HYDROGEOLOGY, HYDROCHEMISTRY AND RECLAMATION ALTERNATIVES FOR AN INACTIVE LEAD-SILVER MINE IN NORTHERN IDAHO

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ABSTRACT

The Idaho Continental Mine is an inactive lead-silver mine located in the Selkirk Mountains near the headwaters of Blue Joe Creek in Boundary County, Idaho. Active mining ceased in the late 1940's. Chemical leaching and physical sedimentation problems associated with a discharging mine adit and unstablized mill tailings are manifest as a loss of indigenous fisheries, reduced macroinvertebrate populations and stream channel instability in nearby Blue Joe Creek. The purpose of this study is to provide hydrologic, hydrogeologic and hydrochemical input to a reclamation plan for the mine.

Surface and ground water quality in the vicinity of the mine was monitored through a series of 40 sample stations. Water samples were analyzed primarily for dissolved Zn, Pb and Cd, in addition to field measured parameters such as pH, EC, temperature and alkalinity. The tailings pile at the mine was surveyed for spatial control. Surface variations in the character of the mineral wastes also were mapped.

Estimates of the original and remaining volume of tailings on site suggest 40 to 60 percent of the tailings have been removed from the mine site by erosion. Chemical water quality impacts are believed to result primarily from toxic levels of dissolved metal cations. Acid drainage is not a problem. Ground water discharge from the base of the tailings contains up to 59 mg/L Zn, 12 mg/L Pb and 0.72 mg/L Cd. Water from the primary discharging adit is thought to contain the seasonally highest dissolved metal concentrations and metal loads during spring high flow. More than 50 percent of the zinc and cadmium load measured in the lower reaches of the creek can be traced to the mine adit during the spring

"metal flushing" event. The concentration of metals in the creek tends to peak near the downstream end of the tailings pile, dropping to much lower levels several miles downstream. Peak concentrations measured during the study are about 1 mg/L Zn, 0.5 mg/L Pb and 0.03 mg/L Cd. The metal load in Blue Joe Creek during low flow periods increases significantly between the mine site and a sampling station several miles downstream. The increase in metal load below the mine site is attributed to mobilization of metals from tailings-rich stream sediments. Metal loads of about 25,000 gms/day Zn, 30,000 gms/day Pb, and 300 gms/day Cd were measured near the mouth during spring high flow, dropping by roughly an order of magnitude during low flow.

Six reclamation alternatives are proposed for mitigation of chemical leaching and physical sedimentation impacts. The favored reclamation alternative is to regrade and stabilize the tailings in association with channel reconstruction activities.

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CHAPTER I

INTRODUCTION

Statement of the Problem

Northern Idaho has hosted an abundance of mining activity since exploration for precious metals began in the 1880's. Underground mining methods usually were employed to extract rich deposits of silver and lead from metamorphic host rocks. Significant amounts of wastes were produced by the mining and milling processes. The milling wastes often were discharged directly into nearby water bodies, or were placed into inadequately barricaded tailings piles. Interim maintenance during inactive periods or post-abandonment reclamation rarely were provided to protect tailings piles from erosion and chemical leaching. Chemical and physical pollution of local surface waters, seasonally degraded air quality, and degraded local aesthetics are some of the documented environmental impacts associated with inactive and abandoned metal mines in the region. Leaching of metals by ground water movement through the tailings also has been a problem.

The Continental Mine located in the Selkirk Mountains of northwest Boundary County, Idaho, is an inactive lead-silver-zinc mine responsible for significant pollution problems (fig. 1). The mine is located in the upper reaches of Blue Joe Creek, approximately five miles south of the International Boundary. The mine was worked actively by various parties until the late 1940's, after which only limited production and exploration has occurred. Mill tailings and mine waste rock deposited into Blue Joe Creek drainage have been and continue to be subject to leaching and erosion. Seasonally variable concentrations of dissolved metals are contributed to the creek from a discharging mine adit. Dissolved metals

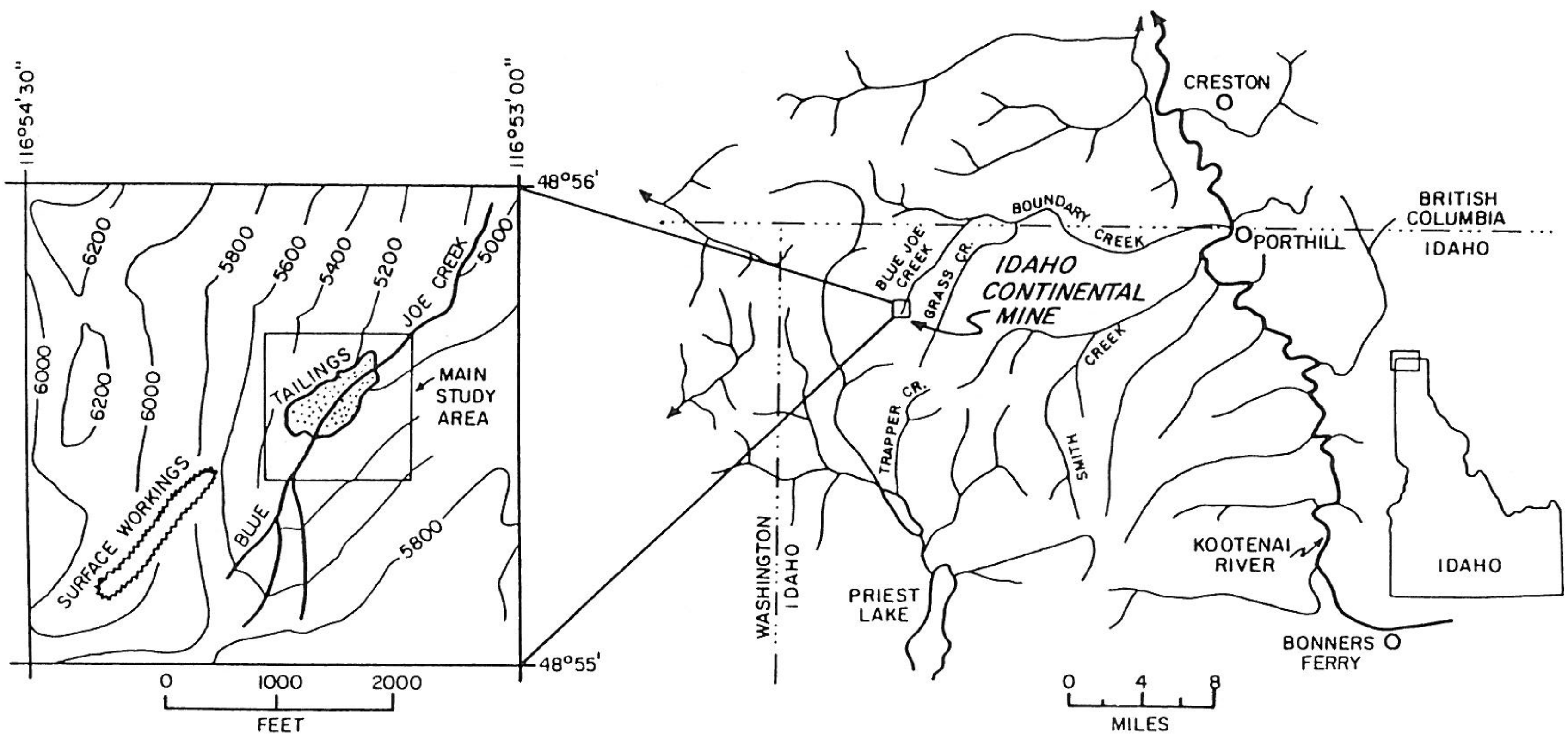


Figure 1. Location of the Idaho Continental Mine Study Area, Boundary County, Idaho (adapted in part from USGS topographic map, 1968).

and sediment entering Blue Joe Creek from mine-related sources have eliminated the indigenous fisheries from the main stem of the creek, reduced macroinvertebrate populations, and increased channel instability. Reclamation efforts are needed to ameliorate the water quality, channel stability, and aesthetic problems that exist within Blue Joe Creek and the mine site vicinity.

Purpose and Objectives

The purpose of this study is to provide hydrologic input to a reclamation plan for the Idaho Continental Mine. The general objective is to describe the hydrologic and hydrochemical characteristics of upper Blue Joe Creek in the vicinity of the Continental Mine. The specific objectives are to:

(1) Describe the physiographic setting, hydrology and hydrogeology of the Idaho Continental Mine study area.

(2) Describe the nature and extent of the tailings/waste rock/ore stockpile deposits within the mine site. Discussion of mine waste impacts on water quality is focussed on the volumetrically dominant and chemically reactive mill tailings.

(3) Evaluate the mine-related impacts to chemical water quality in Blue Joe Creek. Analysis is concentrated on spatial variations in ground water quality, temporal changes in adit discharge, and spatial and temporal variations in the dissolved metal concentration and load in Blue Joe Creek.

(4) Utilize the findings of the study to propose and evaluate reclamation alternatives aimed at mitigating water quality impacts.

Scope of the Literature

Published information describing the hydrology, hydrogeology and hydrochemistry of northwest Boundary County and the Continental Mine study area is limited. Reports by Martin and Mills (1976) and the U.S. Forest Service (1976) cite the Idaho Continental Mine as a major factor responsible for water quality degradation in Blue Joe Creek. The U.S. Forest Service report includes the earliest published assessment of regional hydrology and hydrochemistry. The specific impacts to Blue Joe Creek directly attributable to the Continental Mine were examined in greatest detail by Gerhardt (1981 and 1983). His investigations included water quality sampling for dissolved metals, surveys of aquatic biota, and evaluation of stream channel conditions. His studies found that measurable levels of lead, zinc and cadmium had contributed to the elimination of fisheries and to the reduction in macroinvertebrate populations. In addition he found that channel instability was a problem. Water quality data from Gerhardt (1981), and from the U.S. Forest Service (1976) are presented in appendix A.

