23.7	0.6061	0.6061	2.7
Ca++	214.0	5.3393	10.6786	48.1
Mg++	71.0	2.9204	5.8407	26.3
Cl-	39.0	1.1000	1.1000	6.5
SO4--	723.0	7.5265	15.0531	89.3
HCO3-	43.0	0.7047	0.7047	4.2
CO3--	0.0	0.0000	0.0000	0.0
SiO2	0.0	0.0000	0.0000	0.0
Li+	0.0	0.0000	0.0000	0.0
Sr++	0.0	0.0000	0.0000	0.0
Ba++	0.1	0.0004	0.0008	0.0
Fe++	0.2	0.0035	0.0070	0.0
NO3-	0.5	0.0081	0.0081	0.0
F-	0.0	0.0000	0.0000	0.0
Br-	0.0	0.0000	0.0000	0.0
B	0.0	0.0000	0.0000	0.0

LANGELIER INDEX = -1.13 SAR = 1.8
Conductivity = 1918 umho Est. Cond. = 2218 umho

Analytical checks and comparisons

Sum cations = 22.1788 Sum anions = 16.8659
BALANCE = 13.61 %
TDS entered = 1754 mg/L
TDS calc = 1230 mg/L TDS(180) calc = 1209 mg/L
Entered TDS - TDS(calc) diff= 29.8 % Entered TDS - TDS(180) diff= 31.1 %

Conductivity = 1918 umho
TDS(entered)/Cond ratio = 0.91 Usual range = 0.55 to 0.75
TDS(calc)/Cond = 0.64 Usual range = 0.55 to 0.75
Conductivity/Sum-cations = 86 Usual range = 90 - 110

Entered and calculated density
Meas. Density = 0.0000 Calc. Density = 1.0012

Entered and calculated hardness
Meas. hardness= 0.0 mg/L CaCO3 Calc. hardness= 826.7 mg/L CaCO3

Element ratios
Na/(Na+Cl) = 82.1 % Usually > 50%

Ca/(Ca + SO4) = 41.5 % Usually > 50%
K/(Na + K) = 10.7 % Usually < 20%

Mg/(Mg+Ca) = 35.4 % Usually < 40%

Carbonate/bicarbonate at pH = 6.5
Meas HCO3 = 43.0 mg/L Meas CO3 = 0.0 mg/L
Calc HCO3 = 43.0 mg/L Calc CO3 = 0.0 mg/L

Sample 5-NT62892
SOURCE ROCK ESTIMATE

SiO2 (mmol/L)	=		SiO2 not analysed
HCO3/SiO2	=		SiO2 not analysed
SiO2/(Na+K-Cl)	=		SiO2 not analysed
(Na+K-Cl)/(Na+K-Cl+Ca)	=	0.46	Plagioclase weathering possible
Na/(Na + Cl)	=	0.82	Albite or ion exchange
Mg/(Mg+Ca)	=	0.35	Granitic weathering
Ca/(Ca + SO4)	=	0.41	Ca removal ion exchange or calcite precipitation
(Ca + Mg)/SO4	=	1.1	Dedolomitization likely
TDS calculated	=	1230 mg/L	Carbonate weathering, brine, evaporites or sea water
Cl/sum anions	=	0.07	Silicate or carbonate weathering
HCO3/sum anions	=	0.04	Sea water, brine, or evaporites
Langelier Index	=	-1.13	Undersaturated with respect to calcite

Mass Balance Calculation

Carbonate option

Mineral	Dissolves	Precipitates
HALITE	1.100	
CALCITE		-3.135
DOLOMITE	2.920	
GYPSUM	7.527	
ION EXCH	1.973	
CO2 GAS		-2.001

Silicate option

Mineral	Dissolves	Precipitates
HALITE	1.100	
ALBITE(K)	3.945	
ANORTHIT(K)		-5.108
DIOPSIDE	2.920	
GYPSUM	7.527	
CO2 GAS		-4.707

Analysed silica = 0 Silica from albite and diopside = 588 - 825

TEMPERATURE ESTIMATES IN DEGREES C

Good for temperatures 20 - 350 C

Mg-Li	-->	0
Na-Li	-->	0
Na-K-Ca (Mg corrected)	-->	61

Good for low temperatures 30 - 70 C

Chalcedony	-->	0

Good for temperatures > 70 C

Quartz-no steam loss	-->	0
Quartz-maximum steam loss	-->	0

Do not use for oil-field waters
May not be useful below 150 C

Na-K (Fournier)	-->	287
Na-K (Truesdell)	-->	299
Na-K-Ca (t < 100 C)	-->	77
Na-K-Ca (t > 100 C)	-->	191

Sample 6-NT62892

TempC =	25.0	pH =	7.4
TDS =	1300.0	COND =	1716.0
HARD =	0.0	DENS =	0.0
x-cor =	0.0	y-cor =	0.0
Units =	mg/L	rock =	0.0

	mg/L	mmole/L	meq/L	% meq/L
Na+	163.0	7.0897	7.0897	40.6
K +	17.5	0.4475	0.4475	2.6
Ca++	111.0	2.7695	5.5389	31.8
Mg++	53.0	2.1800	4.3600	25.0
Cl-	96.0	2.7078	2.7078	17.7
SO4--	413.0	4.2994	8.5988	56.1
HCO3-	246.0	4.0317	4.0317	26.3
CO3--	0.0	0.0000	0.0000	0.0
SiO2	0.0	0.0000	0.0000	0.0
Li+	0.0	0.0000	0.0000	0.0
Sr++	0.0	0.0000	0.0000	0.0
Ba++	0.0	0.0003	0.0007	0.0
Fe++	0.1	0.0026	0.0052	0.0
NO3-	0.0	0.0000	0.0000	0.0
F-	0.0	0.0000	0.0000	0.0
Br-	0.0	0.0000	0.0000	0.0
B	0.0	0.0000	0.0000	0.0

LANGELIER INDEX = 0.28 SAR = 3.2
Conductivity = 1716 umho Est. Cond. = 1744 umho

Analytical checks and comparisons

Sum cations = 17.4421 Sum anions = 15.3383
BALANCE = 6.42 %
TDS entered = 1300 mg/L
TDS calc = 1100 mg/L TDS(180) calc = 975 mg/L
Entered TDS - TDS(calc) diff= 15.4 % Entered TDS - TDS(180) diff= 25.0 %

Conductivity = 1716 umho
TDS(entered)/Cond ratio = 0.76 Usual range = 0.55 to 0.75
TDS(calc)/Cond = 0.64 Usual range = 0.55 to 0.75
Conductivity/Sum-cations = 98 Usual range = 90 - 110

Entered and calculated density
Meas. Density = 0.0000 Calc. Density = 1.0010

Entered and calculated hardness
Meas. hardness= 0.0 mg/L CaCO3 Calc. hardness= 495.4 mg/L CaCO3

Element ratios
Na/(Na+Cl) = 72.4 % Usually > 50%

Ca/(Ca + SO4) = 39.2 % Usually > 50%
K/(Na + K) = 5.9 % Usually < 20%

Mg/(Mg+Ca) = 44.0 % Usually < 40%

Carbonate/bicarbonate at pH = 7.4
Meas HCO3 = 246.0 mg/L Meas CO3 = 0.0 mg/L
Calc HCO3 = 245.1 mg/L Calc CO3 = 0.4 mg/L

Sample 6-NT62892
SOURCE ROCK ESTIMATE

SiO2 (mmol/L)	=		SiO2 not analysed
HCO3/SiO2	=		SiO2 not analysed
SiO2/(Na+K-Cl)	=		SiO2 not analysed
(Na+K-Cl)/(Na+K-Cl+Ca)	=	0.64	Plagioclase weathering possible
Na/(Na + Cl)	=	0.72	Albite or ion exchange
Mg/(Mg+Ca)	=	0.44	Granitic weathering
Ca/(Ca + SO4)	=	0.39	Ca removal ion exchange or calcite precipitation
(Ca + Mg)/SO4	=	1.2	Dedolomitization likely
TDS calculated	=	1100 mg/L	Carbonate weathering, brine, evaporites or sea water
Cl/sum anions	=	0.18	Silicate or carbonate weathering
HCO3/sum anions	=	0.26	
Langelier Index	=	0.28	Oversaturated with respect to calcite

Mass Balance Calculation

Carbonate option

Mineral	Dissolves	Precipitates
HALITE	2.708	
CALCITE		-1.519
DOLOMITE	2.180	
GYPSUM	4.299	
ION EXCH	2.191	
CO2 GAS	1.191	

Silicate option

Mineral	Dissolves	Precipitates
HALITE	2.708	
ALBITE(K)	4.382	
ANORTHIT(K)		-3.710
DIOPSIDE	2.180	
GYPSUM	4.299	
CO2 GAS		-1.650

Analysed silica = 0 Silica from albite and diopside = 525 - 789

TEMPERATURE ESTIMATES IN DEGREES C

Good for temperatures 20 - 350 C

Mg-Li	-->	0
Na-Li	-->	0
Na-K-Ca (Mg corrected)	-->	43

Good for low temperatures 30 - 70 C

Chalcedony	-->	0

Good for temperatures > 70 C

Quartz-no steam loss	-->	0
Quartz-maximum steam loss	-->	0

Do not use for oil-field waters
May not be useful below 150 C

Na-K (Fournier)	-->	223
Na-K (Truesdell)	-->	212
Na-K-Ca (t < 100 C)	-->	85
Na-K-Ca (t > 100 C)	-->	169

Sample 7-NT62892

TempC	= 25.0		pH	=	7.5
TDS	= 306.0		COND	=	439.0
HARD	= 0.0		DENS	=	0.0
x-cor	= 0.0		y-cor	=	0.0
Units	= mg/L		rock	=	0.0

	mg/L	mmole/L	meq/L	% meq/L
Na+	28.0	1.2179	1.2179	28.3
K +	6.6	0.1688	0.1688	3.9
Ca++	32.0	0.7984	1.5968	37.1
Mg++	16.0	0.6581	1.3162	30.6
Cl-	16.0	0.4513	0.4513	9.7
SO4--	132.0	1.3741	2.7483	59.0
HCO3-	89.0	1.4586	1.4586	31.3
CO3--	0.0	0.0000	0.0000	0.0
SiO2	0.0	0.0000	0.0000	0.0
Li+	0.0	0.0000	0.0000	0.0
Sr++	0.0	0.0000	0.0000	0.0
Ba++	0.0	0.0002	0.0005	0.0
Fe++	0.1	0.0020	0.0039	0.1
NO3-	0.0	0.0000	0.0000	0.0
F-	0.0	0.0000	0.0000	0.0
Br-	0.0	0.0000	0.0000	0.0
B	0.0	0.0000	0.0000	0.0

LANGELIER INDEX = -0.47 SAR = 1.0
Conductivity = 439 umho Est. Cond. = 430 umho

Analytical checks and comparisons

Sum cations = 4.3041 Sum anions = 4.6582
BALANCE = -3.95 %

TDS entered = 306 mg/L
TDS calc = 320 mg/L TDS(180) calc = 275 mg/L
Entered TDS - TDS(calc) diff= -4.5 % Entered TDS - TDS(180) diff= 10.3 %

Conductivity = 439 umho
TDS(entered)/Cond ratio = 0.70 Usual range = 0.55 to 0.75
TDS(calc)/Cond = 0.73 Usual range = 0.55 to 0.75
Conductivity/Sum-cations = 102 Usual range = 90 - 110

Entered and calculated density
Meas. Density = 0.0000 Calc. Density = 1.0003

Entered and calculated hardness
Meas. hardness= 0.0 mg/L CaCO3 Calc. hardness= 145.8 mg/L CaCO3

Element ratios
Na/(Na+Cl) = 73.0 % Usually > 50%

Ca/(Ca + SO4) = 36.7 % Usually > 50%
K/(Na + K) = 12.2 % Usually < 20%

Mg/(Mg+Ca) = 45.2 % Usually < 40%

Carbonate/bicarbonate at pH = 7.5
Meas HCO3 = 89.0 mg/L Meas CO3 = 0.0 mg/L
Calc HCO3 = 88.7 mg/L Calc CO3 = 0.2 mg/L

Sample 7-NT62892

SOURCE ROCK ESTIMATE

```
SiO2 (mmol/L)          =              SiO2 not analysed
HCO3/SiO2              =              SiO2 not analysed
SiO2/(Na+K-Cl)         =              SiO2 not analysed
(Na+K-Cl)/(Na+K-Cl+Ca)= 0.54          Plagioclase weathering possible
Na/(Na + Cl)           =     0.73     Albite or ion exchange
Mg/(Mg+Ca)             =     0.45     Granitic weathering
Ca/(Ca + SO4)          =     0.37     Ca removal
                                         ion exchange or calcite precipitation
(Ca + Mg)/SO4          =     1.1      Dedolomitization likely
TDS calculated         =   320 mg/L   Silicate weathering possible
Cl/sum anions          =     0.10     Silicate or carbonate weathering
HCO3/sum anions        =     0.31
Langelier Index        =    -0.47     Undersaturated with respect to calcite
```

Mass Balance Calculation

Carbonate option

Mineral	Dissolves	Precipitates
HALITE	0.451	
CALCITE		-0.851
DOLOMITE	0.658	
GYPSUM	1.374	
ION EXCH	0.383	
CO2 GAS	0.993	

Silicate option

Mineral	Dissolves	Precipitates
HALITE	0.451	
ALBITE(K)	0.767	
ANORTHIT(K)		-1.234
DIOPSIDE	0.658	
GYPSUM	1.374	
CO2 GAS	0.527	

Analysed silica = 0 Silica from albite and diopside = 125 - 171

TEMPERATURE ESTIMATES IN DEGREES C

```
                      Good for temperatures 20 - 350 C
Mg-Li                          -->    0
Na-Li                          -->    0
Na-K-Ca (Mg corrected)         -->   53

                      Good for low temperatures 30 - 70 C
Chalcedony                     -->    0

                      Good for temperatures > 70 C
Quartz-no steam loss           -->    0
Quartz-maximum steam loss      -->    0

                      Do not use for oil-field waters
                      May not be useful below 150 C
Na-K (Fournier)                -->  304
Na-K (Truesdell)               -->  323
Na-K-Ca (t < 100 C)            -->   62
Na-K-Ca (t > 100 C)            -->  191
```

APPENDIX B

WATEQ4F PRINTOUTS

DOX = .0000 DOC = .0 INPUT TDS = 1660.0
Anal Cond = 1716.0 Calc Cond = 1727.5
Anal EPMCAT = 23.5372 Anal EPMAN = 14.4567 Percent difference in input cation/anion balance = 47.7995
ERROR IN CALCULATED CHARGE BALANCE GREATER THAN 30 PERCENT. CHECK INPUT DATA.