Regional Description and Physiographic Setting

The Idaho Continental Mine is located in the panhandle of northern Idaho. The mine is within the Selkirk Mountains, a sub-range of the Northern Rocky Mountains (fig. 1). The presence of numerous peaks over 6000 feet and many deeply cutting drainages led Kirkham and Ellis (1926, p. 13) to describe the region as a "rugged and mountainous province...serated and scenic...scarred both by continental and alpine glaciation".

The Continental Mine properties span a regional drainage divide. Most of the surface and ground water draining from the mine property discharges into Blue Joe Creek. Water in Blue Joe Creek is tributary to Boundary Creek, which in turn is tributary to the Kootenai River.

The Continental Mine has been the only large scale mining operation in the district. In adjacent Grass Creek, mining activity occurred during the 1920's and 1930's at the Parker molybdenum mine (Baker, 1979). Operations closed in the early 1930's after only limited development.

The climate of northern Boundary County is similar to the rest of the Northern Rocky Mountain Province. Annual precipitation ranges from 50 to 70 inches per year. Seventy to 75 percent of this falls as snow during the months of November through April. At higher elevations, snowpack accumulations up to ten feet can occur (Gerhardt, 1981). Rainfall occurs primarily during the spring and early fall. Temperature data from the Priest River Experimental Station approximately 25 miles south of the Continental Mine show a mean monthly maximum of 82 F in July. Sub-zero temperatures are common from December through February, with January posting the coldest mean monthly minimum temperature of 17 F.

Much of northern Boundary County is rugged and forested with little flat land except along the floodplain of the Kootenai River. Agricultural activities are concentrated within the Kootenai valley. Timber harvest activities account for the major land use in the area. The most prominent coniferous tree species in the mid and lower elevations include western hemlock, western red cedar, western larch, ponderosa pine, Douglas-fir, and patches of lodgepole pine. Higher elevation slopes contain abundant sub-alpine fir and Englemann spruce (U.S. Forest Service, 1976).

The area is host to several types of wildlife including mule and whitetail deer, mountain goats, white-tailed ptarmigan, golden eagles, grizzly bears and mountain caribou. Management areas for the grizzly bear and caribou have been established in northwest Boundary County (U.S. Forest Service, 1976).

Method of Study

The project was conducted in cooperation with the Bonners Ferry Ranger District of the U.S. Forest Service, the mine's current leaseholder (the New Idaho Continental Corporation), and the Idaho Department of Health and Welfare Division of Environment in Coeur d'Alene. A literature review provided background information on the geology, hydrology, physiographic setting, and mining and production history. The literature also was searched for any documents which deal with reclamation enacted at other inactive or abandoned metal mines in similar physiographic settings.

Water samples were collected from surface channels, tailings seepage and underground workings. These samples were analyzed for dissolved metal concentrations. Standard guidelines (U.S. Geological Survey, 1977; Idaho Dept. of Health and Welfare, 1985) were followed during the collection, filtration and preservation of water samples. Some parameters and constituents were analyzed only once, while others were obtained routinely.

A summary of field methods used in the collection of data is presented in table 1. Chemical analysis of the water samples was performed at both the State of Idaho Department of Health and Welfare lab in Coeur d'Alene, and at the Health and Welfare lab in Boise. Samples were run on a Perkin-Elmer 306 atomic absorption spectrophotometer (AAS). Laboratory methods of analysis and detection limits for the various constituents are listed in table 2.

Table 1. Summary of hydrologic field methods

measurement	methods
Temperature	Measured with a standard unarmored thermometer calibrated in degrees Celcius and read to nearest half degree.
Discharge	Measured with a pygmy meter, bucket and stopwatch or visually estimated. Values reported as cubic feet per second (cfs).
pH	Measured with a Corning temperature compensated pH meter or with litmus paper. Meters were calibrated with buffers before each use. Samples were collected in a prerinsed beaker and measured immediately.
Specific Conductance	Measured with a Yellow Springs Instruments Conductivity meter or with a temperature compensated Myron EP meter. Meters were calibrated with conductance standards. Values reported as μmhos/cm.
Alkalinity	Determined by titrating sample with 0.02 N nitric acid using colorimetric pH indicators. Also measured with a Hach field titration kit. Values reported as ppm of calcium carbonate.
Water Levels	Measured with a chalked, raised-numbered steel tape and read to the nearest 0.01 foot.
Subsurface Water Samples	Collected from auger drilled piezometers with a 12-inch long, 0.75-inch diameter PVC tube fitted with a one-way check valve.

Table 2. Summary of laboratory methods and detection limits (from Albertson, 1985)

Constituent	Analytical Method	Detection Limit (mg/L)
Pb	GF	0.020
Cd	GF	0.001
As	GF	0.010
Zn	DA	0.010
Fe	DA	0.020
Cu	DA	0.010
Mg	DA	0.1
Na	DA	0.1
K	DA	0.1
Ca	EDTA	3
Hardness	EDTA	8
Alkalinity	AT	2
Sulfate	BSP	5
Chloride	MCT	1

GF: Atomic absorption spectrophotometer (AAS) using graphite furnace

DA: AAS using direct aspiration flame

EDTA: Ethylenediamenetetraacetic acid (EDTA) titration

AT: standard acid titration to pH 4.5

BSP: spectrometric analysis of barium sulfate precipitate

MCT: mercuric chloride titration

Piezometers were installed in the tailings pile to allow monitoring of water quality and water levels in these materials. A stadia transit survey was conducted within the main tailings/waste rock disposal areas to provide spatial control of the sampling locations and to define in relative detail the present configuration of the tailings/waste rock areas. The results of the field investigation were compiled into this final report.

Water Data Collection Program

A data collection program was established at the study area to help in the assessment of water quality impacts on Blue Joe Creek attributable to the Continental Mine. Forty different stations provided data on the quality and quantity of surface and ground waters (figs. 2 and 3). The data were obtained during six separate data collection periods: early October, 1984; early June, 1985; mid July, 1985; late August, 1985; early September, 1985; and late September, 1985. The samples are labeled BJ for Blue Joe Creek, MD for miscellaneous discharge, MA for mine adit, PZ for auger-drilled piezometer, and H for shallow piezometers and open holes.

Eight stations (BJ1-BJ8) monitor Blue Joe Creek. BJ5 and BJ6 provide background water quality on the creek. BJ7 documents water quality conditions directly below the mine site. BJ8 is located five miles downstream of the mine and monitors the distant downstream impacts attributable to the Continental Mine. The other sites monitor the creek through the tailings pile. Twelve sites (MD3-MD6, MD9-MD16) are within the tailings pile and four sites (MD1, MD2, MD7, and MD8) are outside the tailings pile. These include gully discharges (MD6, MD9, MD10, MD11, MD12, MD14 MD15 and MD16), tailings and/or mine waste seepage (MD2, MD4, MD5, MD13), surface tributaries (MD1, MD7) and diversion channel discharge (MD8). Stations MA1 and MA2 are located at the adits. MA1 is the

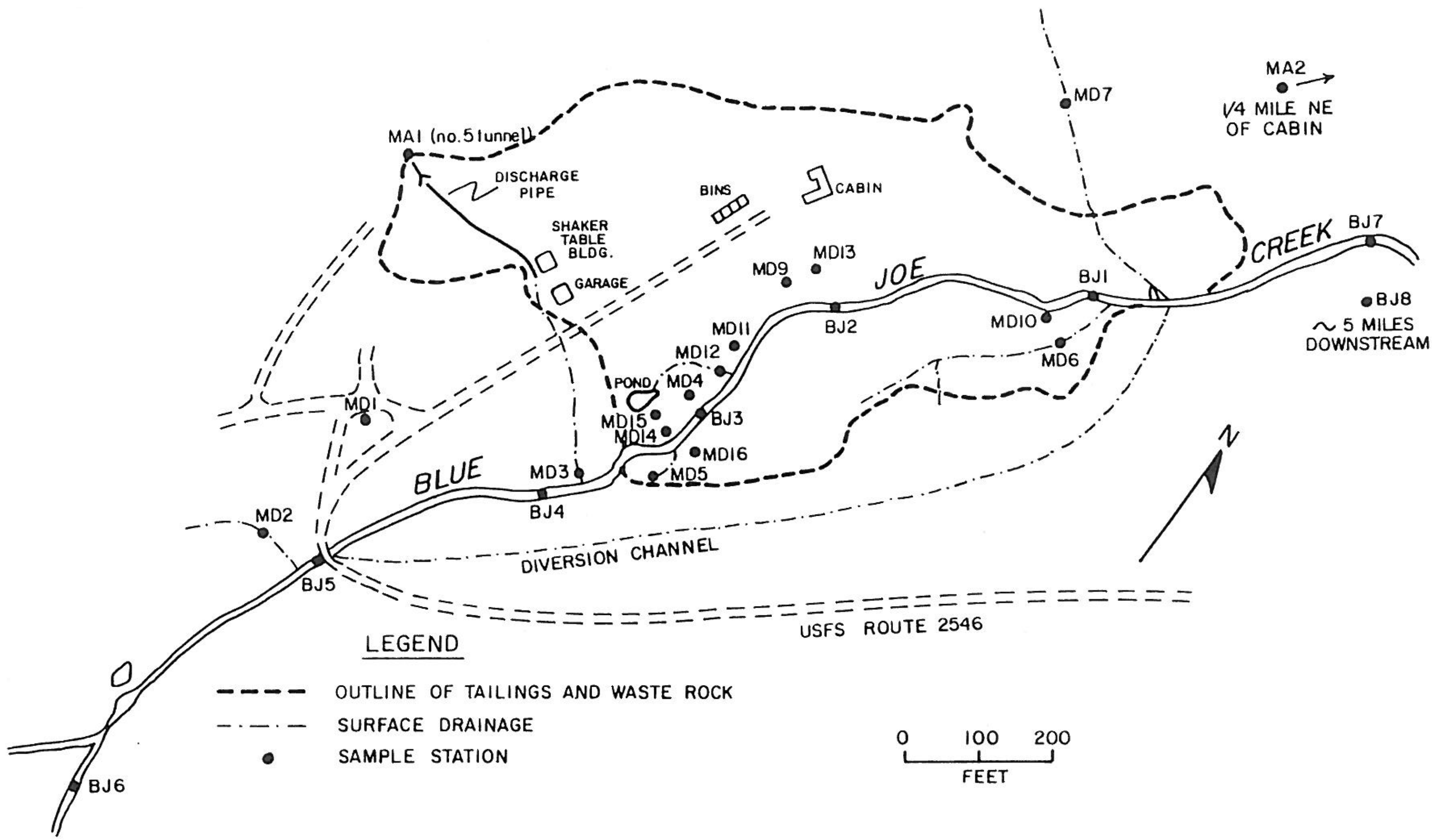


Figure 2. Location of surface seep and surface discharge sample sites

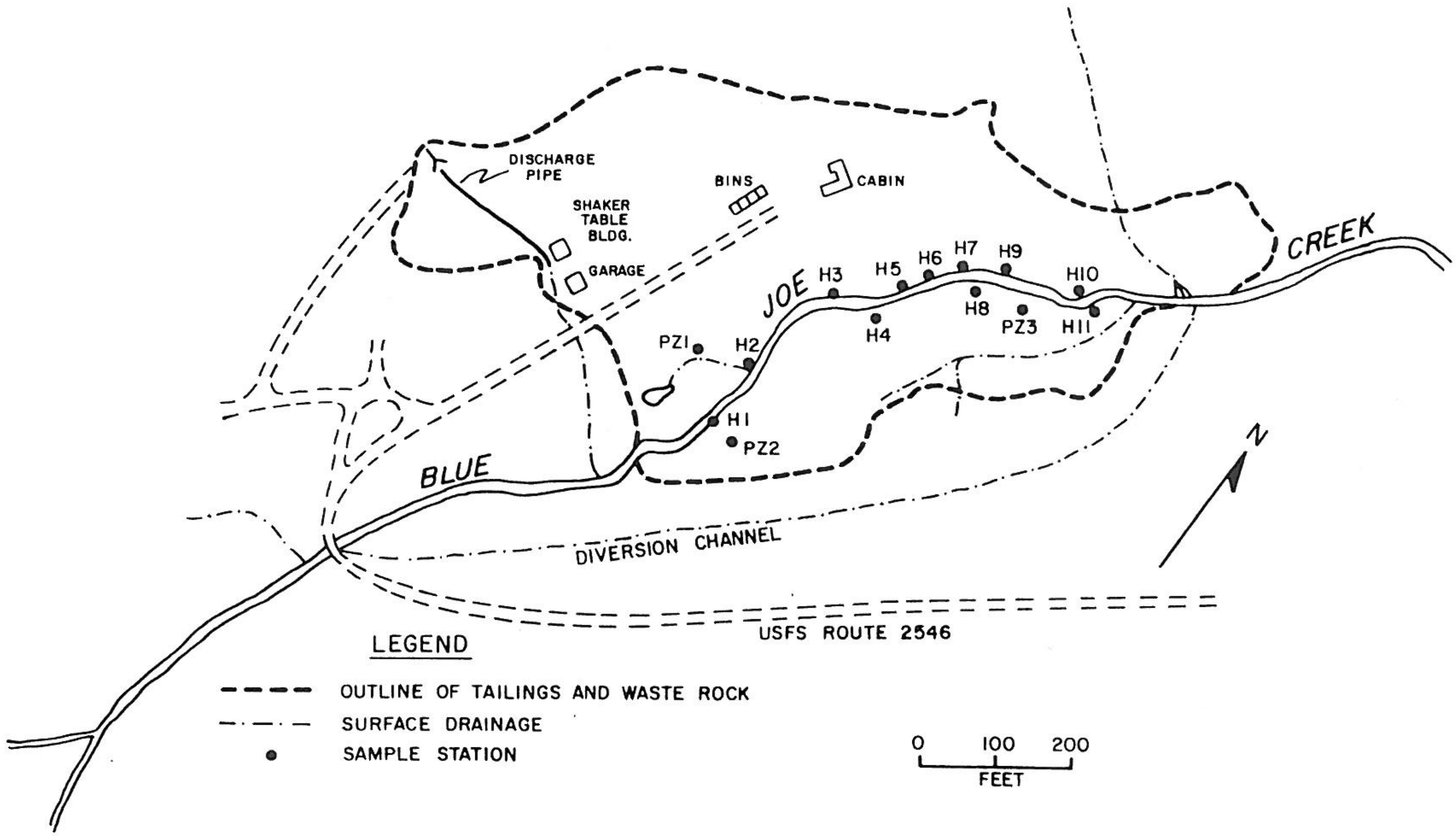


Figure 3. Location of ground water sample sites

lowermost adit and is the primary discharge point for water flowing from the underground workings. Eleven shallow piezometers and open holes (H1-H11) were installed along Blue Joe Creek to monitor the quality of ground water coming from the tailings area. Three auger-drilled piezometers (PZ1-PZ3) were installed to examine subsurface quality and water level changes within the tailings. A more detailed description of the sample stations is given in appendix B.

CHAPTER II

GEOLOGY AND MINING HISTORY

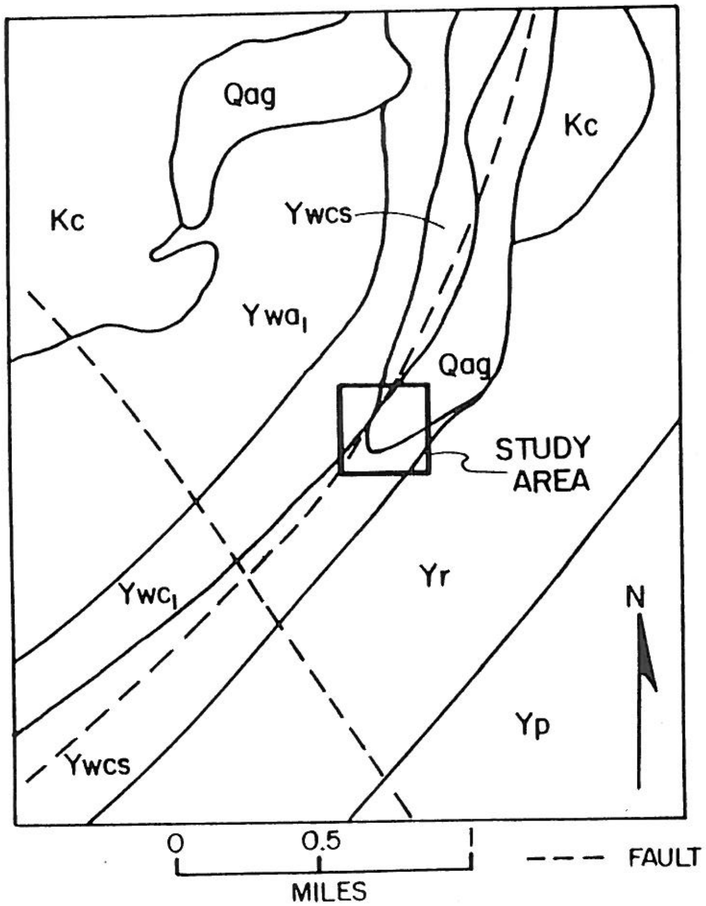
Regional Stratigraphy

The regional bedrock of northwestern Idaho consists of two principal units. These include: (1) thick, areally extensive and highly metamorphosed sandstones, siltstones (argillites), and limestones of the Precambrian Belt Supergroup, and (2) late Cretaceous to Tertiary granitic plutons of the Selkirk Crest Igneous Complex, dominated by the Kaniksu batholith (U.S. Forest Service, 1976; Miller, 1982). Surficial deposits of glacial till and drift were deposited by continental and alpine glaciers, while lacustrine sediments were deposited within large glacial lakes (U.S. Forest Service, 1976).

Local Geology and Pedology

The Idaho Continental Mine lies within the Precambrian metasediments of the Belt Supergroup near the intersection of two roughly orthogonal fault systems (Figure 4). Recent mapping by Miller (1982) identified rocks of the Wallace Formation over most of the mine site. Rocks of the Ravalli Group and Prichard Formation are present further down the drainage of Blue Joe Creek. Within the vicinity of the mine, these Belt rocks occur as interbedded argillites, quartzites, siltites, schists and impure carbonates striking generally N30E to N40E, and dipping westerly from 70 to 89 degrees (Green, 1974).

Alpine glacial till, the dominant surficial deposit in the drainage, shows wide variability in depth depending on glacial scour and deposition patterns. Glacial outwash deposits are important in the lower reaches of Blue Joe Creek. Most soils are developed in the glacial tills. Typical



Formation	Description and Symbol	Thickness
Glacial and Alluvial Material	continental and alpine drift and stream alluvium (Qag)	variable
Continental Mountain Tonalite	medium to coarse grained biotite tonalite (Kc)	
Wallace Formation lower argillite	laminated argillite and siltite (Ywa_1)	150 m
Wallace Formation lower carbonate	dolomite and limy dolomite interlayered with quartzite, siltite and argillite (Ywc_1)	340 m
Wallace Formation calc-silicate unit	interlayered fine grained quartzite, siltite and calc-silicate rock (Ywcs)	unknown
Ravalli Group (undivided)	interlayered siltite and quartzite (Yr)	unknown
Prichard Formation	argillite, quartzite and siltite often highly deformed and metamorphosed (Yp)	1500 m

Figure 4. Local geology and stratigraphic section in the vicinity of the Continental Mine (adapted from Miller, 1982, and Green, 1974).

topsoils have loamy to coarse loamy textures with many coarse fragments in the subsoil (U.S. Forest Service, 1976). The loamy topsoils are derived in part from 6 to 12 inches of volcanic ash which was deposited over the area 6,600 years ago (Gerhardt, 1983).