Calc EPMCAT = 18.8484 Calc EPMAN = 9.8175 Percent difference in calc cation/anion balance = 63.0080
Total Ionic Strength (T.I.S.) from input data = .03651
Effective Ionic Strength (E.I.S.) from speciation = .02671

	Input	Sigma	Fe3/Fe2	Sigma	Sato H2O2/O2	Sigma	NO3/NO2	Sigma	NO3/NH4	Sigma	Calc H2O2/O2	Sigma	SO4/S=	Sigma	As5/As3	Sigma
Eh	9.900	.000	9.900	.000	9.900	.000	.000	.000	9.900	.000	9.900	.000	9.900	.000	9.900	.000
pE	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000

T	pH	TDS ppm	Effective Ionic Str	pO2 Atm	pCO2 Atm	pCH4 Atm	CO2 Tot	Uncom CO2	ppm Uncom CO2	Nerb Alk	aH2O
25.00	3.800	1189.2	.02671	0.00E+00	0.00E+00	0.00E+00	.00000	0.00E+00	0.00E+00	7.48E-11	.9997

I	Species		Anal ppm	Calc ppm	Anal Molal	Calc Molal	Activity	Act Coeff	-Log Act
0	Ca	2	222.000	171.599	5.546E-03	4.286E-03	2.366E-03	.5520	2.626
28	CaOH	1		.000000		4.391E-12	3.759E-12	.8561	11.425
31	CaSO4 aq	0		171.125		1.258E-03	1.266E-03	1.0062	2.897
81	CaHSO4	1		.184		1.343E-06	1.150E-06	.8561	5.939
1	Mg	2	38.000	30.161	1.565E-03	1.242E-03	6.957E-04	.5601	3.158
18	MgOH	1		.000000		8.233E-12	7.048E-12	.8561	11.152
22	MgSO4 aq	0		38.838		3.230E-04	3.250E-04	1.0062	3.488
2	Na	1	84.000	82.907	3.658E-03	3.611E-03	3.098E-03	.8580	2.509
43	NaSO4	1		5.665		4.764E-05	4.079E-05	.8561	4.389
3	K	1	14.200	13.944	3.636E-04	3.570E-04	3.041E-04	.8518	3.517
45	KSO4	-1		.885		6.558E-06	5.615E-06	.8561	5.251
63	H	1		.182		1.804E-04	1.585E-04	.8788	3.800
26	OH	-1		.000001		7.388E-11	6.325E-11	.8561	10.199
5	SO4	-2	693.000	462.454	7.223E-03	4.820E-03	2.627E-03	.5451	2.581
62	HSO4	-1		4.577		4.721E-05	4.042E-05	.8561	4.393
84	NO3	-1	.700	.700	1.130E-05	1.130E-05	9.677E-06	.8561	5.014
50	Al	3	10.950	5.503	4.063E-04	2.042E-04	5.046E-05	.2471	4.297
51	AlOH	2		.266		6.063E-06	3.257E-06	.5373	5.487
52	Al(OH)2	1		.011		1.863E-07	1.595E-07	.8561	6.797
181	Al(OH)3	0		.000098		1.259E-09	1.266E-09	1.0062	8.897
53	Al(OH)4	-1		.000000		9.330E-13	7.988E-13	.8561	12.098
58	AlSO4	1		19.928		1.622E-04	1.388E-04	.8561	3.858
59	Al(SO4)2	-1		7.401		3.382E-05	2.895E-05	.8561	4.538
203	AlHSO4	2		.001357		1.095E-08	5.882E-09	.5373	8.230
16	Fe total	2	3.248		5.823E-05				
109	Mn	2	4.749	3.784	8.655E-05	6.895E-05	3.705E-05	.5373	4.431
114	MnOH	1		.000000		7.016E-12	6.006E-12	.8561	11.221
115	Mn(OH)3	-1		.000000		1.721E-28	1.473E-28	.8561	27.832
118	Mn(NO3)2	0		.000000		1.373E-14	1.381E-14	1.0062	13.860
117	MnSO4 aq	0		2.655		1.760E-05	1.771E-05	1.0062	4.752
130	Cu	2	13.230	10.286	2.084E-04	1.621E-04	8.706E-05	.5373	4.060
138	CuOH	1		.000516		6.414E-09	5.492E-09	.8561	8.260
139	Cu(OH)2	0		.000007		7.193E-11	7.237E-11	1.0062	10.140
140	Cu(OH)3	-1		.000000		3.213E-20	2.751E-20	.8561	19.561
141	Cu(OH)4	-2		.000000		6.443E-29	3.462E-29	.5373	28.461
142	Cu2(OH)2	2		.000004		2.454E-11	1.319E-11	.5373	10.880

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I	Species		Anal ppm	Calc ppm	Anal Molal	Calc Molal	Activity	Act Coeff	-Log Act
143	CuSO4 aq	0		7.399		4.641E-05	4.670E-05	1.0062	4.331
145	Zn	2	103.600	77.211	1.587E-03	1.183E-03	6.353E-04	.5373	3.197
151	ZnOH	1		.000422		5.132E-09	4.394E-09	.8561	8.357
152	Zn(OH)2	0		.000000		3.163E-13	3.182E-13	1.0062	12.497
153	Zn(OH)3	-1		.000000		7.414E-21	6.347E-21	.8561	20.197
154	Zn(OH)4	-2		.000000		1.181E-29	6.345E-30	.5373	29.198
158	ZnSO4 aq	0		62.703		3.889E-04	3.913E-04	1.0062	3.408
159	Zn(SO4)2	-2		3.997		1.554E-05	8.350E-06	.5373	5.078
160	Cd	2	.412	.289	3.670E-06	2.573E-06	1.383E-06	.5373	5.859
167	CdOH	1		.000000		8.472E-13	7.253E-13	.8561	12.139
168	Cd(OH)2	0		.000000		2.442E-19	2.457E-19	1.0062	18.610
169	Cd(OH)3	-1		.000000		2.031E-28	1.739E-28	.8561	27.760
170	Cd(OH)4	-2		.000000		1.819E-38	9.775E-39	.5373	38.010
171	Cd2OH	3		.000000		1.983E-17	4.900E-18	.2471	17.310
173	CdNO3	1		.000007		3.925E-11	3.361E-11	.8561	10.474
174	CdSO4 aq	0		.217		1.041E-06	1.048E-06	1.0062	5.980
277	Cd(SO4)2	-2		.012		5.613E-08	3.016E-08	.5373	7.521
182	Pb	2	.333	.184	1.609E-06	8.896E-07	4.779E-07	.5373	6.321
192	PbOH	1		.000015		6.866E-11	5.878E-11	.8561	10.231
193	Pb(OH)2	0		.000000		1.434E-16	1.442E-16	1.0062	15.841
194	Pb(OH)3	-1		.000000		1.220E-23	1.045E-23	.8561	22.981
242	Pb(OH)4	-2		.000000		2.810E-31	1.509E-31	.5373	30.821
195	Pb2OH	3		.000000		2.536E-15	6.267E-16	.2471	15.203
200	Pb3(OH)4	2		.000000		4.211E-28	2.262E-28	.5373	27.645
196	PbNO3	1		.000021		7.990E-11	6.841E-11	.8561	10.165
197	PbSO4 aq	0		.213		7.017E-07	7.061E-07	1.0062	6.151
243	Pb(SO4)2	-2		.007222		1.811E-08	9.729E-09	.5373	8.012
204	Ni	2	.768	.603	1.310E-05	1.028E-05	5.526E-06	.5373	5.258
208	NiOH	1		.000000		5.619E-12	4.811E-12	.8561	11.318
209	Ni(OH)2	0		.000000		2.185E-17	2.198E-17	1.0062	16.658
210	Ni(OH)3	-1		.000000		1.620E-24	1.387E-24	.8561	23.858
211	NiSO4 aq	0		.435		2.813E-06	2.830E-06	1.0062	5.548
283	Ni(SO4)2	-2		.000186		7.428E-10	3.991E-10	.5373	9.399
89	Ba	2	.042	.025	3.062E-07	1.798E-07	9.661E-08	.5373	7.015
90	BaOH	1		.000000		3.129E-17	2.679E-17	.8561	16.572
201	BaSO4 aq	0		.029		1.264E-07	1.272E-07	1.0062	6.895

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	Phase	Log AP/KT	Sigma(A)	Sigma(T)	Log AP/MinKT	Log AP/MaxKT	Log AP	Log KT	Log MinKT	Log MaxKT
140	AlOH3 (a)	-3.283			-2.594		-34.894	-31.611	-32.300	
471	AlOHSO4	.152			.312	-.008	-3.078	-3.230	-3.390	-3.070
472	Al4(OH)10SO4	-4.470					18.230	22.700		
338	Alum k	-7.807					-12.977	-5.170		
50	Alunite	2.571					-82.763	-85.334		
17	Anhydrite	-.569					-5.206	-4.637		
144	Barite	.381				.178	-9.595	-9.976		-9.773
52	Boehmite	-1.478			-.965		-34.894	-33.416	-33.929	
19	Brucite	-12.351					-23.555	-11.204		
154	Diaspore	.227					-34.894	-35.121		
340	Epsomite	-3.599					-5.739	-2.140		
51	Gibbsite (c)	-1.667		.200	-1.384	-2.337	7.103	8.770	8.487	9.440
18	Gypsum	-.607					-5.207	< -4.600		
66	Mirabilite	-6.486					-7.600	-1.114		
65	Thenardite	-7.419					-7.598	-.179		
188	Pyrocroite	-11.920				-12.213	3.168	15.088		15.381
182	MnSO4	-9.681					-7.012	2.669		
234	Cu(OH)2	-5.100				-5.660	3.540	8.640		9.200
238	Cu2(OH)3NO3	-10.975				-11.045	-1.735	9.240		9.310
239	Antlerite	-7.852				-8.462	.438	8.290		8.900
240	Brochantite	-11.362		.160	-11.172	-11.522	3.978	15.340	15.150	15.500
241	Langite	-12.812				-13.422	3.978	16.790		17.400
242	Tenorite	-4.080			-3.810	-4.350	3.540	7.620	7.350	7.890
243	CuOCuSO4	-22.231					-10.701	11.530		
247	CuSO4	-9.651			-9.291	-10.061	-6.641	3.010	2.650	3.420
248	Chalcanthite	-4.001			-3.681	-4.506	-6.641	-2.640	-2.960	-2.135
271	Zn(OH)2 (a)	-8.047			-7.857	-8.077	4.403	12.450	12.260	12.480
272	Zn(OH)2 (c)	-7.797					4.403	12.200		
273	Zn(OH)2 (b)	-7.347		.020	-6.917	-7.487	4.403	11.750	11.320	11.890
274	Zn(OH)2 (g)	-7.307			-6.787	-7.437	4.403	11.710	11.190	11.840
275	Zn(OH)2 (e)	-7.097		.030	-6.547	-7.217	4.403	11.500	10.950	11.620
278	Zn2(OH)2SO4	-8.875					-1.375	7.500		
279	Zn4(OH)6SO4	-20.969					7.431	28.400		
280	ZnNO3)2,6H2O	-16.666					-13.226	3.440		
281	ZnO(active)	-6.907			-7.167	-7.457	4.403	11.310	11.570	11.860
282	Zincite	-6.737			-6.587	-7.137	4.403	11.140	10.990	11.540
283	Zn3O(SO4)2	-26.172					-7.152	19.020		
290	Zincosite	-8.788				-9.708	-5.778	3.010		3.930
291	ZnSO4, 1H2O	-5.208				-5.278	-5.778	-.570		-.500
292	Bianchite	-4.013				-4.758	-5.778	-1.765		-1.020
293	Goslarite	-3.818				-3.908	-5.778	-1.960		-1.870
320	Cd(OH)2 (a)	-11.990			-11.870	-12.560	1.740	13.730	13.610	14.300
321	Cd(OH)2 (c)	-11.910		.040			1.740	13.650		
323	Cd3(OH)4SO4	-27.519					-4.959	22.560		
324	Cd3OH2(SO4)2	-21.849					-15.139	6.710		
325	Cd4(OH)6SO4	-31.619					-3.219	28.400		
326	Monteponite	-13.379				-13.999	1.741	15.120		15.740
329	CdSO4	-8.340			-8.310	-8.390	-8.440	-.100	-.130	-.050
330	CdSO4, 1H2O	-6.783			-6.760	-6.810	-8.440	-1.657	-1.680	-1.630
331	CdSO4,2.7H2O	-6.567			-6.550	-6.580	-8.440	-1.873	-1.890	-1.860
367	Massicot	-11.631			-11.511		1.279	12.910	12.790	
368	Litharge	-11.441			-11.361	-11.791	1.279	12.720	12.640	13.070
369	PbO, .3H2O	-11.701					1.279	12.980		
371	Larnakite	-7.342			-1.322		-7.622	-.280	-6.300	
372	Pb3O2SO4	-16.743					-6.343	10.400		
373	Pb4O3SO4	-27.163					-5.063	22.100		
384	Anglesite	-1.111		.020	-1.031		-8.901	-7.790	-7.870	

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Phase	Log AP/KT	Sigma(A)	Sigma(T)	Log AP/MinKT	Log AP/MaxKT	Log AP	Log KT	Log MinKT	Log MaxKT
389 Pb(OH)2 (c)	-6.871				-12.351	1.279	8.150		13.630
393 Pb2O(OH)2	-23.642				-24.542	2.558	26.200		27.100
394 Pb4(OH)6SO4	-26.164					-5.064	21.100		
411 Ni(OH)2	-8.458		.100	-8.248	-10.958	2.342	10.800	10.590	13.300
412 Ni4(OH)6SO4	-32.812					-.812	32.000		
413 Bunsenite	-10.108				-10.048	2.342	12.450		12.390
416 Retgersite	-5.799					-7.839	-2.040		
417 Morenosite	-5.479					-7.839	-2.360		

DOX = .0000 DOC = .0 INPUT TDS = 1135.0
Anal Cond = 1262.0 Calc Cond = 1252.1
Anal EPMCAT = 15.3302 Anal EPMAN = 10.1182 Percent difference in input cation/anion balance = 40.9615
ERROR IN CALCULATED CHARGE BALANCE GREATER THAN 30 PERCENT. CHECK INPUT DATA.

Calc EPMCAT = 12.7844 Calc EPMAN = 7.5739 Percent difference in calc cation/anion balance = 51.1879
Total Ionic Strength (T.I.S.) from input data = .02371
Effective Ionic Strength (E.I.S.) from speciation = .01861

	Input	Sigma	Fe3/Fe2	Sigma	Sato H2O2/O2	Sigma	NO3/NO2	Sigma	NO3/NH4	Sigma	Calc H2O2/O2	Sigma	SO4/S=	Sigma	As5/As3	Sigma
Eh	9.900	.000	9.900	.000	9.900	.000	.000	.000	9.900	.000	9.900	.000	9.900	.000	9.900	.000
pE	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000

T	pH	TDS ppm	Effective Ionic Str	pO2 Atm	pCO2 Atm	pCH4 Atm	CO2 Tot	Uncom CO2	ppm Uncom CO2	Ncrb Alk	aH2O
25.00	6.000	814.1	.01861	0.00E+00	2.10E-02	0.00E+00	.00110	3.62E-04	1.59E+01	1.15E-08	.9998

I	Species		Anal ppm	Calc ppm	Anal Molal	Calc Molal	Activity	Act Coeff	-Log Act
0	Ca	2	159.000	126.280	3.970E-03	3.153E-03	1.883E-03	.5971	2.725
28	CaOH	1		.000031		5.422E-10	4.741E-10	.8744	9.324
31	CaSO4 aq	0		109.949		8.083E-04	8.118E-04	1.0043	3.091
81	CaHSO4	1		.000729		5.319E-09	4.650E-09	.8744	8.333
29	CaHCO3	1		.882		8.732E-06	7.635E-06	.8744	5.117
30	CaCO3 aq	0		.004684		4.684E-08	4.704E-08	1.0043	7.328
1	Mg	2	32.000	26.042	1.317E-03	1.072E-03	6.471E-04	.6036	3.189
18	MgOH	1		.000049		1.188E-09	1.039E-09	.8744	8.983
22	MgSO4 aq	0		29.168		2.425E-04	2.436E-04	1.0043	3.613
21	MgHCO3	1		.233		2.736E-06	2.392E-06	.8744	5.621
20	MgCO3 aq	0		.000773		9.170E-09	9.210E-09	1.0043	8.036
2	Na	1	61.000	60.347	2.656E-03	2.627E-03	2.301E-03	.8759	2.638
43	NaSO4	-1		3.321		2.792E-05	2.441E-05	.8744	4.612
42	NaHCO3aq	0		.034		4.097E-07	4.114E-07	1.0043	6.386
41	NaCO3	-1		.000060		7.275E-10	6.361E-10	.8744	9.196
3	K	1	16.100	15.864	4.121E-04	4.061E-04	3.538E-04	.8714	3.451
45	KSO4	-1		.813		6.019E-06	5.263E-06	.8744	5.279
63	H	1		.001129		1.121E-06	1.000E-06	.8922	6.000
26	OH	1		.000195		1.147E-08	1.002E-08	.8744	7.999
17	CO3	-2		.001497		2.497E-08	1.491E-08	.5973	7.826
6	HCO3	-1	24.000	22.047	3.937E-04	3.616E-04	3.179E-04	.8791	3.498
85	H2CO3 aq	0		44.090		7.115E-04	7.147E-04	1.0045	3.146
5	SO4	-2	466.000	343.263	4.855E-03	3.576E-03	2.117E-03	.5918	2.674
62	HSO4	-1		.023		2.350E-07	2.055E-07	.8744	6.687
84	NO3	-1	.900	.900	1.453E-05	1.453E-05	1.270E-05	.8744	4.896
16	Fe total	2	.055		9.856E-07				
109	Mn	2	.359	.292	6.540E-06	5.325E-06	3.113E-06	.5846	5.507
119	MnHCO3	1		.002442		2.108E-08	1.843E-08	.8744	7.735
114	MnOH	1		.000007		9.149E-11	8.000E-11	.8744	10.097
115	Mn(OH)3	-1		.000000		5.638E-23	4.930E-23	.8744	22.307
118	Mn(NO3)2	0		.000000		1.991E-15	1.999E-15	1.0043	14.699
117	MnSO4 aq	0		.180		1.194E-06	1.199E-06	1.0043	5.921
130	Cu	2	.195	.137	3.071E-06	2.157E-06	1.261E-06	.5846	5.899
271	CuHCO3	1		.029		2.298E-07	2.009E-07	.8744	6.697
131	CuCO3 aq	0		.012		1.006E-07	1.010E-07	1.0043	6.996
132	Cu(CO3)2	-2		.000000		3.242E-12	1.895E-12	.5846	11.722

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I	Species		Anal ppm	Calc ppm	Anal Molal	Calc Molal	Activity	Act Coeff	-Log Act
138	CuOH	1		.001161		1.442E-08	1.261E-08	.8744	7.899
139	Cu(OH)2	0		.002556		2.622E-08	2.634E-08	1.0043	7.579
140	Cu(OH)3	-1		.000000		1.814E-15	1.587E-15	.8744	14.800
141	Cu(OH)4	-2		.000000		5.414E-22	3.165E-22	.5846	21.500
142	Cu2(OH)2	2		.000019		1.190E-10	6.958E-11	.5846	10.157
143	CuSO4 aq	0		.087		5.427E-07	5.450E-07	1.0043	6.264
145	Zn	2	53.850	40.594	8.244E-04	6.215E-04	3.633E-04	.5846	3.440
272	ZnHCO3	1		2.100		1.663E-05	1.454E-05	.8744	4.837
273	ZnCO3	0		.135		1.076E-06	1.081E-06	1.0043	5.966
274	Zn(CO3)2	-2		.000109		5.893E-10	3.445E-10	.5846	9.463
151	ZnOH	1		.037		4.555E-07	3.983E-07	.8744	6.400
152	Zn(OH)2	0		.000452		4.552E-09	4.572E-09	1.0043	8.340
153	Zn(OH)3	1		.000000		1.653E-14	1.445E-14	.8744	13.840
154	Zn(OH)4	-2		.000000		3.918E-21	2.290E-21	.5846	20.640
158	ZnSO4 aq	0		28.952		1.795E-04	1.803E-04	1.0043	3.744
159	Zn(SO4)2	-2		1.365		5.304E-06	3.101E-06	.5846	5.509
160	Cd	2	.255	.182	2.271E-06	1.624E-06	9.491E-07	.5846	6.023
166	Cd(CO3)3	-4		.000000		4.469E-23	5.218E-24	.1168	23.283
275	CdHCO3	1		.007528		4.344E-08	3.799E-08	.8744	7.420
276	CdCO3	0		.000610		3.540E-09	3.555E-09	1.0043	8.449
167	CdOH	1		.000012		9.026E-11	7.893E-11	.8744	10.103
168	Cd(OH)2	0		.000000		4.219E-15	4.238E-15	1.0043	14.373
169	Cd(OH)3	-1		.000000		5.436E-22	4.754E-22	.8744	21.323
170	Cd(OH)4	-2		.000000		7.246E-30	4.236E-30	.5846	29.373
171	Cd2OH	3		.000000		1.227E-15	3.666E-16	.2988	15.436
173	CdNO3	1		.000006		3.463E-11	3.028E-11	.8744	10.519
174	CdSO4 aq	0		.120		5.769E-07	5.794E-07	1.0043	6.237
277	Cd(SO4)2	2		.004790		2.300E-08	1.344E-08	.5846	7.871
204	Ni	2	.335	.251	5.711E-06	4.281E-06	2.502E-06	.5846	5.602
280	NiHCO3	1		.015		1.256E-07	1.098E-07	.8744	6.959
281	NiCO3	0		.033		2.755E-07	2.766E-07	1.0043	6.558
282	Ni(CO3)2	-2		.000002		1.226E-11	7.165E-12	.5846	11.145
208	NiOH	1		.000030		3.950E-10	3.454E-10	.8744	9.462
209	Ni(OH)2	0		.000000		2.491E-13	2.501E-13	1.0043	12.602
210	Ni(OH)3	-1		.000000		2.860E-18	2.501E-18	.8744	17.602
211	NiSO4 aq	0		.159		1.028E-06	1.033E-06	1.0043	5.986
283	Ni(SO4)2	-2		.000050		2.008E-10	1.174E-10	.5846	9.930
89	Ba	2	.028	.017	2.040E-07	1.262E-07	7.375E-08	.5846	7.132
90	BaOH	1		.000000		3.706E-15	3.241E-15	.8744	14.489
201	BaSO4 aq	0		.018		7.790E-08	7.823E-08	1.0043	7.107

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Phase	Log AP/KT	Sigma(A)	Sigma(T)	Log AP/MinKT	Log AP/MaxKT	Log AP	Log KT	Log MinKT	Log MaxKT
17 Anhydrite	-.763					-5.400	-4.637		
21 Aragonite	-2.216		.020			-10.552	-8.336		
150 Artinite	-10.877					-1.277	9.600		
144 Barite	.169				-.034	-9.807	-9.976		-9.773
19 Brucite	-7.983					-19.187	-11.204		
12 Calcite	-2.072		.020	-1.992		-10.552	-8.480	-8.560	
11 Dolomite	-4.567					-21.567	-17.000		
340 Epsomite	-3.724					-5.864	-2.140		
18 Gypsum	-.800					-5.400	-4.600		
117 Huntite	-13.630					-43.598	-29.968		
38 Hydrmagnesit	-26.487					-63.249	-36.762		
10 Magnesite	-2.986			-2.736	-3.236	-11.015	-8.029	-8.279	-7.779
66 Mirabilite	-6.837					-7.951	-1.114		
58 Nahcolite	-5.588					-6.136	-.548		
60 Natron	-11.793					-13.104	-1.311		
149 Nesquehonite	-5.395			-5.883	-6.470	-11.016	-5.621	-5.133	-4.546
65 Thenardite	-7.771					-7.950	-.179		
61 Thermonatr	-13.228					-13.103	.125		
59 Trona	-18.443					-19.238	-.795		
145 Witherite	-6.374			-1.624		-14.959	-8.585	-13.335	
188 Pyrocroite	-8.595				-8.888	6.493	15.088		15.381
190 Rhodochrosit	-2.923			-2.314	-3.340	-13.333	-10.410	-11.019	-9.993
182 MnSO4	-10.850					-8.181	2.669		
231 CuCO3	-4.096			-4.076	-4.116	-13.726	-9.630	-9.650	-9.610
234 Cu(OH)2	-2.539				-3.099	6.101	8.640		9.200
235 Malachite	-2.446		.080	-1.796	-2.656	2.704	5.150	4.500	5.360
236 Azurite	-4.443		.090	-1.873		-.693	3.750	1.180	
238 Cu2(OH)3NO3	-7.935				-8.005	1.305	9.240		9.310
239 Antlerite	-4.662				-5.272	3.628	8.290		8.900
240 Brochantite	-5.612		.160	-5.422	-5.772	9.728	15.340	15.150	15.500
241 Langite	-7.062				-7.672	9.728	16.790		17.400
242 Tenorite	-1.519			-1.249	-1.789	6.101	7.620	7.350	7.890
243 CuOCuSO4	-26.003					-14.473	11.530		
247 CuSO4	-11.584			-11.224	-11.994	-8.574	3.010	2.650	3.420
248 Chalcanthite	-5.934			-5.614	-6.439	-8.574	-2.640	-2.960	-2.135
268 Smithsonite	-1.266			-.456	-1.446	-11.266	-10.000	-10.810	-9.820
269 ZnCO3, 1H2O	-1.006					-11.266	-10.260		
271 Zn(OH)2 (a)	-3.890			-3.700	-3.920	8.560	12.450	12.260	12.480
272 Zn(OH)2 (c)	-3.640					8.560	12.200		
273 Zn(OH)2 (b)	-3.190		.020	-2.760	-3.330	8.560	11.750	11.320	11.890
274 Zn(OH)2 (g)	-3.150			-2.630	-3.280	8.560	11.710	11.190	11.840
275 Zn(OH)2 (e)	-2.940		.030	-2.390	-3.060	8.560	11.500	10.950	11.620
278 Zn2(OH)2SO4	-5.054					2.446	7.500		
279 Zn4(OH)6SO4	-8.834					19.566	28.400		
280 ZnNO3)2,6H2O	-16.673					-13.233	3.440		
281 ZnO(active)	-2.750			-3.010	-3.300	8.560	11.310	11.570	11.860
282 Zincite	-2.580			-2.430	-2.980	8.560	11.140	10.990	11.540
283 Zn3O(SO4)2	-22.688					-3.668	19.020		
290 Zincosite	-9.124				-10.044	-6.114	3.010		3.930
291 ZnSO4, 1H2O	-5.544				-5.614	-6.114	-.570		-.500
292 Bianchite	-4.350				-5.095	-6.115	-1.765		-1.020
293 Goslarite	-4.155				-4.245	-6.115	-1.960		-1.870
315 Otavite	-.109			-.039	-2.639	-13.849	-13.740	-13.810	-11.210
320 Cd(OH)2 (a)	-7.753			-7.633	-8.323	5.977	13.730	13.610	14.300
321 Cd(OH)2 (c)	-7.673		.040			5.977	13.650		
323 Cd3(OH)4SO4	-19.303					3.257	22.560		
324 Cd3OH2(SO4)2	-18.127					-11.417	6.710		

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	Phase	Log AP/KT	Sigma(A)	Sigma(T)	Log AP/MinKT	Log AP/MaxKT	Log AP	Log KT	Log MinKT	Log MaxKT
325	Cd4(OH)6SO4	-19.166					9.234	28.400		
326	Monteponite	-9.143				-9.763	5.977	15.120		15.740
329	CdSO4	-8.597			-8.567	-8.647	-8.697	-.100	-.130	-.050
330	CdSO4, 1H2O	-7.040			-7.017	-7.067	-8.697	-1.657	-1.680	-1.630
331	CdSO4,2.7H2O	-6.824			-6.807	-6.837	-8.697	-1.873	-1.890	-1.860
410	NiCO3	-6.588					-13.428	-6.840		
411	Ni(OH)2	-4.402		.100	-4.192	-6.902	6.398	10.800	10.590	13.300
412	Ni4(OH)6SO4	-21.081					10.919	32.000		
413	Bunsenite	-6.052				-5.992	6.398	12.450		12.390
416	Retgersite	-6.237					-8.277	-2.040		
417	Morenosite	-5.917					-8.277	-2.360		

3-ST62892 Date = 10/14/95 21:45

DOX = .0000 DOC = .0 INPUT TDS = 1062.0
Anal Cond = 1211.0 Calc Cond = 1196.0
Anal EPMCAT = 14.8419 Anal EPMAN = 9.5178 Percent difference in input cation/anion balance = 43.7122
ERROR IN CALCULATED CHARGE BALANCE GREATER THAN 30 PERCENT. CHECK INPUT DATA.