Mineralization

The ore mined at the Continental was predominantly argentiferous galena (a silver-bearing lead sulfide) with lesser amounts of pyrite also present. Sparsely disseminated chalcopyrite, sphalerite and titaniferous magnetite also have been observed. Gangue mineralization consisted primarily of quartz and siderite. The bulk of the mineralization was emplaced within the lower carbonate unit of the Wallace Formation (Miller, 1982). Lead isotope studies of the lead-silver mineralization indicated a Precambrian age (Zartman and Stacey, 1971). The ore was localized within two lensoid bodies (the Black and Red Veins) and occurred as composites of stringers, bands, veins and bunches of sulfides which paralleled the schistocity and bedding (Green, 1974).

Exploration and Production History

The existence of a sizable lead-silver ore body in the upper drainage of Blue Joe Creek was disclosed late in the 1800's by Albert Klockmann. Following initial staking of claims, surveying, and assessment of mineralization, a mill operation was set up along Blue Joe Creek, and active mining commenced. A mining settlement developed near the mine, expanded to well over 100 people, and was named Klockmann after the mine's founder.

Extraction of the ore initially took place by surface mining along the strike of the mineralized bedding in the Belt rocks. As these more easily accessible reserves played out, underground stoping methods were utilized to extract the ore from deeper beneath the surface. Two main portals were developed (the No. 4 and No. 5 tunnels), with lengths of 1600 and 3000 feet respectively (fig. 5). A number of raises connected the two main levels, in addition to about five sublevels which were maintained above each of the tunnels. In all, about 13,000 lineal feet of underground workings were developed at the Idaho Continental Mine (Gammell, 1946).

Production records from the mine's most active years of 1914 to 1944 indicated that about 514,000 tons of ore were produced with an average return of 5.98 percent lead and 2.45 ounces silver per ton. Scavenging type operations between 1944 and 1955 reworked a considerable amount of the jig tailings, recovering additional amounts of lead, silver and zinc. Including these later activities, Green (1974) reported the following statistics on the total production from the Idaho Continental Mine:

Ore tonnage	567,755
Lead (lbs)	62,889,468
Zinc (lbs)	205,242
Copper (lbs)	124,784
Silver (oz)	1,322,995
Gold (oz)	12,174

Waste rock and tailings from the mill were dumped into Blue Joe Creek, and impounded by crib dams. The creek was diverted around the tailings pond by a ditch along the southeast side of Blue Joe Creek. The tailings dam(s) reportedly failed in the early 1940's, allowing much of the impounded material to be eroded and transported downstream (Gerhardt, 1981).

Green (1974) gave a detailed chronology of the Continental Mine's history and operation. Gerhardt (1981) synopsized Green's report, part of which is listed below:

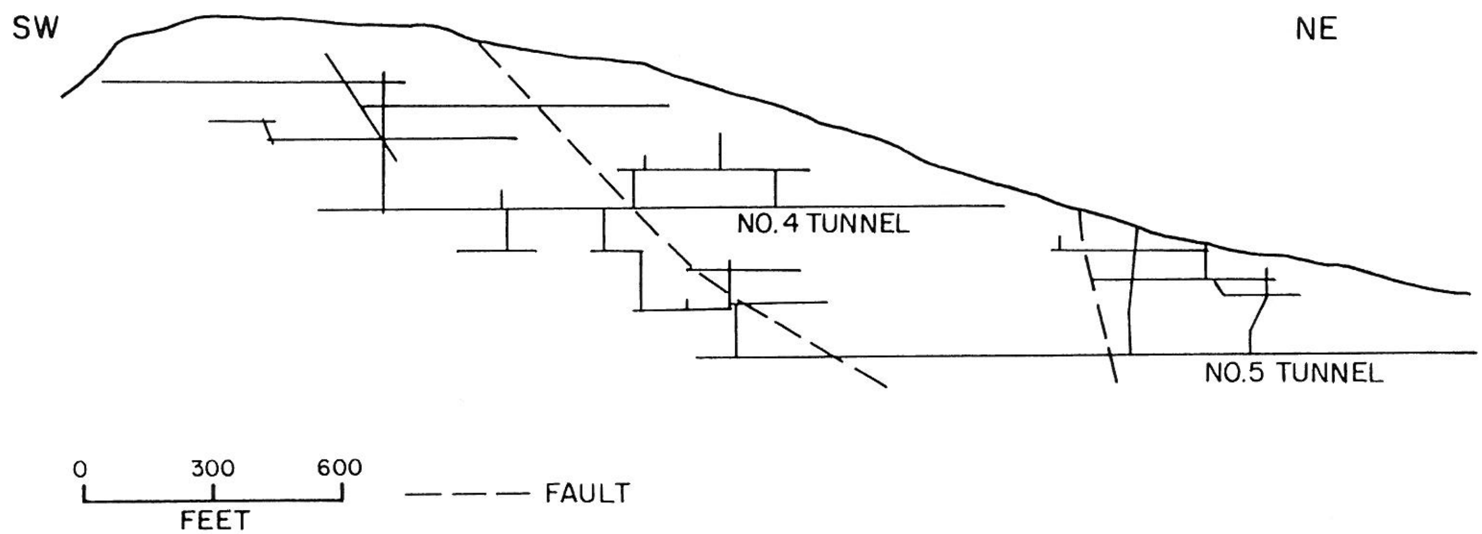


Figure 5. Northwest looking longitudinal projection of the underground workings at the Continental Mine (adapted from Green, 1974).

late 1800's	mineralization discovered
early 1900's	claims staked and patented
1914	Idaho Continental Company is established; acquisition of mining and milling equipment including a tramway, compressors, vanners, ball mill, cone crusher and jig separator
1915-1922	mining production reaches 43000 tons/year, town of Klockmann expands to over 100 people
1922-1929	Bunker Hill and Sullivan Mining and Concentrating Company lease the property and control the mining operation; the jig separator is replaced by a floatation circuit; total mining production for this period increases to 230,000 tons of ore mined and milled.
1929-1949	shipments decrease with intermittent operation by several lessees; early jig tailings reworked
1949-1971	small shipments by various lessees
1971	P and B Silver Mines leases and purchases claims
1972-1973	limited geophysical exploration
1979-1980	some ore shipments
1980	acquisition of mine property by the New Idaho Continental Corporation

CHAPTER III

TAILINGS AND WASTE ROCK DEPOSITS

Description of Mine Site

Remnant features of past mining activity at the Continental Mine include the underground workings, surface workings, mill tailings and waste rock pile, and some assorted surface structures (fig. 6). Two main adits (no. 4 and 5 tunnels) located at elevations of 5678 and 5333 feet, respectively, provide access to the underground workings. Water from the underground workings discharges perennially from the no. 5 tunnel. Surface mining activities near the drainage divide follow the strike of the local geology, leaving large, barren, linear depressions. Mill tailings, waste rock and stockpiled ore are located over roughly a six-acre area near the headwaters of Blue Joe Creek. The mill is no longer present. Wooden and metallic debris are found scattered throughout the tailings pile, as well as within the creek channel. Riparian vegetation virtually is non-existent within the tailings pile. A diversion channel was constructed prior to 1932 (based on 1932 aerial photographs) to route the flow from the creek around the east side of the tailings disposal area. Breaches presently occur in several places along the length of the channel. Leakage probably contributes to localized tailings saturation and surface erosion, limiting the effectiveness of this structure. Remaining surface structures include a cabin, shaker table building, garage and ore bins.

Maximum dimensions of the tailings pile measure 1100 and 600 feet, parallel to and transverse to Blue Joe Creek, respectively (fig. 6). Human activities and erosional processes have contributed to a variable thickness and irregular topography (plate 1) observed in the tailings pile. Tailings deposits up to 25 feet thick are found along Blue Joe Creek, but average

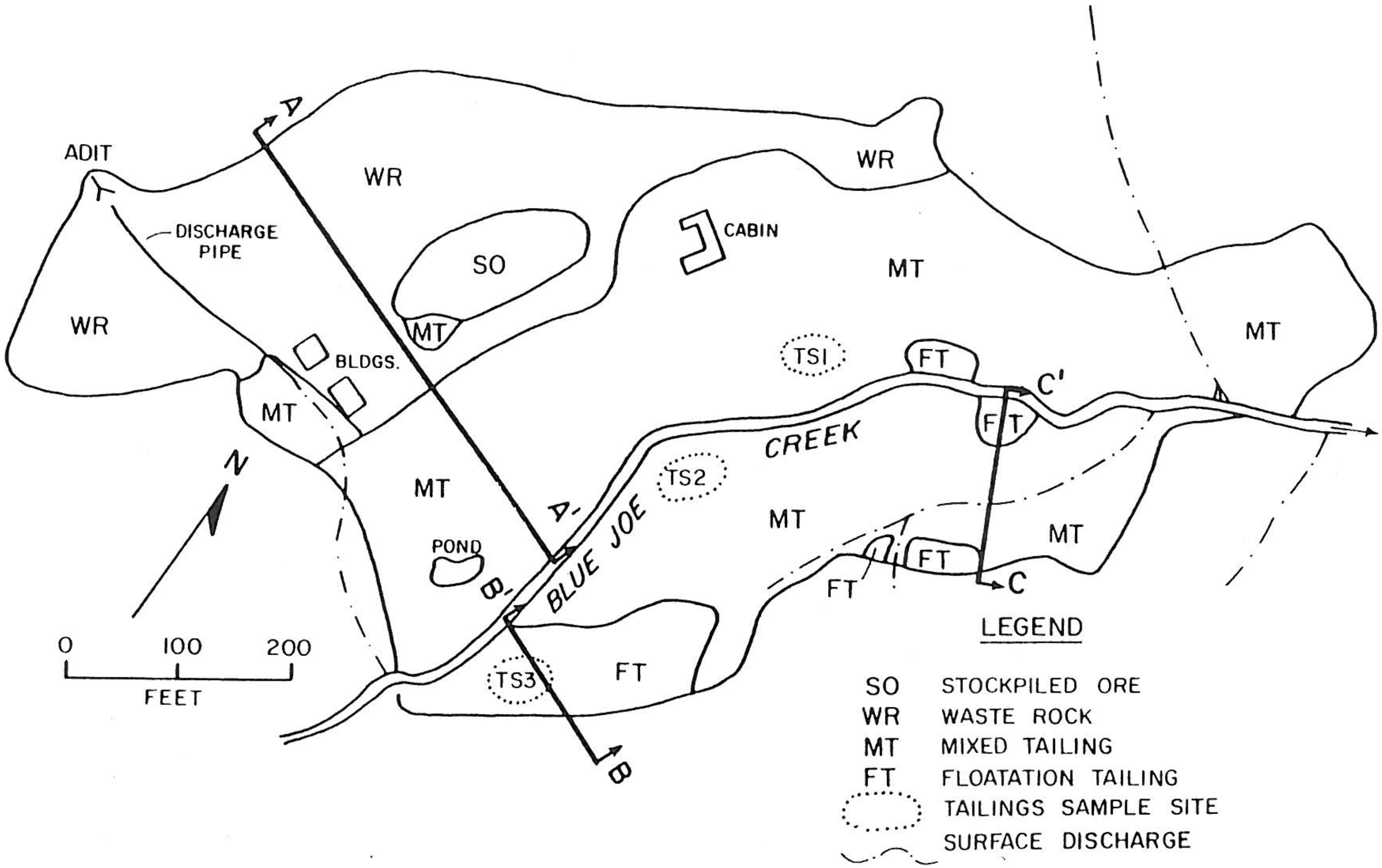


Figure 6. General feature map of the Continental Mine site showing surface structures, surface variations in mineral wastes, tailings sample areas, and the location of cross-sections.

thicknesses of five to seven feet are more typical. The present volume of mine wastes at the mine site is estimated to be 30,000 to 40,000 cubic yards. Mill tailings constitute approximately 90 percent of this. Using average estimates of crude ore grade and total production tonnage from Green (1974) along with known mill concentrate values for lead given by Kirkham and Ellis (1926), the amount of tailings generated at the mine is estimated to be 70,000 cubic yards. This value represents 24 percent of the total production volume, or the amount of silicate removed from the crude ore to upgrade it from six percent to 65 percent by weight. The volume estimates suggest that 40 to 60 percent of the tailings have been removed from the mine site by erosion and downstream transport.

Variations in the surface character of the mine wastes were mapped on a reconnaissance basis. The mine wastes are sub-divided into four major types of material: floatation tailings, intermixed jig and floatation tailings, waste rock, and crude ore stockpile. Their distribution is shown in figure 6. The bulk of the wastes on site appears to be the intermixed jig and floatation tailings found as a swath parallel to and on both sides of Blue Joe Creek. Floatation tailings are concentrated along the southeast side of the creek. Waste rock is most abundant near the lower mine adit, at the western end of the mine waste zone.

The drill cuttings from the three augered piezometers provide the only information regarding the subsurface stratigraphy and grain size variability (appendix C). The drill logs could not be correlated laterally because of the small number and dispersed distribution of holes. The logs primarily provide information regarding the depth to native soil and depth to the potentiometric surface.

Collection and Analysis of Tailings Material

Tailings samples were collected from three separate sites within the disposal area. The samples were analyzed for nutrient content and grain size distribution to provide a better understanding of the chemical composition, plant media potential and size of mine wastes. The locations of the sample sites are shown in figure 6. Each sample consisted of a composite of seven to ten small portions collected within a radial distance of about 13 feet. Using a shovel, the top six inches of surface material was scraped away, revealing the less disturbed underlying tailings. The representative samples were taken from a depth of six to 12 inches to minimize the effects of surface leaching and oxidation. Nutrient analysis of the tailings was performed by A & L Midwest Agricultural Laboratories Incorporated in Omaha, Nebraska. The results of the grain size and nutrient analyses are presented and discussed below, along with the results from an unpublished spectrographic analysis of the tailings provided by the U.S. Forest Service.

Using a standard set of sand/soil sieves, the three samples were partitioned into the various size fractions, and distribution curves constructed (fig. 7). The first tailings sample (TS1) represents the intermixed jig and floatation tailings. The second tailings sample (TS2) is similar to TS1, but shows less coarse grained material. TS3 represents the fine floatation tailings.

The elemental composition of the tailings was analyzed semi-quantitatively with a DC arc emission spectrograph, and also by assaying (Stentz, 1973). The results are given in tables 3 and 4. A nutrient analysis also was conducted to evaluate the fertility

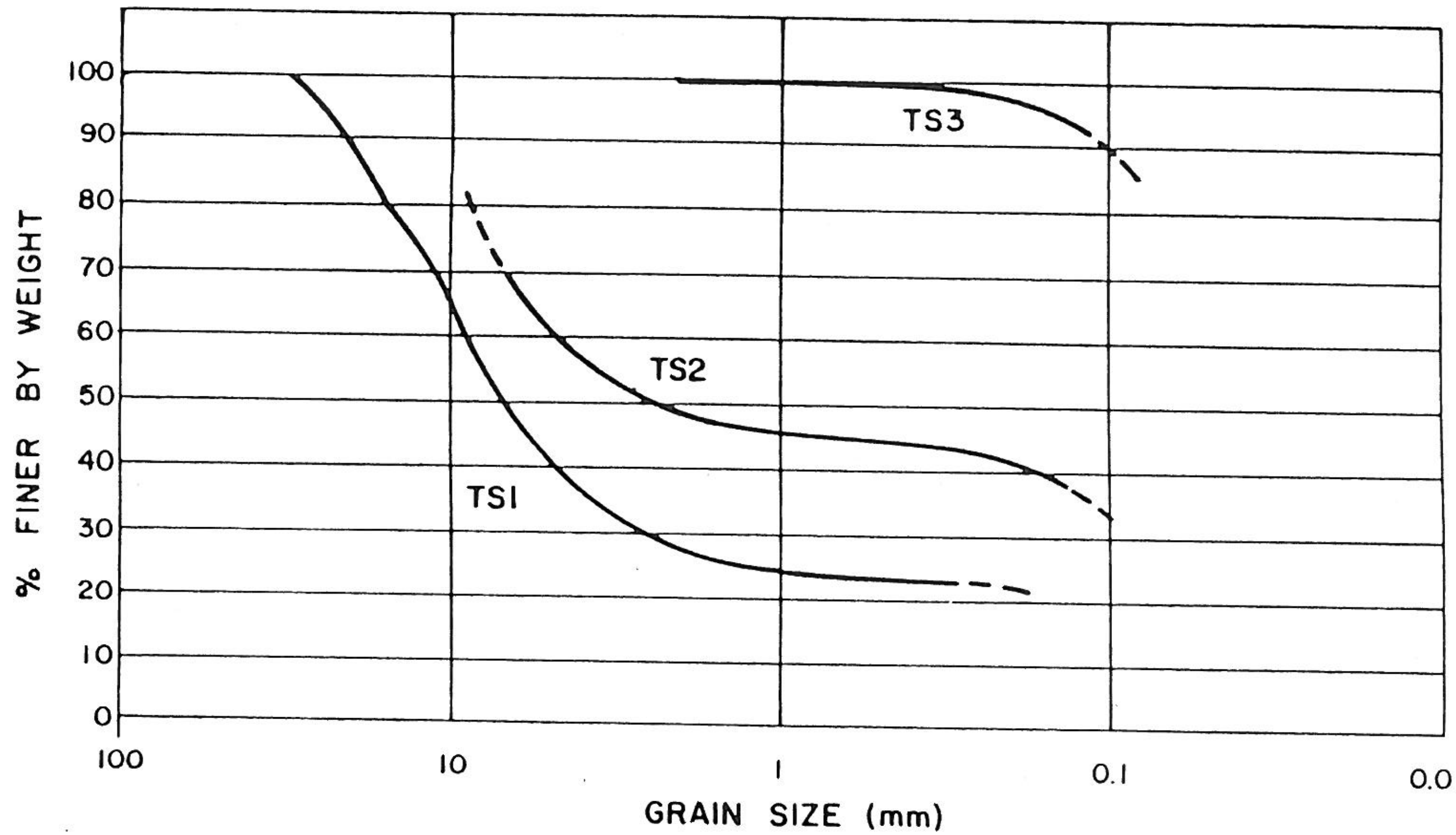


Figure 7. Grain size distribution curves for the tailings at the Continental Mine.

of the tailings as a plant growth medium. These data are shown in table 5.

Data from the assay and spectographic analysis show that significant amounts of residual heavy metals are present in the tailings. The single sample assayed by Stentz (1973) was listed as "coarse tailing material", and probably is equivalent to the intermixed tailings. The assay indicates that an appreciable amount of lead still is present in these tailings. Fairly high concentrations of zinc, copper and arsenic also are reported. The semi-quantitative spectrographic analysis of the tailings (Stentz, 1973) shows similar results, and suggests that a detectable amount of chromium also is present. The results from these analyses provide a crude but useful documentation of the metals concentration in the tailings material.

The data from the nutrient analysis (table 5) indicate an overall deficiency in the tailings in some major cations and other nutrients necessary for vigorous plant growth. The organic content of this material also is quite low. Not surprisingly, micronutrients such as copper and zinc are found at levels known to be potentially phytotoxic (A & L Agricultural Laboratories, Inc., 1984; Williamson, 1982). Results from an analysis of metal and nutrient uptake by barley grown in tailings and local soils from the Continental Mine are given in appendix D. The data suggest that significant amounts of heavy metals can be taken up by vegetation grown on mill tailings at the Continental.

Some native vegetation does exist within the mine waste area. It occurs almost exclusively in areas where the native soil has been exposed due to erosion of the overlying tailing, or where ground water discharge maintains saturated conditions in the mine wastes. The former zones favor the growth of grasses and sedges, while the latter are dominated by horsetail (Genus equisetum) (Richardson, 1985). Pine seedlings planted by

Table 3. Spectrographic analysis results of Continental Mine tailings (from Stentz, 1973).