Calc EPMCAT = 12.5613 Calc EPMAN = 7.2423 Percent difference in calc cation/anion balance = 53.7180
Total Ionic Strength (T.I.S.) from input data = .02242
Effective Ionic Strength (E.I.S.) from speciation = .01786

	Input	Sigma	Fe3/Fe2	Sigma	Sato H202/02	Sigma	N03/N02	Sigma	N03/NH4	Sigma	Calc H202/02	Sigma	S04/S=	Sigma	As5/As3	Sigma
Eh	9.900	.000	9.900	.000	9.900	.000	.000	.000	9.900	.000	9.900	.000	9.900	.000	9.900	.000
pE	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000

T	pH	TDS ppm	Effective Ionic Str	p02 Atm	pC02 Atm	pCH4 Atm	C02 Tot	Uncom C02	ppm Uncom C02	Ncrb Alk	aH2O
25.00	6.300	770.7	.01786	0.00E+00	1.53E-02	0.00E+00	.00109	5.26E-04	2.31E+01	2.28E-08	.9998

I	Species		Anal ppm	Calc ppm	Anal Molal	Calc Molal	Activity	Act Coeff	-Log Act
0	Ca	2	147.000	118.853	3.670E-03	2.968E-03	1.787E-03	.6021	2.748
28	CaOH	1		.000058		1.025E-09	8.979E-10	.8764	9.047
31	CaSO4 aq	0		93.958		6.907E-04	6.935E-04	1.0041	3.159
81	CaHSO4	1		.000311		2.272E-09	1.991E-09	.8764	8.701
29	CaHCO3	1		1.216		1.204E-05	1.055E-05	.8764	4.977
30	CaCO3 aq	0		.013		1.292E-07	1.297E-07	1.0041	6.887
1	Mg	2	35.000	28.948	1.441E-03	1.192E-03	7.251E-04	.6085	3.140
18	MgOH	1		.000109		2.651E-09	2.323E-09	.8764	8.634
22	MgSO4 aq	0		29.428		2.447E-04	2.457E-04	1.0041	3.610
21	MgHCO3	1		.380		4.454E-06	3.903E-06	.8764	5.409
20	MgCO3 aq	0		.002516		2.986E-08	2.998E-08	1.0041	7.523
2	Na	1	60.000	59.416	2.612E-03	2.587E-03	2.271E-03	.8779	2.644
43	NaSO4	-1		2.943		2.474E-05	2.168E-05	.8764	4.664
42	NaHCO3aq	0		.049		5.886E-07	5.910E-07	1.0041	6.228
41	NaCO3	-1		.000173		2.080E-09	1.823E-09	.8764	8.739
3	K	1	15.500	15.295	3.967E-04	3.915E-04	3.420E-04	.8735	3.466
45	KSO4	-1		.706		5.225E-06	4.579E-06	.8764	5.339
63	H	1		.000565		5.608E-07	5.012E-07	.8937	6.300
26	OH	-1		.000388		2.282E-08	2.000E-08	.8764	7.699
17	CO3	-2		.004312		7.191E-08	4.332E-08	.6024	7.363
6	HCO3	-1	35.000	32.032	5.741E-04	5.254E-04	4.629E-04	.8810	3.335
85	H2CO3 aq	0		32.180		5.192E-04	5.215E-04	1.0044	3.283
5	SO4	-2	415.000	306.289	4.323E-03	3.191E-03	1.905E-03	.5971	2.720
62	HSO4	-1		.010		1.058E-07	9.269E-08	.8764	7.033
4	Cl	-1	10.000	9.989	2.823E-04	2.820E-04	2.463E-04	.8735	3.609
84	NO3	-1	.900	.900	1.453E-05	1.453E-05	1.273E-05	.8764	4.895
16	Fe total	2	.132		2.365E-06				
109	Mn	2	1.589	1.313	2.895E-05	2.392E-05	1.411E-05	.5899	4.850
119	MnHCO3	1		.016		1.388E-07	1.216E-07	.8764	6.915
111	MnCl	1		.001449		1.604E-08	1.406E-08	.8764	7.852
112	MnCl2 aq	0		.000000		9.369E-13	9.408E-13	1.0041	12.027
113	MnCl3	-1		.000000		1.192E-16	1.045E-16	.8764	15.981
114	MnOH	1		.000059		8.255E-10	7.235E-10	.8764	9.141
115	Mn(OH)3	-1		.000000		2.026E-21	1.775E-21	.8764	20.751
118	Mn(NO3)2	0		.000000		9.066E-15	9.104E-15	1.0041	14.041
117	MnSO4 aq	0		.735		4.872E-06	4.892E-06	1.0041	5.311

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I	Species		Anal ppm	Calc ppm	Anal Molal	Calc Molal	Activity	Act Coeff	-Log Act
130	Cu	2	.137	.086	2.158E-06	1.362E-06	8.034E-07	.5899	6.095
271	CuHCO3	1		.026		2.127E-07	1.864E-07	.8764	6.730
131	CuCO3 aq	0		.023		1.861E-07	1.869E-07	1.0041	6.728
132	Cu(CO3)2	-2		.000003		1.727E-11	1.019E-11	.5899	10.992
133	CuCl	1		.000060		6.077E-10	5.326E-10	.8764	9.274
134	CuCl2 aq	0		.000000		7.016E-14	7.045E-14	1.0041	13.152
135	CuCl3	-1		.000000		7.025E-20	6.157E-20	.8764	19.211
136	CuCl4	-2		.000000		1.288E-25	7.601E-26	.5899	25.119
138	CuOH	1		.001472		1.829E-08	1.603E-08	.8764	7.795
139	Cu(OH)2	0		.006484		6.652E-08	6.679E-08	1.0041	7.175
140	Cu(OH)3	-1		.000000		9.161E-15	8.028E-15	.8764	14.095
141	Cu(OH)4	-2		.000000		5.417E-21	3.195E-21	.5899	20.495
142	Cu2(OH)2	2		.000031		1.906E-10	1.124E-10	.5899	9.949
143	CuSO4 aq	0		.050		3.112E-07	3.125E-07	1.0041	6.505
145	Zn	2	49.910	37.939	7.641E-04	5.808E-04	3.426E-04	.5899	3.465
272	ZnHCO3	1		2.876		2.278E-05	1.997E-05	.8764	4.700
273	ZnCO3	0		.369		2.949E-06	2.962E-06	1.0041	5.528
274	Zn(CO3)2	-2		.000861		4.647E-09	2.741E-09	.5899	8.562
146	ZnCl	1		.026		2.592E-07	2.271E-07	.8764	6.644
147	ZnCl2 aq	0		.000008		5.834E-11	5.858E-11	1.0041	10.232
148	ZnCl3	-1		.000000		1.847E-14	1.619E-14	.8764	13.791
149	ZnCl4	-2		.000000		3.388E-18	1.999E-18	.5899	17.699
151	ZnOH	1		.070		8.551E-07	7.494E-07	.8764	6.125
152	Zn(OH)2	0		.001698		1.709E-08	1.716E-08	1.0041	7.765
153	Zn(OH)3	-1		.000000		1.235E-13	1.083E-13	.8764	12.965
154	Zn(OH)4	-2		.000000		5.803E-20	3.423E-20	.5899	19.466
155	ZnOHClaq	0		.000654		5.552E-09	5.575E-09	1.0041	8.254
158	ZnSO4 aq	0		24.583		1.524E-04	1.530E-04	1.0041	3.815
159	Zn(SO4)2	-2		1.033		4.017E-06	2.369E-06	.5899	5.625
160	Cd	2	.215	.154	1.914E-06	1.371E-06	8.090E-07	.5899	6.092
166	Cd(CO3)3	-4		.000000		9.005E-22	1.090E-22	.1211	21.962
275	CdHCO3	1		.009321		5.379E-08	4.714E-08	.8764	7.327
276	CdCO3	0		.001510		8.767E-09	8.803E-09	1.0041	8.055
161	CdCl	1		.003208		2.171E-08	1.903E-08	.8764	7.721
162	CdCl2 aq	0		.000004		1.946E-11	1.954E-11	1.0041	10.709
163	CdCl3	-1		.000000		3.465E-15	3.037E-15	.8764	14.518
167	CdOH	1		.000020		1.532E-10	1.342E-10	.8764	9.872
168	Cd(OH)2	0		.000000		1.432E-14	1.438E-14	1.0041	13.842
169	Cd(OH)3	-1		.000000		3.673E-21	3.219E-21	.8764	20.492
170	Cd(OH)4	-2		.000000		9.700E-29	5.722E-29	.5899	28.242
171	Cd2OH	3		.000000		1.743E-15	5.315E-16	.3050	15.274
172	CdOHClaq	0		.000003		1.562E-11	1.568E-11	1.0041	10.805
173	CdNO3	1		.000005		2.952E-11	2.587E-11	.8764	10.587
174	CdSO4 aq	0		.092		4.427E-07	4.445E-07	1.0041	6.352
277	Cd(SO4)2	-2		.003278		1.574E-08	9.285E-09	.5899	8.032
204	Ni	2	.322	.222	5.489E-06	3.784E-06	2.232E-06	.5899	5.651
280	NiHCO3	1		.019		1.628E-07	1.426E-07	.8764	6.846
281	NiCO3	0		.085		7.139E-07	7.169E-07	1.0041	6.145
282	Ni(CO3)2	-2		.000016		9.144E-11	5.394E-11	.5899	10.268
206	NiCl	1		.000148		1.576E-09	1.381E-09	.8764	8.860
279	NiCl2	0		.000000		1.230E-12	1.235E-12	1.0041	11.908
208	NiOH	1		.000053		7.014E-10	6.147E-10	.8764	9.211
209	Ni(OH)2	0		.000000		8.846E-13	8.883E-13	1.0041	12.051
210	Ni(OH)3	-1		.000000		2.022E-17	1.772E-17	.8764	16.752
211	NiSO4 aq	0		.128		8.259E-07	8.293E-07	1.0041	6.081
283	Ni(SO4)2	-2		.000036		1.438E-10	8.483E-11	.5899	10.071
89	Ba	2	.033	.021	2.405E-07	1.541E-07	9.088E-08	.5899	7.042

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I	Species		Anal ppm	Calc ppm	Anal Molal	Calc Molal	Activity	Act Coeff	-Log Act
90	BaOH	1		.000000		9.092E-15	7.968E-15	.8764	14.099
201	BaSO4 aq	0		.020		8.642E-08	8.678E-08	1.0041	7.062

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Phase	Log AP/KT	Sigma(A)	Sigma(T)	Log AP/MinKT	Log AP/MaxKT	Log AP	Log KT	Log MinKT	Log MaxKT
17 Anhydrite	-.831					-5.468	-4.637		
21 Aragonite	-1.775		.020			-10.111	-8.336		
150 Artinite	-9.860					-.260	9.600		
144 Barite	.214				.011	-9.762	-9.976		-9.773
19 Brucite	-7.333					-18.537	-11.204		
12 Calcite	-1.631		.020	-1.551		-10.111	-8.480	-8.560	
11 Dolomite	-3.614					-20.614	-17.000		
340 Epsomite	-3.720					-5.860	-2.140		
18 Gypsum	-.868					-5.468	-4.600		
64 Halite	-7.834					-6.252	1.582		
117 Huntite	-11.652					-41.620	-29.968		
38 Hydrmagnesit	-23.787					-60.549	-36.762		
10 Magnesite	-2.474			-2.224	-2.724	-10.503	-8.029	-8.279	-7.779
66 Mirabilite	-6.895					-8.009	-1.114		
58 Nahcolite	-5.430					-5.978	-.548		
60 Natron	-11.341					-12.652	-1.311		
149 Nesquehonite	-4.882			-5.370	-5.957	-10.503	-5.621	-5.133	-4.546
65 Thenardite	-7.829					-8.008	-.179		
61 Thermonatr	-12.776					-12.651	.125		
59 Trona	-17.835					-18.630	-.795		
145 Witherite	-5.820			-1.070		-14.405	-8.585	-13.335	
188 Pyrocroite	-7.339				-7.632	7.749	15.088		15.381
190 Rhodochrosit	-1.804			-1.195	-2.221	-12.214	-10.410	-11.019	-9.993
191 MnCl2, 4H2O	-14.778					-12.068	2.710		
182 MnSO4	-10.240					-7.571	2.669		
230 Melanothalli	-17.042				-17.762	-13.312	3.730		4.450
231 CuCO3	-3.828			-3.808	-3.848	-13.458	-9.630	-9.650	-9.610
234 Cu(OH)2	-2.135				-2.695	6.505	8.640		9.200
235 Malachite	-1.775		.080	-1.125	-1.985	3.375	5.150	4.500	5.360
236 Azurite	-3.505		.090	-.935		.245	3.750	1.180	
237 Atacamite	-4.239			-4.139	-4.389	3.101	7.340	7.240	7.490
238 Cu2(OH)3NO3	-7.426				-7.496	1.814	9.240		9.310
239 Antlerite	-4.096				-4.706	4.194	8.290		8.900
240 Brochantite	-4.641		.160	-4.451	-4.801	10.699	15.340	15.150	15.500
241 Langite	-6.091				-6.701	10.699	16.790		17.400
242 Tenorite	-1.115			-.845	-1.385	6.505	7.620	7.350	7.890
243 CuOCuSO4	-26.440					-14.910	11.530		
247 CuSO4	-11.825			-11.465	-12.235	-8.815	3.010	2.650	3.420
248 Chalcanthite	-6.176			-5.856	-6.681	-8.816	-2.640	-2.960	-2.135
267 ZnCl2	-17.712				-17.742	-10.682	7.030		7.060
268 Smithsonite	-.828			-.018	-1.008	-10.828	-10.000	-10.810	-9.820
269 ZnCO3, 1H2O	-.569					-10.829	-10.260		
271 Zn(OH)2 (a)	-3.315			-3.125	-3.345	9.135	12.450	12.260	12.480
272 Zn(OH)2 (c)	-3.065					9.135	12.200		
273 Zn(OH)2 (b)	-2.615		.020	-2.185	-2.755	9.135	11.750	11.320	11.890
274 Zn(OH)2 (g)	-2.575			-2.055	-2.705	9.135	11.710	11.190	11.840
275 Zn(OH)2 (e)	-2.365		.030	-1.815	-2.485	9.135	11.500	10.950	11.620
276 Zn2(OH)3Cl	-6.839					8.361	15.200		
277 Zn5(OH)8Cl	-12.644					25.856	38.500		
278 Zn2(OH)2SO4	-4.551					2.949	7.500		
279 Zn4(OH)6SO4	-7.181					21.219	28.400		
280 ZnNO3)2,6H2O	-16.696					-13.256	3.440		
281 ZnO(active)	-2.175			-2.435	-2.725	9.135	11.310	11.570	11.860
282 Zincite	-2.005			-1.855	-2.405	9.135	11.140	10.990	11.540
283 Zn3O(SO4)2	-22.256					-3.236	19.020		
290 Zincosite	-9.195				-10.115	-6.185	3.010		3.930
291 ZnSO4, 1H2O	-5.615				-5.685	-6.185	-.570		-.500

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	Phase	Log AP/KT	Sigma(A)	Sigma(T)	Log AP/MinKT	Log AP/MaxKT	Log AP	Log KT	Log MinKT	Log MaxKT
292	Bianchite	-4.421				-5.166	-6.186	-1.765		-1.020
293	Goslarite	-4.226				-4.316	-6.186	-1.960		-1.870
315	Otavite	.285			.355	-2.245	-13.455	-13.740	-13.810	-11.210
316	CdCl2	-12.629				-12.839	-13.309	-.680		-.470
317	CdCl2, 1H2O	-11.599					-13.309	-1.710		
318	CdCl2,2.5H2O	-11.369					-13.309	-1.940		
320	Cd(OH)2 (a)	-7.222			-7.102	-7.792	6.508	13.730	13.610	14.300
321	Cd(OH)2 (c)	-7.142		.040			6.508	13.650		
322	CdOHCl	-6.921			-6.701		-3.401	3.520	3.300	
323	Cd3(OH)4SO4	-18.357					4.203	22.560		
324	Cd3OH2(SO4)2	-17.826					-11.116	6.710		
325	Cd4(OH)6SO4	-17.689					10.711	28.400		
326	Monteponite	-8.612				-9.232	6.508	15.120		15.740
329	CdSO4	-8.712			-8.682	-8.762	-8.812	-.100	-.130	-.050
330	CdSO4, 1H2O	-7.155			-7.132	-7.182	-8.812	-1.657	-1.680	-1.630
331	CdSO4,2.7H2O	-6.939			-6.922	-6.952	-8.812	-1.873	-1.890	-1.860
410	NiCO3	-6.175					-13.015	-6.840		
411	Ni(OH)2	-3.851		.100	-3.641	-6.351	6.949	10.800	10.590	13.300
412	Ni4(OH)6SO4	-19.526					12.474	32.000		
413	Bunsenite	-5.501				-5.441	6.949	12.450		12.390
416	Retgersite	-6.332					-8.372	-2.040		
417	Morenosite	-6.012					-8.372	-2.360		

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     DOX =          .0000          DOC =            .0       INPUT TDS =    1766.0
Anal Cond =    1867.0      Calc Cond =    1846.0
Anal EPMCAT =   24.1202    Anal EPMAN =    15.5948   Percent difference in input cation/anion balance =   42.9328
ERROR IN CALCULATED CHARGE BALANCE GREATER THAN 30 PERCENT.  CHECK INPUT DATA.

Calc EPMCAT =   19.9265    Calc EPMAN =    11.4044   Percent difference in calc  cation/anion balance =   54.4004
Total  Ionic  Strength    (T.I.S.) from input data =      .03588
Effective Ionic Strength (E.I.S.) from speciation =      .02749
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Input	Sigma	Fe3/Fe2	Sigma	Sato H2O2/O2	Sigma	NO3/NO2	Sigma	NO3/NH4	Sigma	Calc H2O2/O2	Sigma	SO4/S=	Sigma	As5/As3	Si
Eh															
9.900	.000	9.900	.000	9.900	.000	.000	.000	9.900	.000	9.900	.000	9.900	.000	9.900	.
pE															
100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.

T	pH	TDS ppm	Effective Ionic Str	pO2 Atm	pCO2 Atm	pCH4 Atm	CO2 Tot	Uncom CO2	ppm Uncom CO2	Ncrb Alk	aH2
25.00	6.400	1253.2	.02749	0.00E+00	1.50E-02	0.00E+00	.00125	6.61E-04	2.91E+01	2.95E-08	.9

I	Species		Anal ppm	Calc ppm	Anal Molal	Calc Molal	Activity	Act Coeff	-Log Act
0	Ca	2	203.000	156.844	5.071E-03	3.918E-03	2.149E-03	.5484	2.668
28	CaOH	1		.000091		1.590E-09	1.359E-09	.8546	8.867
31	CaSO4 aq	0		154.306		1.135E-03	1.142E-03	1.0063	2.942
81	CaHSO4	1		.000417		3.048E-09	2.605E-09	.8546	8.584
29	CaHCO3	1		1.841		1.823E-05	1.558E-05	.8546	4.807
30	CaCO3 aq	0		.024		2.396E-07	2.412E-07	1.0063	6.618
1	Mg	2	62.000	49.169	2.553E-03	2.025E-03	1.127E-03	.5567	2.948
18	MgOH	1		.000220		5.320E-09	4.546E-09	.8546	8.342
22	MgSO4 aq	0		62.485		5.198E-04	5.231E-04	1.0063	3.281
21	MgHCO3	1		.743		8.722E-06	7.454E-06	.8546	5.128
20	MgCO3 aq	0		.006031		7.162E-08	7.207E-08	1.0063	7.142
2	Na	1	120.000	118.413	5.226E-03	5.157E-03	4.417E-03	.8565	2.355
43	NaSO4	-1		8.037		6.759E-05	5.777E-05	.8546	4.238
42	NaHCO3aq	0		.118		1.403E-06	1.412E-06	1.0063	5.850
41	NaCO3	-1		.000532		6.418E-09	5.485E-09	.8546	8.261
3	K	1	27.000	26.516	6.914E-04	6.790E-04	5.772E-04	.8501	3.239
45	KSO4	-1		1.672		1.239E-05	1.059E-05	.8546	4.975
63	H	1		.000457		4.536E-07	3.981E-07	.8777	6.400
26	OH	-1		.000500		2.946E-08	2.518E-08	.8546	7.599
17	CO3	-2		.007323		1.222E-07	6.699E-08	.5483	7.174
6	HCO3	-1	46.000	40.267	7.548E-04	6.608E-04	5.686E-04	.8605	3.245
85	H2CO3 aq	0		31.312		5.055E-04	5.089E-04	1.0067	3.293
5	SO4	-2	664.000	462.476	6.921E-03	4.821E-03	2.609E-03	.5413	2.583
62	HSO4	-1		.011		1.180E-07	1.008E-07	.8546	6.996
4	Cl	-1	35.000	34.939	9.885E-04	9.868E-04	8.389E-04	.8501	3.076
84	NO3	-1	.600	.600	9.689E-06	9.689E-06	8.280E-06	.8546	5.082
16	Fe total	2	.090		1.614E-06				
109	Mn	2	4.484	3.558	8.172E-05	6.484E-05	3.459E-05	.5335	4.461
119	MnHCO3	1		.050		4.285E-07	3.662E-07	.8546	6.436
111	MnCl	1		.012		1.374E-07	1.174E-07	.8546	6.930
112	MnCl2 aq	0		.000003		2.658E-11	2.675E-11	1.0063	10.573
113	MnCl3	-1		.000000		1.184E-14	1.012E-14	.8546	13.995
114	MnOH	1		.000188		2.612E-09	2.232E-09	.8546	8.651
115	Mn(OH)3	-1		.000000		1.016E-20	8.679E-21	.8546	20.062
118	Mn(NO3)2	0		.000000		9.382E-15	9.442E-15	1.0063	14.025
117	MnSO4 aq	0		2.461		1.632E-05	1.642E-05	1.0063	4.785

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I	Species		Anal ppm	Calc ppm	Anal Molal	Calc Molal	Activity	Act Coeff	-Log Act
130	Cu	2	.046	.026	7.248E-07	4.171E-07	2.225E-07	.5335	6.653
271	CuHCO3	1		.009229		7.419E-08	6.341E-08	.8546	7.198
131	CuCO3 aq	0		.009815		7.954E-08	8.005E-08	1.0063	7.097
132	Cu(CO3)2	-2		.000002		1.264E-11	6.745E-12	.5335	11.171
133	CuCl	1		.000058		5.878E-10	5.024E-10	.8546	9.299
134	CuCl2 aq	0		.000000		2.249E-13	2.263E-13	1.0063	12.645
135	CuCl3	-1		.000000		7.882E-19	6.737E-19	.8546	18.172
136	CuCl4	-2		.000000		5.309E-24	2.832E-24	.5335	23.548
138	CuOH	1		.000526		6.537E-09	5.587E-09	.8546	8.253
139	Cu(OH)2	0		.002838		2.912E-08	2.931E-08	1.0063	7.533
140	Cu(OH)3	-1		.000000		5.189E-15	4.434E-15	.8546	14.353
141	Cu(OH)4	-2		.000000		4.164E-21	2.222E-21	.5335	20.653
142	Cu2(OH)2	2		.000004		2.559E-11	1.365E-11	.5335	10.865
143	CuSO4 aq	0		.019		1.178E-07	1.185E-07	1.0063	6.926
145	Zn	2	89.580	64.347	1.372E-03	9.856E-04	5.258E-04	.5335	3.279
272	ZnHCO3	1		5.558		4.404E-05	3.764E-05	.8546	4.424
273	ZnCO3	0		.875		6.984E-06	7.028E-06	1.0063	5.153
274	Zn(CO3)2	-2		.003490		1.885E-08	1.006E-08	.5335	7.997
146	ZnCl	1		.140		1.389E-06	1.187E-06	.8546	5.925
147	ZnCl2 aq	0		.000141		1.036E-09	1.043E-09	1.0063	8.982
148	ZnCl3	-1		.000000		1.149E-12	9.816E-13	.8546	12.008
149	ZnCl4	-2		.000000		7.736E-16	4.127E-16	.5335	15.384
151	ZnOH	1		.139		1.694E-06	1.448E-06	.8546	5.839
152	Zn(OH)2	0		.004116		4.147E-08	4.173E-08	1.0063	7.380
153	Zn(OH)3	-1		.000000		3.878E-13	3.314E-13	.8546	12.480
154	Zn(OH)4	-2		.000000		2.472E-19	1.319E-19	.5335	18.880
155	ZnOHClaq	0		.004289		3.644E-08	3.667E-08	1.0063	7.436
158	ZnSO4 aq	0		51.527		3.196E-04	3.216E-04	1.0063	3.493
159	Zn(SO4)2	-2		3.287		1.278E-05	6.819E-06	.5335	5.166
160	Cd	2	.431	.283	3.839E-06	2.519E-06	1.344E-06	.5335	5.872
166	Cd(CO3)3	-4		.000000		8.264E-21	6.694E-22	.0810	21.174
275	CdHCO3	1		.019		1.125E-07	9.619E-08	.8546	7.017
276	CdCO3	0		.003869		2.247E-08	2.261E-08	1.0063	7.646
161	CdCl	1		.019		1.260E-07	1.077E-07	.8546	6.968
162	CdCl2 aq	0		.000068		3.741E-10	3.765E-10	1.0063	9.424
163	CdCl3	-1		.000000		2.332E-13	1.993E-13	.8546	12.701
167	CdOH	1		.000042		3.284E-10	2.806E-10	.8546	9.552
168	Cd(OH)2	0		.000000		3.760E-14	3.784E-14	1.0063	13.422
169	Cd(OH)3	-1		.000000		1.248E-20	1.066E-20	.8546	19.972
170	Cd(OH)4	-2		.000000		4.473E-28	2.386E-28	.5335	27.622
171	Cd2OH	3		.000000		7.582E-15	1.844E-15	.2432	14.734
172	CdOHClaq	0		.000018		1.109E-10	1.117E-10	1.0063	9.952
173	CdNO3	1		.000006		3.270E-11	2.795E-11	.8546	10.554
174	CdSO4 aq	0		.209		1.005E-06	1.011E-06	1.0063	5.995
277	Cd(SO4)2	-2		.011		5.421E-08	2.892E-08	.5335	7.539
204	Ni	2	.949	.599	1.618E-05	1.022E-05	5.453E-06	.5335	5.263
280	NiHCO3	1		.060		5.008E-07	4.280E-07	.8546	6.369
281	NiCO3	0		.319		2.691E-06	2.708E-06	1.0063	5.567
282	Ni(CO3)2	-2		.000105		5.905E-10	3.150E-10	.5335	9.502
206	NiCl	1		.001264		1.345E-08	1.149E-08	.8546	7.940
279	NiCl2	0		.000005		3.478E-11	3.500E-11	1.0063	10.456
208	NiOH	1		.000167		2.212E-09	1.890E-09	.8546	8.724
209	Ni(OH)2	0		.000000		3.416E-12	3.438E-12	1.0063	11.464
210	Ni(OH)3	-1		.000000		1.010E-16	8.633E-17	.8546	16.064
211	NiSO4 aq	0		.426		2.757E-06	2.774E-06	1.0063	5.557
283	Ni(SO4)2	-2		.000182		7.285E-10	3.886E-10	.5335	9.410
89	Ba	2	.044	.026	3.208E-07	1.895E-07	1.011E-07	.5335	6.995

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I	Species		Anal ppm	Calc ppm	Anal Molal	Calc Molal	Activity	Act Coeff	-Log Act
90	BaOH	1		.000000		1.305E-14	1.116E-14	.8546	13.953
201	BaSO4 aq	0		.031		1.314E-07	1.322E-07	1.0063	6.879

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Phase	Log AP/KT	Sigma(A)	Sigma(T)	Log AP/MinKT	Log AP/MaxKT	Log AP	Log KT	Log MinKT	Log Ms
17 Anhydrite	-.614					-5.251	-4.637		
21 Aragonite	-1.506		.020			-9.842	-8.336		
150 Artinite	-9.310					.290	9.600		
144 Barite	.397				.194	-9.579	-9.976		-9.77
19 Brucite	-6.942					-18.146	-11.204		
12 Calcite	-1.362		.020	-1.282		-9.842	-8.480	-8.560	
11 Dolomitu	-2.964					-19.964	-17.000		
340 Bpsomite	-3.393					-5.533	-2.140		
18 Gypsum	-.652					-5.252	-4.600		
64 Halite	-7.013					-5.431	1.582		
117 Huntite	-10.240					-40.208	-29.968		
38 Hydrmagnesit	-21.872					-58.634	-36.762		
10 Magnesite	-2.093			-1.843	-2.343	-10.122	-8.029	-8.279	-7.77
66 Mirabilite	-6.181					-7.295	-1.114		
58 Nahcolite	-5.052					-5.600	-.548		
60 Natron	-10.574					-11.885	-1.311		
149 Nesquehonite	-4.501			-4.989	-5.576	-10.122	-5.621	-5.133	-4.54
65 Thenardite	-7.114					-7.293	-.179		
61 Thermonatr	-12.009					-11.884	.125		
59 Trona	-16.689					-17.484	-.795		
145 Witherite	-5.584			-.834		-14.169	-8.585	-13.335	
188 Pyrocroite	-6.749				-7.042	8.339	15.088		15.38
190 Rhodochrosit	-1.225			-.616	-1.642	-11.635	-10.410	-11.019	-9.99
191 MnCl2, 4H2O	-13.324					-10.614	2.710		
182 MnSO4	-9.714					-7.045	2.669		
230 Melanothulli	-16.535				-17.255	-12.805	3.730		4.45
231 CuCO3	-4.197			-4.177	-4.217	-13.827	-9.630	-9.650	-9.61
234 Cu(OH)2	-2.493				-3.053	6.147	8.640		9.20
235 Malachite	-2.501		.080	-1.851	-2.711	2.649	5.150	4.500	5.36
236 Azurite	-4.599		.090	-2.029		-.849	3.750	1.180	
237 Atacamite	-4.522			-4.422	-4.672	2.818	7.340	7.240	7.49
238 Cu2(OH)3NO3	-8.428				-8.498	.812	9.240		9.31
239 Antlerite	-5.232				-5.842	3.058	8.290		8.90
240 Brochantite	-6.135		.160	-5.945	-6.295	9.205	15.340	15.150	15.50
241 Langite	-7.585				-8.195	9.205	16.790		17.40
242 Tenorite	-1.473			-1.203	-1.743	6.147	7.620	7.350	7.89
243 CuOCuSO4	-27.419					-15.889	11.530		
247 CuSO4	-12.246			-11.886	-12.656	-9.236	3.010	2.650	3.42
248 Chalcanthite	-6.597			-6.277	-7.102	-9.237	-2.640	-2.960	-2.13
267 ZnCl2	-16.462				-16.492	-9.432	7.030		7.06
268 Smithsonite	-.453			.357	-.633	-10.453	-10.000	-10.810	-9.82
269 ZnCO3, 1H2O	-.193					-10.453	-10.260		
271 Zn(OH)2 (a)	-2.930			-2.740	-2.960	9.520	12.450	12.260	12.48
272 Zn(OH)2 (c)	-2.680					9.520	12.200		
273 Zn(OH)2 (b)	-2.230		.020	-1.800	-2.370	9.520	11.750	11.320	11.89
274 Zn(OH)2 (g)	-2.190			-1.670	-2.320	9.520	11.710	11.190	11.84
275 Zn(OH)2 (e)	-1.980		.030	-1.430	-2.100	9.520	11.500	10.950	11.62
276 Zn2(OH)3Cl	-5.635					9.565	15.200		
277 Zn5(OH)8Cl	-9.850					28.650	38.500		
278 Zn2(OH)2SO4	-3.842					3.658	7.500		
279 Zn4(OH)6SO4	-5.701					22.699	28.400		
280 ZnNO3)2,6H2O	-16.884					-13.444	3.440		
281 ZnO(active)	-1.789			-2.049	-2.339	9.521	11.310	11.570	11.86
282 Zincite	-1.619			-1.469	-2.019	9.521	11.140	10.990	11.54
283 Zn3O(SO4)2	-21.225					-2.205	19.020		
290 Zincosite	-8.873				-9.793	-5.863	3.010		3.93
291 ZnSO4, 1H2O	-5.293				-5.363	-5.863	-.570		-.50