Tailings	Ag	Cu	Pb	Zn	Cr	Mn
Floatation	20	400	>10,000	2000	300	150
Floatation	15	400	>10,000	200	200	150
Floatation	10	400	10,000	700	200	200
Floatation	7	300	3000	700	200	300
Mixed	15	300	10,000	1000	200	300
Mixed	30	700	>10,000	1500	200	200
DL	0.5	5	10	200	20	10

Note: Sample locations not specified.
All values in parts per million.
Analysis performed with a Wadsworth mounted, Jarrell-Ash 1.5 meter, DC arc emission spectrograph on 3/8/73 by W.A. Bowes and Associates, Steamboat Springs, Colo.

Table 4. Single assay result of tailing sample (from Stentz, 1973).

Material	Pb	Zn	Fe	Cu	As
Mixed Tailings	12,500	1300	15,000	100	200

Note: Sample location not specified.
Sample values in parts per million.

Table 5. Soil analysis results of the tailings from the Continental Mine

Sample	Ca	Mg	Na	K	P	S	Zn	Mn	Fe	Cu	B	Org	pH
TS1	340	20	26	43	9	4	100	1	4	23	1.2	1.0	7.3
TS2	30	8	22	31	8	5	13	1	1	16	1.4	0.7	5.8
TS3	40	7	25	30	5	5	11	1	1	23	1.3	0.4	5.3

NOTE: analysis of elements given in parts per million; organic content in percent
Samples analyzed in 8/85 by A&L Agricultural Laboratories, Inc., Omaha, Nebraska
TS1 and TS2 represent intermixed jig and floatation tailings
TS3 represents floatation tailings
Phosphorus value represents a composite of Weak and Strong Bray

the U.S. Forest Service also are found scattered throughout the tailings pile, showing various degrees of growth success.

Tailings Erosion

The mill tailings at the Continental Mine have undergone extensive erosion during the past 40 to 50 years. The combination of steep slopes, inadequate protection from stream erosion, and abundant precipitation (often as intense rainfall events) has favored the removal and downstream transport of substantial volumes of the relatively loose, unconsolidated mine wastes. The largest movement of mill tailings is thought to have occurred in the early 1940's when the tailings pond dam was breached (Gerhardt, 1981). This event, and the subsequent surface erosion and slope failures that followed, are responsible for much of the extensive sediment deposition, channel braiding, bank failure and debris observed in the lower reaches of Blue Joe Creek (Gerhardt, 1983).

Erosion of the mine wastes is ongoing and annually contributes suspended and bedload sediment to Blue Joe Creek. Hydrologic conditions in existence at a mine, and soil mechanic properties of tailings deposits largely determine the stability of tailings and their resistance to mass movement (McWhorter et al., 1979). Erosion is greatest during the spring peak runoff period of late May to early June. Rills and gullies develop on the unvegetated and unstable slopes where surface water is free to flow over the loose mine wastes. Along the creek, steep, unstable slopes are susceptable to mass failure and bank sloughing. This can result from a combination of erosional and shear failure processes, including: (1) tailings saturation, (2) degradation of the channel bottom, (3) undercutting of the bank due to channel obstructions, and (4) loss of toe support due to base seepage or channel erosion (Soil Conservation Service, 1977). During the hot summer months strong winds also can dislodge and transport fine tailing particles, depositing them over broad areas of the upper watershed.

CHAPTER IV

HYDROLOGY AND HYDROGEOLOGY

Basin Characteristics and Surface Hydrology

Blue Joe Creek begins high within the Selkirk Mountains and flows in a general northeastward direction (fig. 8). The creek drops about 1700 feet from its headwaters near the mine site to its confluence with Boundary Creek 1/3 mile north of the International Boundary. Gradients averaging five to ten percent characterize the upper three miles of stream. Gentler gradients of one to three percent in the lower four miles have allowed braiding to occur in some reaches due to the increased sediment load created by mining activities. Stream widths of four to ten feet and 20 to 40 feet characterize the upper and lower portions, respectively. Northwest and southeast facing landslopes average 30 percent (Gerhardt, 1981). Blue Joe Creek basin encompasses an area of about 10.7 square miles with a maximum length (from divide to mouth) of approximately seven miles.

The discharges in Blue Joe Creek and selected tributaries were measured in the fall of 1984, and the late spring and summer of 1985. The data for some sample stations on Blue Joe Creek and major tributaries are presented in table 6 (see figure 2 for site locations). Discharges of similar magnitude were recorded in October 1984, and July, August and September of 1985. Climatic and hydrologic conditions during these periods suggest that the measured discharges probably represent baseflow. The highest flows recorded during this investigation occurred in June of 1985. The June discharge represents a combination of ground water discharge, rainfall and snowmelt (predominantly the latter two).

An annual hydrograph for the estimated flow of Blue Joe Creek at its mouth is shown in Figure 9. The hydrograph is based upon available

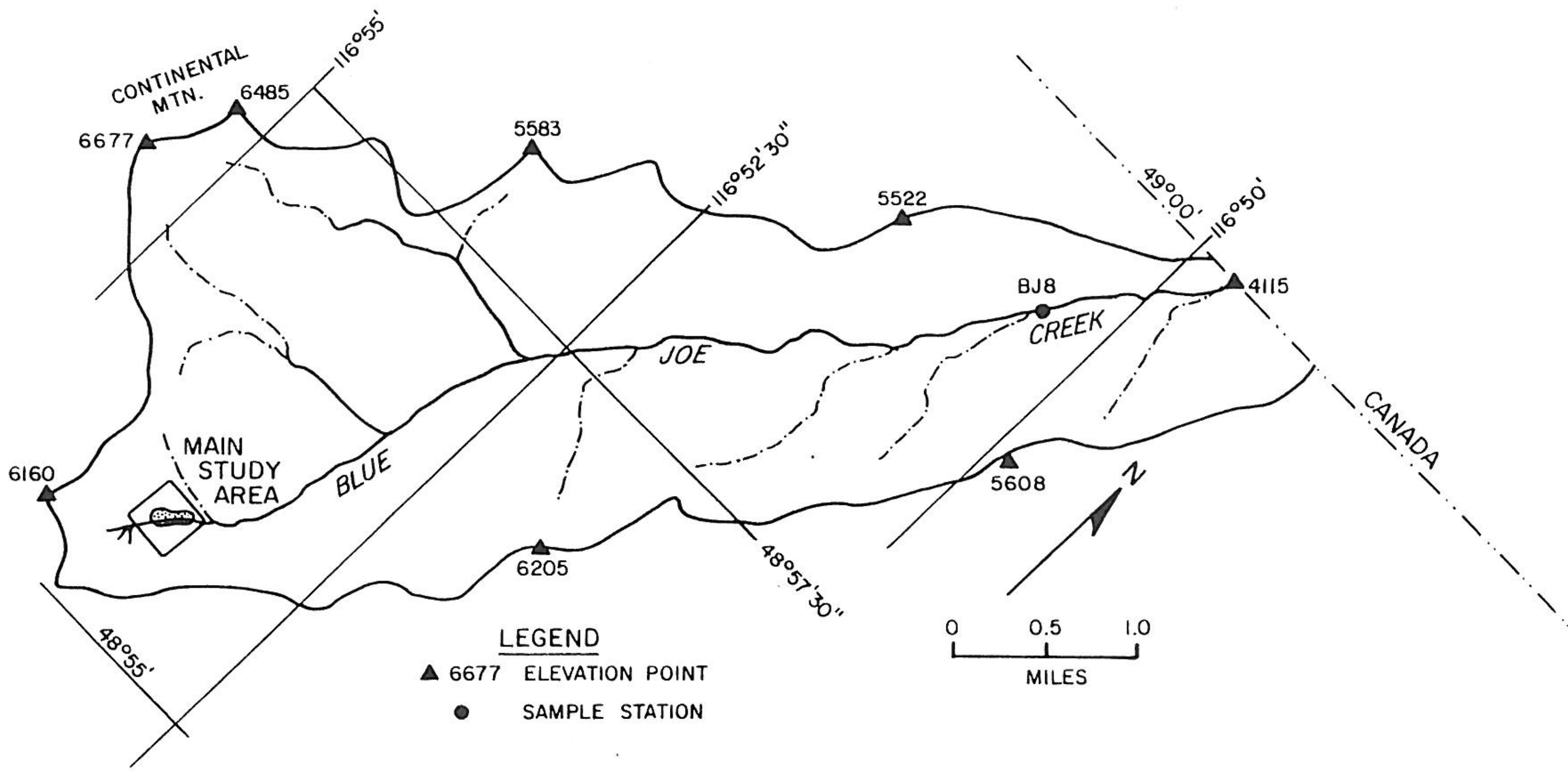


Figure 8. Outline of Blue Joe Creek watershed (adapted from USGS topographic map, 1968).

Table 6. Discharge measurements for selected sites (in cfs).

Station	10/11/84	6/7/85	7/19/85	8/26/85	9/5/85
BJ5	0.06	10.	0.13	0.03	0.13
BJ1	0.11	10.	0.22	----	0.14
BJ7	0.11	20.	0.28	----	0.19
BJ8	5.80	140.	5.90	----	----
MA1	----	0.55	0.10	0.05	0.10
MD3	0.03	2.70	0.11	----	0.07
MD6	0.01	0.50	0.01	----	0.01
MD7	0.01	2.40	0.04	----	0.04

streamflow measurements of Blue Joe Creek, and hydrographs for nearby Smith and Boundary Creeks (fig. 1) (U.S. Forest Service, 1976). Blue Joe Creek is tributary to Boundary Creek; Boundary Creek generally flows in an easterly direction, whereas Blue Joe Creek flows more to the northwest. The drainage area of Smith Creek (70.8 square miles) is roughly seven times larger than Blue Joe Creek (10.7 square miles), but has similar aspects and elevations. Spring peak flows near the mouth of Blue Joe Creek range from 100 to 200 cfs, while summer low flow discharges are four to six cfs (Gerhardt, 1981). The average annual discharge is estimated at about 40 cfs (U.S. Forest Service, 1976). This is based on 70-80 inches of annual precipitation and 40-50 inches of annual runoff.