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	Phase	Log AP/KT	Sigma(A)	Sigma(T)	Log AP/MinKT	Log AP/MaxKT	Log AP	Log KT	Log MinKT	Log Ma
292	Bianchite	-4.099				-4.844	-5.864	-1.765		-1.02
293	Goslarite	-3.904				-3.994	-5.864	-1.960		-1.87
315	Otavite	.694			.764	-1.836	-13.046	-13.740	-13.810	-11.21
316	CdCl2	-11.344				-11.554	-12.024	-.680		-.47
317	CdCl2, 1H2O	-10.314					-12.024	-1.710		
318	CdCl2,2.5H2O	-10.085					-12.025	-1.940		
320	Cd(OH)2 (a)	-6.802			-6.682	-7.372	6.928	13.730	13.610	14.30
321	Cd(OH)2 (c)	-6.722		.040			6.928	13.650		
322	CdOHCl	-6.068			-5.848		-2.548	3.520	3.300	
323	Cd3(OH)4SO4	-17.159					5.401	22.560		
324	Cd3OH2(SO4)2	-16.692					-9.982	6.710		
325	Cd4(OH)6SO4	-16.071					12.329	28.400		
326	Monteponite	-8.192				-8.812	6.928	15.120		15.74
329	CdSO4	-8.355			-8.325	-8.405	-8.455	-.100	-.130	-.05
330	CdSO4, 1H2O	-6.798			-6.775	-6.825	-8.455	-1.657	-1.680	-1.63
331	CdSO4,2.7H2O	-6.583			-6.566	-6.596	-8.456	-1.873	-1.890	-1.86
410	NiCO3	-5.597					-12.437	-6.840		
411	Ni(OH)2	-3.264		.100	-3.054	-5.764	7.536	10.800	10.590	13.30
412	Ni4(OH)6SO4	-17.238					14.762	32.000		
413	Bunsenite	-4.914				-4.854	7.536	12.450		12.39
416	Retgersite	-5.808					-7.848	-2.040		
417	Morenosite	-5.488					-7.848	-2.360		

5-NT62892 Date = 10/12/95 19:30

DOX = .0000 DOC = .0 INPUT TDS = 1754.0
nal Cond = 1918.0 Calc Cond = 1953.5
nal EPMCAT = 24.6947 Anal EPMAN = 16.8878 Percent difference in input cation/anion balance = 37.5486
RROR IN CALCULATED CHARGE BALANCE GREATER THAN 30 PERCENT. CHECK INPUT DATA.

alc EPMCAT = 20.1298 Calc EPMAN = 12.3301 Percent difference in calc cation/anion balance = 48.0573
otal Ionic Strength (T.I.S.) from input data = .03785
ffective Ionic Strength (E.I.S.) from speciation = .02871

Input	Sigma	Fe3/Fe2	Sigma	Sato H2O2/O2	Sigma	NO3/NO2	Sigma	NO3/NH4	Sigma	Calc H2O2/O2	Sigma	SO4/S=	Sigma	As5/As3	Sigma
Eh															
9.900	.000	9.900	.000	9.900	.000	.000	.000	9.900	.000	9.900	.000	9.900	.000	9.900	.000
pE															
00.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000

T	pH	TDS ppm	Effective Ionic Str	pO2 Atm	pCO2 Atm	pCH4 Atm	CO2 Tot	Uncom CO2	ppm Uncom CO2	Ncrb Alk	aH2O
25.00	6.500	1310.9	.02871	0.00E+00	1.12E-02	0.00E+00	.00107	6.23E-04	2.74E+01	3.72E-08	.9996

I	Species		Anal ppm	Calc ppm	Anal Molal	Calc Molal	Activity	Act Coeff	-Log Act
0	Ca	2	214.000	162.986	5.346E-03	4.072E-03	2.211E-03	.5429	2.656
28	CaOH	1		.000118		2.065E-09	1.760E-09	.8523	8.754
31	CaSO4 aq	0		170.884		1.257E-03	1.265E-03	1.0066	2.898
81	CaHSO4	1		.000368		2.689E-09	2.292E-09	.8523	8.640
29	CaHCO3	1		1.785		1.768E-05	1.507E-05	.8523	4.822
30	CaCO3 aq	0		.029		2.916E-07	2.936E-07	1.0066	6.532
1	Mg	2	71.000	55.570	2.924E-03	2.289E-03	1.262E-03	.5514	2.899
18	MgOH	1		.000310		7.518E-09	6.407E-09	.8523	8.193
22	MgSO4 aq	0		75.300		6.264E-04	6.305E-04	1.0066	3.200
21	MgHCO3	1		.784		9.202E-06	7.843E-06	.8523	5.106
20	MgCO3 aq	0		.007986		9.484E-08	9.547E-08	1.0066	7.020
2	Na	1	116.000	114.355	5.052E-03	4.981E-03	4.255E-03	.8542	2.371
43	NaSO4	-1		8.358		7.030E-05	5.991E-05	.8523	4.222
42	NaHCO3aq	0		.107		1.270E-06	1.279E-06	1.0066	5.893
41	NaCO3	-1		.000608		7.334E-09	6.251E-09	.8523	8.204
3	K	1	23.700	23.243	6.069E-04	5.952E-04	5.045E-04	.8476	3.297
45	KSO4	-1		1.578		1.169E-05	9.962E-06	.8523	5.002
63	H	1		.000363		3.610E-07	3.162E-07	.8760	6.500
26	OH	-1		.000632		3.719E-08	3.170E-08	.8523	7.499
17	CO3	-2		.008753		1.461E-07	7.927E-08	.5427	7.101
6	HCO3	-1	43.000	37.939	7.056E-04	6.226E-04	5.344E-04	.8583	3.272
85	H2CO3 aq	0		23.367		3.772E-04	3.799E-04	1.0070	3.420
5	SO4	-2	723.000	503.291	7.536E-03	5.246E-03	2.810E-03	.5356	2.551
62	HSO4	-1		.009809		1.012E-07	8.624E-08	.8523	7.064
4	Cl	-1	39.000	38.943	1.101E-03	1.100E-03	9.323E-04	.8476	3.030
84	NO3	-1	.500	.500	8.074E-06	8.074E-06	6.882E-06	.8523	5.162
16	Fe total	2	.196		3.514E-06				
09	Mn	2	4.221	3.307	7.693E-05	6.027E-05	3.181E-05	.5277	4.497
19	MnHCO3	1		.043		3.713E-07	3.165E-07	.8523	6.500
11	MnCl	1		.013		1.408E-07	1.200E-07	.8523	6.921
12	MnCl2 aq	0		.000004		3.018E-11	3.038E-11	1.0066	10.517
13	MnCl3	-1		.000000		1.498E-14	1.277E-14	.8523	13.894
14	MnOH	1		.000218		3.032E-09	2.584E-09	.8523	8.588
15	Mn(OH)3	-1		.000000		1.868E-20	1.592E-20	.8523	19.798
18	Mn(NO3)2	0		.000000		5.957E-15	5.997E-15	1.0066	14.222
17	MnSO4 aq	0		2.436		1.615E-05	1.626E-05	1.0066	4.789

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I	Species		Anal ppm	Calc ppm	Anal Molal	Calc Molal	Activity	Act Coeff	-Log Act
30	Cu	2	.012000	.006593	1.891E-07	1.039E-07	5.482E-08	.5277	7.261
71	CuHCO3	1		.002143		1.723E-08	1.468E-08	.8523	7.833
31	CuCO3 aq	0		.002861		2.318E-08	2.334E-08	1.0066	7.632
32	Cu(CO3)2	-2		.000000		4.409E-12	2.327E-12	.5277	11.633
33	CuCl	1		.000016		1.614E-10	1.376E-10	.8523	9.861
34	CuCl2 aq	0		.000000		6.843E-14	6.888E-14	1.0066	13.162
35	CuCl3	-1		.000000		2.673E-19	2.279E-19	.8523	18.642
36	CuCl4	-2		.000000		2.018E-24	1.065E-24	.5277	23.973
38	CuOH	1		.000164		2.033E-09	1.733E-09	.8523	8.761
39	Cu(OH)2	0		.001108		1.137E-08	1.145E-08	1.0066	7.941
40	Cu(OH)3	-1		.000000		2.558E-15	2.180E-15	.8523	14.662
41	Cu(OH)4	-2		.000000		2.606E-21	1.375E-21	.5277	20.862
42	Cu2(OH)2	2		.000000		2.489E-12	1.313E-12	.5277	11.882
43	CuSO4 aq	0		.004980		3.124E-08	3.145E-08	1.0066	7.502
45	Zn	2	74.970	53.019	1.148E-03	8.121E-04	4.286E-04	.5277	3.368
72	ZnHCO3	1		4.269		3.383E-05	2.883E-05	.8523	4.540
73	ZnCO3	0		.843		6.734E-06	6.778E-06	1.0066	5.169
74	Zn(CO3)2	-2		.004026		2.175E-08	1.148E-08	.5277	7.940
46	ZnCl	1		.127		1.262E-06	1.075E-06	.8523	5.968
47	ZnCl2 aq	0		.000142		1.043E-09	1.050E-09	1.0066	8.979
48	ZnCl3	-1		.000000		1.289E-12	1.098E-12	.8523	11.959
49	ZnCl4	-2		.000000		9.725E-16	5.132E-16	.5277	15.290
51	ZnOH	1		.143		1.743E-06	1.485E-06	.8523	5.828
52	Zn(OH)2	0		.005316		5.356E-08	5.391E-08	1.0066	7.268
53	Zn(OH)3	-1		.000000		6.323E-13	5.389E-13	.8523	12.268
54	Zn(OH)4	-2		.000000		5.116E-19	2.700E-19	.5277	18.569
55	ZnOHClaq	0		.004889		4.155E-08	4.183E-08	1.0066	7.379
58	ZnSO4 aq	0		45.210		2.804E-04	2.823E-04	1.0066	3.549
59	Zn(SO4)2	-2		3.140		1.221E-05	6.445E-06	.5277	5.191
60	Cd	2	.355	.228	3.163E-06	2.031E-06	1.072E-06	.5277	5.970
66	Cd(CO3)3	-4		.000000		1.140E-20	8.843E-22	.0776	21.053
75	CdHCO3	1		.015		8.459E-08	7.210E-08	.8523	7.142
76	CdCO3	0		.003650		2.120E-08	2.134E-08	1.0066	7.671
61	CdCl	1		.017		1.120E-07	9.542E-08	.8523	7.020
62	CdCl2 aq	0		.000067		3.684E-10	3.709E-10	1.0066	9.431
63	CdCl3	-1		.000000		2.560E-13	2.182E-13	.8523	12.661
67	CdOH	1		.000043		3.306E-10	2.818E-10	.8523	9.550
68	Cd(OH)2	0		.000000		4.752E-14	4.784E-14	1.0066	13.320
69	Cd(OH)3	-1		.000000		1.991E-20	1.697E-20	.8523	19.770
70	Cd(OH)4	-2		.000000		9.058E-28	4.780E-28	.5277	27.321
71	Cd2OH	3		.000000		6.220E-15	1.476E-15	.2374	14.831
72	CdOHClaq	0		.000020		1.238E-10	1.246E-10	1.0066	9.905
73	CdNO3	1		.000004		2.174E-11	1.853E-11	.8523	10.732
74	CdSO4 aq	0		.180		8.627E-07	8.685E-07	1.0066	6.061
77	Cd(SO4)2	-2		.011		5.068E-08	2.675E-08	.5277	7.573
04	Ni	2	.848	.516	1.446E-05	8.806E-06	4.647E-06	.5277	5.333
80	NiHCO3	1		.048		4.022E-07	3.428E-07	.8523	6.465
81	NiCO3	0		.322		2.713E-06	2.731E-06	1.0066	5.564
82	Ni(CO3)2	-2		.000127		7.121E-10	3.758E-10	.5277	9.425
06	NiCl	1		.001201		1.277E-08	1.088E-08	.8523	7.963
79	NiCl2	0		.000005		3.660E-11	3.684E-11	1.0066	10.434
08	NiOH	1		.000180		2.379E-09	2.028E-09	.8523	8.693
09	Ni(OH)2	0		.000000		4.613E-12	4.643E-12	1.0066	11.333
10	Ni(OH)3	-1		.000000		1.722E-16	1.468E-16	.8523	15.833
11	NiSO4 aq	0		.391		2.529E-06	2.546E-06	1.0066	5.594
83	Ni(SO4)2	-2		.000182		7.277E-10	3.840E-10	.5277	9.416
89	Ba	2	.055	.032	4.010E-07	2.307E-07	1.218E-07	.5277	6.915

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I	Species		Anal ppm	Calc ppm	Anal Molal	Calc Molal	Activity	Act Coeff	-Log Act
90	BaOH	1		.000000		1.985E-14	1.692E-14	.8523	13.772
01	BaSO4 aq	0		.040		1.703E-07	1.715E-07	1.0066	6.766