Using methods presented by Thomas et al. (1973), the 10-year peak flow for the portion of Blue Joe Creek watershed above the tailings pile (0.48 square miles) was calculated. A flow of 26 cfs was obtained from the appropriate empirical equation for this region: $Q10 = 49.8 \times (\text{drainage area in square miles})^{0.862}$. This discharge compares favorably with

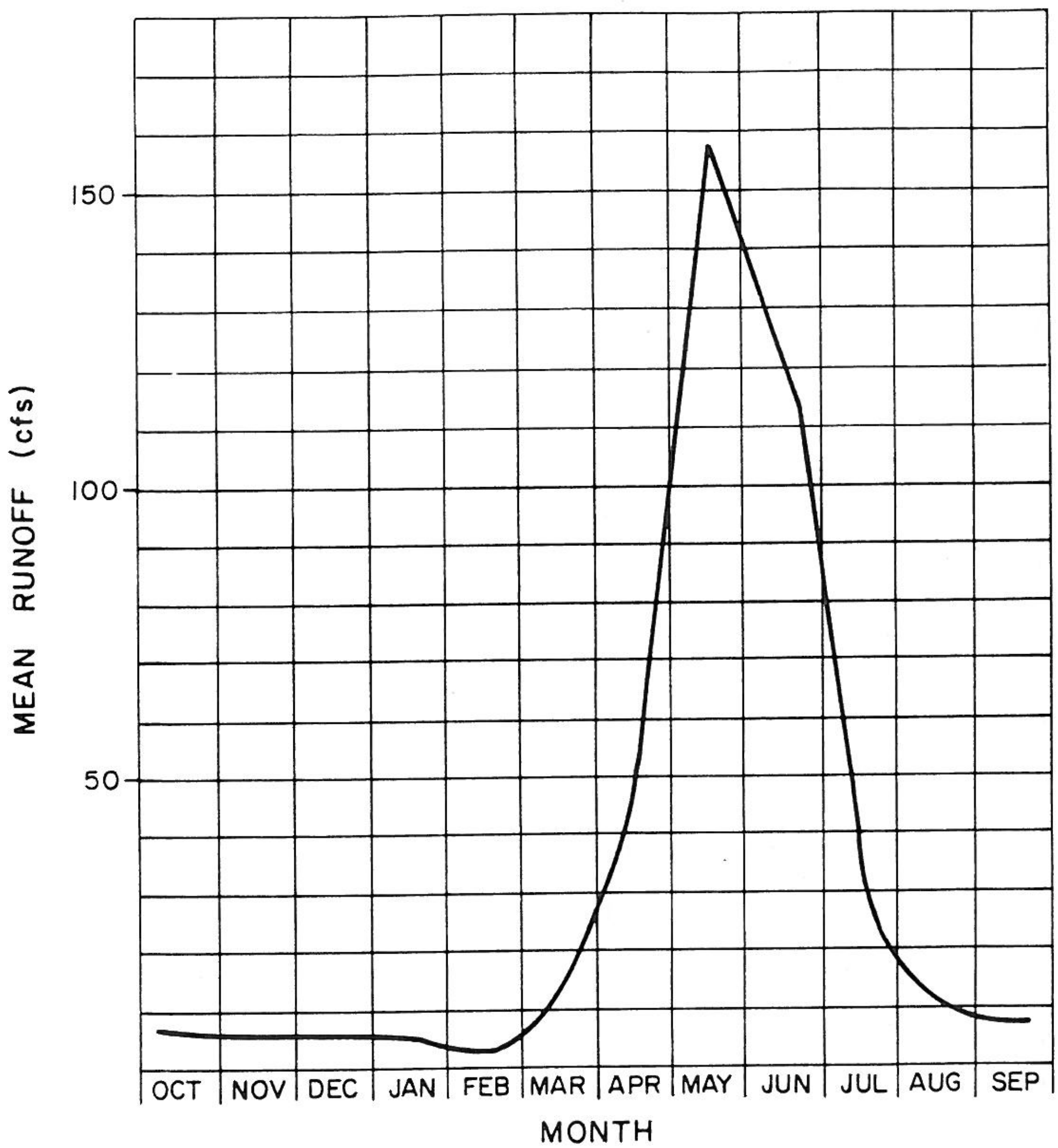


Figure 9. Average annual hydrograph for the estimated flow of Blue Joe Creek at its mouth (adapted from U.S. Forest Service, 1976).

the 10-year peak flow discharge estimated by Thomas et al. (1973) for the upper portion of Trapper Creek basin located 3.5 miles southeast of Blue Joe Creek (fig. 1). The Trapper Creek basin is slightly smaller than the Blue Joe Creek basin. Trapper Creek flows in the opposite direction of Blue Joe Creek and has similar elevations. Using historical discharge data and the log-Pearson Type III method, Thomas et al. (1973) calculated a 10-year peak flow of 56 cfs from 1.12 square miles of drainage in the Trapper Creek basin. Scaling this discharge to the area of upper Blue Joe Creek gives an estimated 10-year peak flow of 24 cfs.

Peak discharge for a 10-year 24-hour SCS type II storm event was estimated at two places in the upper watershed of Blue Joe Creek (Curry, 1986). A peak discharge of 49 cfs was calculated for a drainage area of 0.26 miles, representing the watershed above the culverted mine road crossing just upstream of the mine wastes. Peak discharge at the base of the mine wastes (drainage area of 0.48 square miles) was estimated at 67 cfs.

A comparison of the 10-year peak flow estimates of Curry (1986) and Thomas et al. (1973) with discharges measured during this investigation shows the field measurements to fall well below the expected 10-year peak. The 10-year peak flow conditions probably were not present during the spring discharge measurement. Similarly, the methods described above may not be totally appropriate for estimating peak flow conditions in Blue Joe Creek.

Hydrogeology

Ground water flow systems within the vicinity of the Continental Mine can be divided broadly into three categories: (1) ground water flow through naturally fractured metamorphic bedrock, (2) ground water flow through mine-disturbed bedrock, and (3) ground water flow through unconsolidated mine wastes. The local bedrock geology in the vicinity of the Continental Mine consists primarily of faulted and fractured metamorphic rock of the Belt Supergroup. Hydraulic conductivity of similar bedrock at the Bunker Hill Mine at Kellogg, Idaho, is governed primarily by extension fractures and release or unloading fractures (Hunt, 1984). The primary hydraulic conductivity of the Belt rocks near the Continental Mine (i.e. the crystalline matrix) is thought to be low. The secondary hydraulic conductivity (which may include faults, joints, bedding planes and other fracture features) may be several orders of magnitude higher than the primary hydraulic conductivity, but still is considered low to moderate in magnitude.

The well-defined relief in the area, coupled with a near-surface concentration of fracture features, should result in short, local ground water flow systems similar to those described by Toth (1963). The general features of ground water flow within a steep mountain basin prior to mining as summarized by Hunt (1984) are presented below.

1) Topographic divides are ground water divides.
2) Peaks, ridges and upper mountain slopes are areas of recharge.
3) Valleys or lower mountain slopes are areas of ground water discharge.
4) Ground water flow velocities decrease with depth.
5) Secondary openings resulting from fracturing and faulting are the only significant source of natural hydraulic conductivity.

The mining activities conducted at the Idaho Continental Mine have altered the natural hydrogeologic regime within the upper portion of Blue Joe Creek watershed. Depressions created by surface mining near the drainage divide probably have increased the amount of recharge to the subsurface. The extensive labyrinth of underground workings--over 13,000 feet--presumably routes the ground water collected by the mine out the lowermost adit. The discharge from this adit is a significant part of the summer baseflow of upper Blue Joe Creek (MD3 on table 6).

The mine waste area constitutes a distinct and generally localized hydrogeologic regime compared with the rest of the upper portion of the basin. As a relatively porous granular medium, the tailings are capable of storing more water than the undisturbed metamorphic country rock. Horizontal and vertical hydraulic conductivities may differ spatially by several orders of magnitude because of lateral variability in grain size and the degree of sorting. These heterogeneities influence the rate and volume of water moving through the tailings.

The mine wastes are thought to be located in the zone of ground water discharge according to the generalizations given above by Hunt (1984). This has important implications with regard to the local surface and ground water quality. Dissolved metal contamination of ground water in the native material beneath the tailings probably is minimal due to the predominant upward component of flow in this area. Surface water quality, however, is affected by ground water discharge from the mine wastes.

Temporal Variations in Ground Water Levels

Three piezometers were installed in the tailings pile to permit measurement of ground water levels and subsurface quality. The piezometer locations are shown on figure 3. Water level data are presented on figure 10. PZ1 was placed in the south central portion of the tailings on the west side of Blue Joe Creek. PZ2 was drilled directly across the creek from PZ1 near the southern end of the tailings disposal zone. PZ3 was installed in the northeast end of the tailings pile near the stream bank. Construction details of the piezometers are provided in appendix C. The