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	Phase	Log AP/KT	Sigma(A)	Sigma(T)	Log AP/MinKT	Log AP/MaxKT	Log AP	Log KT	Log MinKT	Log MaxKT
17	Anhydrite	-.570					-5.207	-4.637		
21	Aragonite	-1.420		.020			-9.756	-8.336		
50	Artinite	-9.013					.587	9.600		
44	Barite	.510				.307	-9.466	-9.976		-9.773
19	Brucite	-6.693					-17.897	-11.204		
12	Calcite	-1.277		.020	-1.196		-9.756	-8.480	-8.560	
11	Dolomite	-2.756					-19.756	-17.000		
40	Epsomite	-3.311					-5.451	-2.140		
18	Gypsum	-.607					-5.207	-4.600		
64	Halite	-6.984					-5.402	1.582		
17	Huntite	-9.788					-39.756	-29.968		
38	Hydrmagnesit	-21.135					-57.897	-36.762		
10	Magnesite	-1.971			-1.721	-2.221	-10.000	-8.029	-8.279	-7.779
66	Mirabilite	-6.181					-7.295	-1.114		
58	Nahcolite	-5.095					-5.643	-.548		
60	Natron	-10.534					-11.845	-1.311		
49	Nesquehonite	-4.379			-4.867	-5.454	-10.000	-5.621	-5.133	-4.546
65	Thenardite	-7.115					-7.294	-.179		
61	Thermonatr	-11.968					-11.843	.125		
59	Trona	-16.692					-17.487	-.795		
45	Witherite	-5.430			-.680		-14.015	-8.585	-13.335	
88	Pyrocroite	-6.586				-6.879	8.502	15.088		15.381
90	Rhodochrosit	-1.188			-.579	-1.605	-11.598	-10.410	-11.019	-9.993
91	MnCl2, 4H2O	-13.269					-10.559	2.710		
82	MnSO4	-9.718					-7.049	2.669		
30	Melanothalli	-17.052				-17.772	-13.322	3.730		4.450
31	CuCO3	-4.732			-4.712	-4.752	-14.362	-9.630	-9.650	-9.610
34	Cu(OH)2	-2.901				-3.461	5.739	8.640		9.200
35	Malachite	-3.445		.080	-2.795	-3.655	1.705	5.150	4.500	5.360
36	Azurite	-6.078		.090	-3.508		-2.328	3.750	1.180	
37	Atacamite	-5.393			-5.293	-5.543	1.947	7.340	7.240	7.490
38	Cu2(OH)3NO3	-9.425				-9.495	-.185	9.240		9.310
39	Antlerite	-6.625				-7.235	1.665	8.290		8.900
40	Brochantite	-7.936		.160	-7.746	-8.096	7.404	15.340	15.150	15.500
41	Langite	-9.387				-9.997	7.403	16.790		17.400
42	Tenorite	-1.881			-1.611	-2.151	5.739	7.620	7.350	7.890
43	CuOCuSO4	-28.604					-17.074	11.530		
47	CuSO4	-12.822			-12.462	-13.232	-9.812	3.010	2.650	3.420
48	Chalcanthite	-7.173			-6.853	-7.678	-9.813	-2.640	-2.960	-2.135
67	ZnCl2	-16.459				-16.489	-9.429	7.030		7.060
68	Smithsonite	-.469			.341	-.649	-10.469	-10.000	-10.810	-9.820
69	ZnCO3, 1H2O	-.209					-10.469	-10.260		
71	Zn(OH)2 (a)	-2.818			-2.628	-2.848	9.632	12.450	12.260	12.480
72	Zn(OH)2 (c)	-2.568					9.632	12.200		
73	Zn(OH)2 (b)	-2.118		.020	-1.688	-2.258	9.632	11.750	11.320	11.890
74	Zn(OH)2 (g)	-2.078			-1.558	-2.208	9.632	11.710	11.190	11.840
75	Zn(OH)2 (e)	-1.868		.030	-1.318	-1.988	9.632	11.500	10.950	11.620
76	Zn2(OH)3Cl	-5.467					9.733	15.200		
77	Zn5(OH)8Cl	-9.402					29.098	38.500		
78	Zn2(OH)2SO4	-3.788					3.712	7.500		
79	Zn4(OH)6SO4	-5.424					22.976	28.400		
80	ZnNO3)2,6H2O	-17.134					-13.694	3.440		
81	ZnO(active)	-1.678			-1.938	-2.228	9.632	11.310	11.570	11.860
82	Zincite	-1.508			-1.358	-1.908	9.632	11.140	10.990	11.540
83	Zn3O(SO4)2	-21.227					-2.207	19.020		
90	Zincosite	-8.929				-9.849	-5.919	3.010		3.930
91	ZnSO4, 1H2O	-5.349				-5.419	-5.919	-.570		-.500

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Phase	Log AP/KT	Sigma(A)	Sigma(T)	Log AP/MinKT	Log AP/MaxKT	Log AP	Log KT	Log MinKT	Log MaxKT
92 Bianchite	-4.155				-4.900	-5.920	-1.765		-1.020
93 Goslarite	-3.960				-4.050	-5.920	-1.960		-1.870
.15 Otavite	.669			.739	-1.861	-13.071	-13.740	-13.810	-11.210
.16 CdCl2	-11.351				-11.561	-12.031	-.680		-.470
.17 CdCl2, 1H2O	-10.321					-12.031	-1.710		
.18 CdCl2,2.5H2O	-10.091					-12.031	-1.940		
.20 Cd(OH)2 (a)	-6.700			-6.580	-7.270	7.030	13.730	13.610	14.300
.21 Cd(OH)2 (c)	-6.620		.040			7.030	13.650		
.22 CdOHCl	-6.021			-5.801		-2.501	3.520	3.300	
.23 Cd3(OH)4SO4	-17.022					5.538	22.560		
.24 Cd3OH2(SO4)2	-16.723					-10.013	6.710		
.25 Cd4(OH)6SO4	-15.832					12.568	28.400		
.26 Monteponite	-8.090				-8.710	7.030	15.120		15.740
.29 CdSO4	-8.421			-8.391	-8.471	-8.521	-.100	-.130	-.050
.30 CdSO4, 1H2O	-6.864			-6.841	-6.891	-8.521	-1.657	-1.680	-1.630
.31 CdSO4,2.7H2O	-6.649			-6.632	-6.662	-8.522	-1.873	-1.890	-1.860
10 NiCO3	-5.594					-12.434	-6.840		
11 Ni(OH)2	-3.133		.100	-2.923	-5.633	7.667	10.800	10.590	13.300
12 Ni4(OH)6SO4	-16.884					15.116	32.000		
13 Bunsenite	-4.783				-4.723	7.667	12.450		12.390
16 Retgersite	-5.845					-7.885	-2.040		
17 Morenosite	-5.525					-7.885	-2.360		

DOX = .0000 DOC = .0 INPUT TDS = 1300.0
Anal Cond = 1716.0 Calc Cond = 1651.9
Anal EPMCAT = 17.7113 Anal EPMAN = 15.3554 Percent difference in input cation/anion balance = 14.2498
Calc EPMCAT = 15.7107 Calc EPMAN = 13.3615 Percent difference in calc cation/anion balance = 16.1611
Total Ionic Strength (T.I.S.) from input data = .02592
Effective Ionic Strength (E.I.S.) from speciation = .02194

	Input	Sigma	Fe3/Fe2	Sigma	Sato H2O2/O2	Sigma	NO3/NO2	Sigma	NO3/NH4	Sigma	Calc H2O2/O2	Sigma	SO4/S=	Sigma	As5/As3	Sigma
Eh	9.900	.000	9.900	.000	9.900	.000	.000	.000	9.900	.000	9.900	.000	9.900	.000	9.900	.000
pE	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000

T	pH	TDS ppm	Effective Ionic Str	pO2 Atm	pCO2 Atm	pCH4 Atm	CO2 Tot	Uncom CO2	ppm Uncom CO2	Nerb Alk	aH2O
25.00	7.400	1107.2	.02194	0.00E+00	8.77E-03	0.00E+00	.00429	3.84E-03	1.69E+02	2.91E-07	.9996

I	Species		Anal ppm	Calc ppm	Anal Molal	Calc Molal	Activity	Act Coeff	-Log Act
0	Ca	2	111.000	88.330	2.773E-03	2.206E-03	1.272E-03	.5766	2.895
28	CaOH	1		.000530		9.288E-09	8.046E-09	.8663	8.094
31	CaSO4 aq	0		67.330		4.951E-04	4.976E-04	1.0051	3.303
81	CaHSO4	1		.000018		1.310E-10	1.135E-10	.8663	9.945
29	CaHCO3	1		6.313		6.251E-05	5.415E-05	.8663	4.266
30	CaCO3 aq	0		.834		8.338E-06	8.381E-06	1.0051	5.077
1	Mg	2	53.000	43.200	2.182E-03	1.779E-03	1.039E-03	.5839	2.984
18	MgOH	1		.001996		4.836E-08	4.189E-08	.8663	7.378
22	MgSO4 aq	0		42.429		3.529E-04	3.547E-04	1.0051	3.450
21	MgHCO3	1		3.966		4.653E-05	4.031E-05	.8663	4.395
20	MgCO3 aq	0		.327		3.878E-06	3.898E-06	1.0051	5.409
2	Na	1	163.000	161.170	7.098E-03	7.018E-03	6.092E-03	.8679	2.215
43	NaSO4	-1		8.048		6.767E-05	5.862E-05	.8663	4.232
42	NaHCO3aq	0		.954		1.137E-05	1.143E-05	1.0051	4.942
41	NaCO3	1		.042		5.125E-07	4.440E-07	.8663	6.353
3	K	1	17.500	17.268	4.480E-04	4.421E-04	3.814E-04	.8627	3.419
45	KSO4	-1		.802		5.941E-06	5.147E-06	.8663	5.288
63	H	1		.000045		4.492E-08	3.981E-08	.8862	7.400
26	OH	1		.004938		2.906E-07	2.518E-07	.8663	6.599
17	CO3	2		.409		6.817E-06	3.932E-06	.5768	5.405
6	HCO3	-1	246.000	233.393	4.036E-03	3.829E-03	3.337E-03	.8715	2.477
85	H2CO3 aq	0		18.405		2.971E-04	2.987E-04	1.0054	3.525
5	SO4	-2	413.000	322.853	4.304E-03	3.365E-03	1.920E-03	.5707	2.717
62	HSO4	-1		.000831		8.566E-09	7.420E-09	.8663	8.130
4	Cl	-1	96.000	95.982	2.711E-03	2.710E-03	2.338E-03	.8627	2.631
16	Fe total	2	.146		2.617E-06				
109	Mn	2	3.365	2.707	6.132E-05	4.934E-05	2.778E-05	.5631	4.556
119	MnHCO3	1		.231		1.993E-06	1.726E-06	.8663	5.763
111	MnCl	1		.027		3.034E-07	2.628E-07	.8663	6.580
112	MnCl2 aq	0		.000021		1.661E-10	1.669E-10	1.0051	9.777
113	MnCl3	-1		.000000		2.031E-13	1.760E-13	.8663	12.755
114	MnOH	1		.001488		2.070E-08	1.793E-08	.8663	7.746
115	Mn(OH)3	-1		.000000		8.047E-18	6.971E-18	.8663	17.157
117	MnSO4 aq	0		1.457		9.659E-06	9.708E-06	1.0051	5.013
145	Zn	2	4.054	1.963	6.208E-05	3.006E-05	1.693E-05	.5631	4.771
272	ZnHCO3	1		1.036		8.210E-06	7.112E-06	.8663	5.148
273	ZnCO3	0		1.655		1.321E-05	1.328E-05	1.0051	4.877
274	Zn(CO3)2	2		.367		1.982E-06	1.116E-06	.5631	5.952

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I	Species		Anal ppm	Calc ppm	Anal Molal	Calc Molal	Activity	Act Coeff	-Log Act
146	ZnCl	1		.012		1.230E-07	1.065E-07	.8663	6.973
147	ZnCl2 aq	0		.000035		2.595E-10	2.608E-10	1.0051	9.584
148	ZnCl3	-1		.000000		7.900E-13	6.843E-13	.8663	12.165
149	ZnCl4	-2		.000000		1.424E-15	8.020E-16	.5631	15.096
151	ZnOH	1		.044		5.380E-07	4.660E-07	.8663	6.332
152	Zn(OH)2	0		.013		1.337E-07	1.344E-07	1.0051	6.872
153	Zn(OH)3	1		.000001		1.232E-11	1.067E-11	.8663	10.972
154	Zn(OH)4	-2		.000000		7.539E-17	4.245E-17	.5631	16.372
155	ZnOHClaq	0		.003854		3.274E-08	3.291E-08	1.0051	7.483
158	ZnSO4 aq	0		1.222		7.581E-06	7.620E-06	1.0051	5.118
159	Zn(SO4)2	2		.054		2.113E-07	1.190E-07	.5631	6.925
160	Cd	2	.010000	.004353	8.907E-08	3.877E-08	2.183E-08	.5631	7.661
166	Cd(CO3)3	4		.000000		2.189E-17	2.201E-18	.1005	17.657
275	CdHCO3	1		.001834		1.059E-08	9.172E-09	.8663	8.038
276	CdCO3	0		.003695		2.145E-08	2.156E-08	1.0051	7.666
161	CdCl	1		.000831		5.627E-09	4.875E-09	.8663	8.312
162	CdCl2 aq	0		.000009		4.728E-11	4.752E-11	1.0051	10.323
163	CdCl3	-1		.000000		8.093E-14	7.010E-14	.8663	13.154
167	CdOH	1		.000007		5.263E-11	4.559E-11	.8663	10.341
168	Cd(OH)2	0		.000000		6.117E-14	6.148E-14	1.0051	13.211
169	Cd(OH)3	-1		.000000		1.999E-19	1.732E-19	.8663	18.761
170	Cd(OH)4	2		.000000		6.883E-26	3.876E-26	.5631	25.412
171	Cd2OH	3		.000000		1.754E-17	4.818E-18	.2747	17.317
172	CdOHClaq	0		.000008		5.030E-11	5.056E-11	1.0051	10.296
174	CdSO4 aq	0		.002505		1.203E-08	1.209E-08	1.0051	7.918
277	Cd(SO4)2	-2		.000094		4.522E-10	2.547E-10	.5631	9.594
204	Ni	2	.074000	.004102	1.262E-06	6.995E-08	3.939E-08	.5631	7.405
280	NiHCO3	1		.002505		2.095E-08	1.815E-08	.8663	7.741
281	NiCO3	0		.135		1.142E-06	1.148E-06	1.0051	5.940
282	Ni(CO3)2	2		.002486		1.393E-08	7.842E-09	.5631	8.106
206	NiCl	1		.000025		2.671E-10	2.314E-10	.8663	9.636
279	NiCl2	0		.000000		1.954E-12	1.964E-12	1.0051	11.707
208	NiOH	1		.000012		1.576E-10	1.365E-10	.8663	9.865
209	Ni(OH)2	0		.000000		2.471E-12	2.483E-12	1.0051	11.605
210	Ni(OH)3	1		.000000		7.199E-16	6.236E-16	.8663	15.205
211	NiSO4 aq	0		.002269		1.467E-08	1.475E-08	1.0051	7.831
283	Ni(SO4)2	-2		.000000		2.702E-12	1.522E-12	.5631	11.818
89	Ba	2	.045	.029	3.280E-07	2.131E-07	1.200E-07	.5631	6.921
90	BaOH	1		.000000		1.529E-13	1.324E-13	.8663	12.878
201	BaSO4 aq	0		.027		1.149E-07	1.155E-07	1.0051	6.938

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Phase	Log AP/KT	Sigma(A)	Sigma(T)	Log AP/MinKT	Log AP/MaxKT	Log AP	Log KT	Log MinKT	Log MaxKT
17 Anhydrite	-.975					-5.612	-4.637		
21 Aragonite	.035		.020			-8.301	-8.336		
150 Artinite	-5.997					3.603	9.600		
144 Barite	.338				.135	-9.638	-9.976		-9.773
19 Brucite	-4.977					-16.181	-11.204		
12 Calcite	.179		.020	.259		-8.301	-8.480	-8.560	
11 Dolomite	.310					-16.690	-17.000		
340 Epsomite	-3.561					-5.701	-2.140		
18 Gypsum	-1.012					-5.612	-4.600		
64 Halite	-6.428					-4.846	1.582		
117 Huntite	-3.500					-33.468	-29.968		
38 Hydrmagnesit	-12.976					-49.738	-36.762		
10 Magnesite	-.360			-.110	-.610	-8.389	-8.029	-8.279	-7.779
66 Mirabilite	-6.035					-7.149	-1.114		
58 Nahcolite	-4.144					-4.692	-.548		
60 Natron	-8.527					-9.838	-1.311		
149 Nesquehonite	-2.768			-3.256	-3.843	-8.389	-5.621	-5.133	-4.546
65 Thenardite	-6.968					-7.147	-.179		
61 Thermonatr	-9.961					-9.836	.125		
59 Trona	-13.733					-14.528	-.795		
145 Witherite	-3.741			1.009		-12.326	-8.585	-13.335	
188 Pyrocroite	-4.845				-5.138	10.243	15.088		15.381
190 Rhodochrosit	.448			1.057	.031	-9.962	-10.410	-11.019	-9.993
191 MnCl2, 4H2O	-12.529					-9.819	2.710		
182 MnSO4	-9.942					-7.273	2.669		
267 ZnCl2	-17.064				-17.094	-10.034	7.030		7.060
268 Smithsonite	-.177			.633	-.357	-10.177	-10.000	-10.810	-9.820
269 ZnCO3, 1H2O	.083					-10.177	-10.260		
271 Zn(OH)2 (a)	-2.422			-2.232	-2.452	10.028	12.450	12.260	12.480
272 Zn(OH)2 (c)	-2.172					10.028	12.200		
273 Zn(OH)2 (b)	-1.722		.020	-1.292	-1.862	10.028	11.750	11.320	11.890
274 Zn(OH)2 (g)	-1.682			-1.162	-1.812	10.028	11.710	11.190	11.840
275 Zn(OH)2 (e)	-1.472		.030	-.922	-1.592	10.028	11.500	10.950	11.620
276 Zn2(OH)3Cl	-5.174					10.026	15.200		
277 Zn5(OH)8Cl	-8.421					30.079	38.500		
278 Zn2(OH)2SO4	-4.960					2.540	7.500		
279 Zn4(OH)6SO4	-5.803					22.597	28.400		
281 ZnO(active)	-1.282			-1.542	-1.832	10.028	11.310	11.570	11.860
282 Zincite	-1.112			-.962	-1.512	10.028	11.140	10.990	11.540
283 Zn3O(SO4)2	-23.968					-4.948	19.020		
290 Zincosite	-10.498				-11.418	-7.488	3.010		3.930
291 ZnSO4, 1H2O	-6.918				-6.988	-7.488	-.570		-.500
292 Bianchite	-5.724				-6.469	-7.489	1.765		-1.020
293 Goslarite	-5.529				-5.619	-7.489	-1.960		-1.870
315 Otavite	.674			.744	-1.856	-13.066	-13.740	-13.810	-11.210
316 CdCl2	-12.243				-12.453	-12.923	-.680		-.470
317 CdCl2, 1H2O	-11.213					-12.923	-1.710		
318 CdCl2,2.5H2O	-10.984					-12.924	-1.940		
320 Cd(OH)2 (a)	-6.591			-6.471	-7.161	7.139	13.730	13.610	14.300
321 Cd(OH)2 (c)	-6.511		.040			7.139	13.650		
322 CdOHCl	-6.412			-6.192		-2.892	3.520	3.300	
323 Cd3(OH)4SO4	-18.660					3.900	22.560		
324 Cd3OH2(SO4)2	-20.326					-13.616	6.710		
325 Cd4(OH)6SO4	-17.361					11.039	28.400		
326 Monteponite	-7.981				-8.601	7.139	15.120		15.740
329 CdSO4	-10.278			-10.248	-10.328	-10.378	-.100	-.130	-.050
330 CdSO4, 1H2O	-8.721			-8.698	-8.748	-10.378	-1.657	-1.680	-1.630

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	Phase	Log AP/KT	Sigma(A)	Sigma(T)	Log AP/MinKT	Log AP/MaxKT	Log AP	Log KT	Log MinKT	Log MaxKT
331	CdSO4,2.7H2O	-8.505			-8.488	-8.518	-10.378	-1.873	-1.890	-1.860
410	NiCO3	-5.970					-12.810	-6.840		
411	Ni(OH)2	-3.405		.100	-3.195	-5.905	7.395	10.800	10.590	13.300
412	Ni4(OH)6SO4	-19.936					12.064	32.000		
413	Bunsenite	-5.055				-4.995	7.395	12.450		12.390
416	Retgersite	-8.082					-10.122	-2.040		
417	Morenosite	-7.762					-10.122	-2.360		

DOX = .0000 DOC = .0 INPUT TDS = 306.0
Anal Cond = 439.0 Calc Cond = 494.4
Anal EPMCAT = 4.3528 Anal EPMAN = 4.6600 Percent difference in input cation/anion balance = -6.8166
Calc EPMCAT = 4.0085 Calc EPMAN = 4.3194 Percent difference in calc cation/anion balance = -7.4676
Total Ionic Strength (T.I.S.) from input data = .00736
Effective Ionic Strength (E.I.S.) from speciation = .00668

Input	Sigma	Fe3/Fe2	Sigma	Sato H2O2/O2	Sigma	NO3/NO2	Sigma	NO3/NH4	Sigma	Calc H2O2/O2	Sigma	SO4/S=	Sigma	As5/As3	Sigma
Eh															
9.900	.000	9.900	.000	9.900	.000	.000	.000	9.900	.000	9.900	.000	9.900	.000	9.900	.000
pE															
100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000	100.000	.000

T	pH	TDS ppm	Effective Ionic Str	pO2 Atm	pCO2 Atm	pCH4 Atm	CO2 Tot	Uncom CO2	ppm Uncom CO2	Ncrb Alk	aH2O
25.00	7.500	321.1	.00668	0.00E+00	2.74E-03	0.00E+00	.00155	1.43E-03	6.31E+01	3.46E-07	.9999

I	Species		Anal ppm	Calc ppm	Anal Molal	Calc Molal	Activity	Act Coeff	-Log Act
0	Ca	2	32.000	28.042	7.987E-04	6.999E-04	5.004E-04	.7149	3.301
28	CaOH	1		.000248		4.344E-09	3.985E-09	.9173	8.400
31	CaSO4 aq	0		11.977		8.800E-05	8.814E-05	1.0015	4.055
81	CaHSO4	1		.000002		1.741E-11	1.597E-11	.9173	10.797
29	CaHCO3	1		.924		9.145E-06	8.389E-06	.9173	5.076
30	CaCO3 aq	0		.163		1.632E-06	1.634E-06	1.0015	5.787
1	Mg	2	16.000	14.240	6.583E-04	5.859E-04	4.208E-04	.7182	3.376
18	MgOH	1		.000962		2.330E-08	2.137E-08	.9173	7.670
22	MgSO4 aq	0		7.774		6.460E-05	6.470E-05	1.0015	4.189
21	MgHCO3	1		.598		7.011E-06	6.432E-06	.9173	5.192
20	MgCO3 aq	0		.066		7.817E-07	7.829E-07	1.0015	6.106
2	Na	1	28.000	27.859	1.218E-03	1.212E-03	1.113E-03	.9181	2.954
43	NaSO4	-1		.626		5.258E-06	4.823E-06	.9173	5.317
42	NaHCO3aq	0		.069		8.213E-07	8.226E-07	1.0015	6.085
41	NaCO3	1		.003638		4.384E-08	4.022E-08	.9173	7.396
3	K	1	6.600	6.560	1.688E-04	1.678E-04	1.538E-04	.9163	3.813
45	KSO4	-1		.138		1.019E-06	9.345E-07	.9173	6.029
63	H	1		.000034		3.416E-08	3.162E-08	.9257	7.500
26	OH	-1		.005876		3.456E-07	3.171E-07	.9173	6.499
17	CO3	-2		.163		2.725E-06	1.950E-06	.7154	5.710
6	HCO3	-1	89.000	87.175	1.459E-03	1.429E-03	1.314E-03	.9197	2.881
85	H2CO3 aq	0		5.784		9.328E-05	9.344E-05	1.0016	4.029
5	SO4	-2	132.000	116.516	1.375E-03	1.213E-03	8.647E-04	.7127	3.063
62	HSO4	-1		.000281		2.893E-09	2.654E-09	.9173	8.576
4	Cl	1	16.000	15.999	4.514E-04	4.514E-04	4.136E-04	.9163	3.383
16	Fe total	2	.110		1.970E-06				
109	Mn	2	1.071	.946	1.950E-05	1.723E-05	1.220E-05	.7082	4.914
119	MnHCO3	1		.038		3.255E-07	2.986E-07	.9173	6.525
111	MnCl	1		.002011		2.225E-08	2.041E-08	.9173	7.690
112	MnCl2 aq	0		.000000		2.290E-12	2.294E-12	1.0015	11.639
113	MnCl3	1		.000000		4.663E-16	4.277E-16	.9173	15.369
114	MnOH	1		.000777		1.081E-08	9.914E-09	.9173	8.004
115	Mn(OH)3	-1		.000000		6.663E-18	6.112E-18	.9173	17.214
117	MnSO4 aq	0		.289		1.917E-06	1.920E-06	1.0015	5.717
145	Zn	2	.268	.167	4.101E-06	2.562E-06	1.815E-06	.7082	5.741
272	ZnHCO3	1		.041		3.273E-07	3.003E-07	.9173	6.523
273	ZnCO3	0		.088		7.048E-07	7.059E-07	1.0015	6.151
274	Zn(CO3)2	-2		.007697		4.154E-08	2.941E-08	.7082	7.531

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I	Species		Anal ppm	Calc ppm	Anal Molal	Calc Molal	Activity	Act Coeff	-Log Act
146	ZnCl	1		.000222		2.202E-09	2.020E-09	.9173	8.695
147	ZnCl2 aq	0		.000000		8.737E-13	8.750E-13	1.0015	12.058
148	ZnCl3	-1		.000000		4.427E-16	4.061E-16	.9173	15.391
149	ZnCl4	-2		.000000		1.189E-19	8.419E-20	.7082	19.075
151	ZnOH	1		.005648		6.858E-08	6.291E-08	.9173	7.201
152	Zn(OH)2	0		.002266		2.280E-08	2.284E-08	1.0015	7.641
153	Zn(OH)3	-1		.000000		2.489E-12	2.284E-12	.9173	11.641
154	Zn(OH)4	-2		.000000		1.616E-17	1.144E-17	.7082	16.941
155	ZnOHClaq	0		.000092		7.847E-10	7.859E-10	1.0015	9.105
158	ZnSO4 aq	0		.059		3.673E-07	3.678E-07	1.0015	6.434
159	Zn(SO4)2	-2		.000940		3.651E-09	2.585E-09	.7082	8.587
89	Ba	2	.032	.024	2.331E-07	1.784E-07	1.263E-07	.7082	6.898
90	BaOH	1		.000000		1.914E-13	1.756E-13	.9173	12.756
201	BaSO4 aq	0		.013		5.467E-08	5.475E-08	1.0015	7.262

[illegible]

Phase	Log AP/KT	Sigma(A)	Sigma(T)	Log AP/MinKT	Log AP/MaxKT	Log AP	Log KT	Log MinKT	Log MaxKT
17 Anhydrite	-1.727					-6.364	-4.637		
21 Aragonite	-.675		.020			-9.011	-8.336		
150 Artinite	-6.912					2.688	9.600		
144 Barite	.014				-.189	-9.962	-9.976		-9.773
19 Brucite	-5.170					-16.374	-11.204		
12 Calcite	-.531		.020	-.451		-9.011	-8.480	-8.560	
11 Dolomite	-1.097					-18.097	-17.000		
340 Epsomite	-4.299					-6.439	-2.140		
18 Gypsum	-1.764					-6.364	-4.600		
64 Halite	-7.919					-6.337	1.582		
117 Huntite	-6.301					-36.269	-29.968		
38 Hydrmagnesit	-15.956					-52.718	-36.762		
10 Magnesite	-1.057			-.807	-1.307	-9.086	-8.029	-8.279	-7.779
66 Mirabilite	-7.857					-8.971	-1.114		
58 Nahcolite	-5.287					-5.835	-.548		
60 Natron	-10.307					-11.618	-1.311		
149 Nesquehonite	-3.465			-3.953	-4.540	-9.086	-5.621	-5.133	-4.546
65 Thenardite	-8.791					-8.970	-.179		
61 Thermonatr	-11.742					-11.617	.125		
59 Trona	-16.657					-17.452	-.795		
145 Witherite	-4.024			.726		-12.609	-8.585	-13.335	
188 Pyrocroite	-5.002				-5.295	10.086	15.088		15.381
190 Rhodochrosit	-.214			.395	-.631	-10.624	-10.410	-11.019	-9.993
191 MnCl2, 4H2O	-14.391					-11.681	2.710		
182 MnSO4	-10.646					-7.977	2.669		
267 ZnCl2	-19.538				-19.568	-12.508	7.030		7.060
268 Smithsonite	-1.451			-.641	-1.631	-11.451	-10.000	-10.810	-9.820
269 ZnCO3, 1H2O	-1.191					-11.451	-10.260		
271 Zn(OH)2 (a)	-3.191			-3.001	-3.221	9.259	12.450	12.260	12.480
272 Zn(OH)2 (c)	-2.941					9.259	12.200		
273 Zn(OH)2 (b)	-2.491		.020	-2.061	-2.631	9.259	11.750	11.320	11.890
274 Zn(OH)2 (g)	-2.451			-1.931	-2.581	9.259	11.710	11.190	11.840
275 Zn(OH)2 (e)	-2.241		.030	-1.691	-2.361	9.259	11.500	10.950	11.620
276 Zn2(OH)3Cl	-7.566					7.634	15.200		
277 Zn5(OH)8Cl	-13.973					24.527	38.500		
278 Zn2(OH)2SO4	-7.046					.454	7.500		
279 Zn4(OH)6SO4	-9.428					18.972	28.400		
281 ZnO(active)	-2.051			-2.311	-2.601	9.259	11.310	11.570	11.860
282 Zincite	-1.881			-1.731	-2.281	9.259	11.140	10.990	11.540
283 Zn3O(SO4)2	-27.370					-8.350	19.020		
290 Zincosite	-11.814				-12.734	-8.804	3.010		3.930
291 ZnSO4, 1H2O	-8.234				-8.304	-8.804	-.570		-.500
292 Bianchite	-7.040				-7.785	-8.805	-1.765		-1.020
293 Goslarite	-6.845				-6.935	-8.805	-1.960		-1.870

VITA

Larry L. Wooten

Candidate for the Degree of

Master of Science

Thesis: WATER QUALITY OF COAL CREEK TRIBUTARIES DRAINING AN EAGLE-PICHER SMELTER SITE, OKMULGEE COUNTY, OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Canyon, Texas, March 15, 1950, the son of Leroy and Juanita Wooten.

Education: Graduated from Canyon High School, Canyon, Texas, in May 1968; received a Bachelor of Science Degree in Geology from West Texas State University in May 1976; completed the requirements for the Master of Science degree at Oklahoma State University in May 1998.

Profession Experience: Petroleum Geologist for Diamond Shamrock Corporation from 1976 to 1977, Petroleum Geologist for Amarillo Oil Company from 1977 to 1979, Petroleum Geologist for Argonaut Energy from 1979 to 1980, Petroleum Geologist for Republic Resources Corporation from 1980 to 1982, Petroleum Geologist for Red Land Energy, Ltd. from 1982 to 1983, Independent Petroleum Geologist from 1983 to 1991, Hydrogeologist for Roberts/Schornick & Associates, Inc. from 1991 to present.