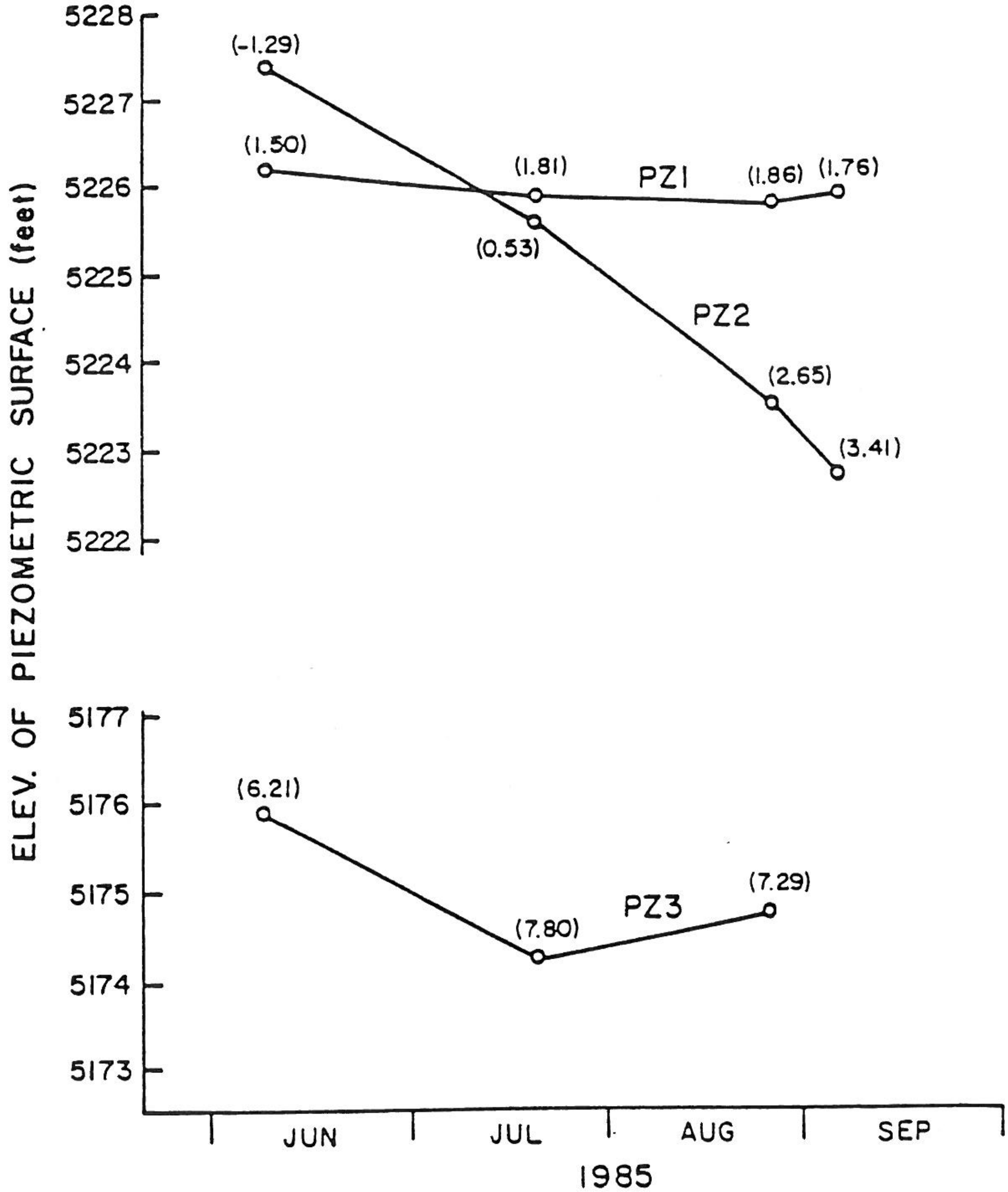


Figure 10. Temporal variations in ground water levels in the auger-drilled piezometers (values in parentheses indicate depth to water below land surface).

location of cross sections through PZ1, PZ2 and PZ3 can be seen on figure 6.

Water levels in PZ1 declined less than 0.5 feet through the summer of 1985, while remaining within two feet of the surface. A cross section through this piezometer is given in figure 11. The potentiometric surface at PZ1 remained well above the slotted interval. This may indicate that ground water at the tailings/native soil interface is confined by the tailings. Data are insufficient to confirm the existence of vertical ground water flow in the area around PZ1.

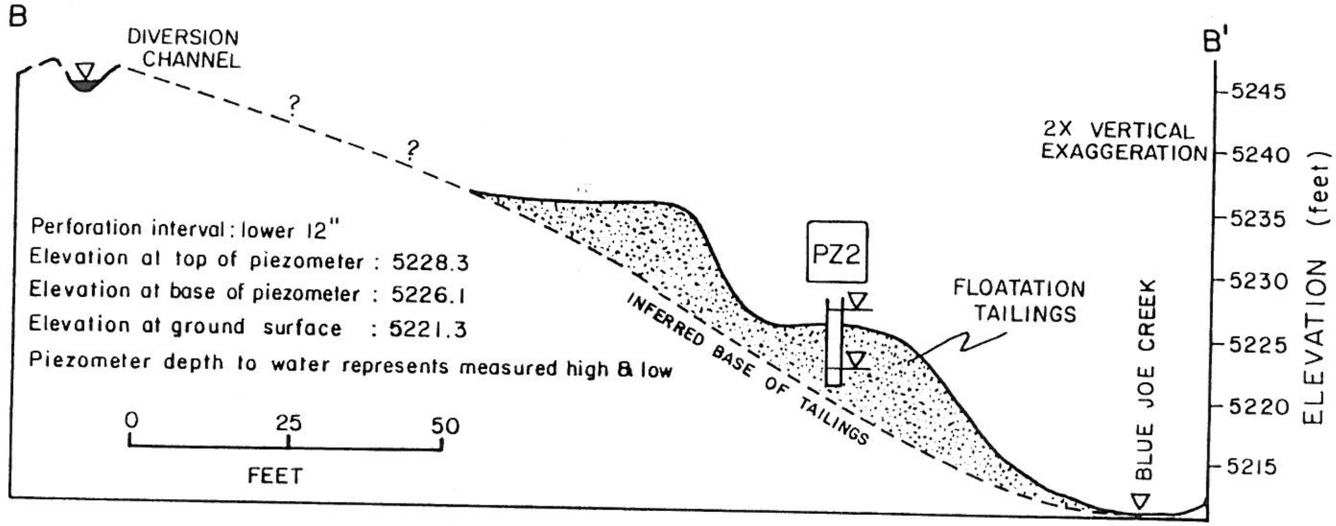
The primary recharge area for the ground water system in existence near PZ1 is not well defined. Recharge to the tailings from localized infiltration of snowmelt and rainfall is not expected to produce the stable water level pattern at PZ1. The distinct seasonal changes in climatic and hydrologic conditions present at the site would favor a more variable ground water level pattern. Ground water in this area may be derived from a longer flow system in the fractured rock and alluvium that is recharged near the drainage divide, and discharges near the valley bottom. This is consistent with the conditions hypothesized by Toth (1963). The effects of individual precipitation events generally are less noticable in a longer flow system; water levels remain more constant. Presumably, the degree of tailings saturation also should remain fairly constant around PZ1 and perhaps over most of the tailings on the west side of Blue Joe Creek.

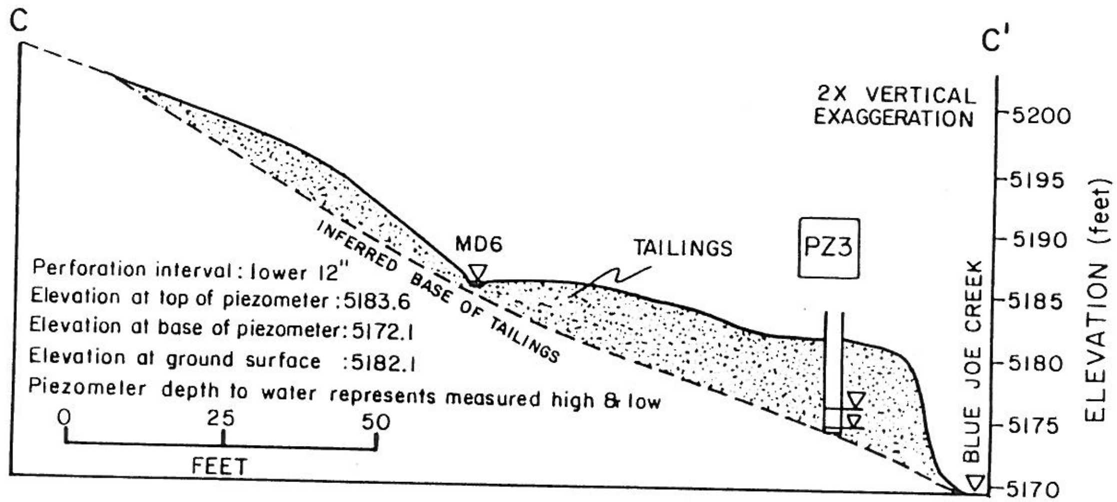
Water levels in PZ2 decline steadily throughout the summer. A cross section through this piezometer can be seen in figure 12. The potentiometric surface was above land surface during the late spring measurement. This suggests that the ground water potential increases with depth, and that the low permeability floatation tailings act as a confining layer. Recharge from flow in the diversion channel may account for the

artesian conditions at PZ2 during this time. As summer progressed, the snowpack melted, precipitation levels dropped off, evapotranspiration increased and the diversion channel essentially went dry. These factors may have contributed to the steady decline in water levels observed at PZ2.

The water level at PZ3 shows an initial decline from June to July, followed by a slight rise into August. The decline from June to July is similar in magnitude to the decline at PZ2 over the same period. The rise from July to August is somewhat unexpected. It may be a measurement error, or the manifestation of an earlier precipitation event that was not recorded at the other two piezometers. This may imply that the ground water system in the area around PZ3 is recharged primarily by intra-tailings infiltration, instead of coming from a longer flow system.

A cross section through PZ3 is given in figure 13. The large depth to water (compared with PZ1 and PZ2) is best explained as a function of the close proximity of PZ3 to the creek channel, and the thickness of the tailings at this point. The saturated thickness of tailings near the creek probably remains low in this area throughout the year.





Figures 12 and 13. South looking cross section through PZ2 (top) and southwest looking cross section through PZ3 (bottom).

CHAPTER V

COLLECTION AND ANALYSIS OF WATER QUALITY DATA

Introduction

The intent of this analysis is to identify spatial and temporal characteristics of water quality impacts to Blue Joe Creek. Water quality data are assessed primarily with respect to dissolved metal concentration and load. A brief synopsis of the hydrochemistry and water quality criteria for lead, zinc and cadmium (U.S. EPA, 1980a, b and c) is presented in appendix E. The magnitude of water quality impacts to aquatic life in Blue Joe Creek is related closely to the dissolved metal concentration. Metal load calculations (which incorporate both the discharge and concentration at a given source or location) provide an estimate of the mass flux of a given constituent coming from a particular source area. Identification of primary dissolved metal source areas is an essential prerequisite to the evaluation of various reclamation alternatives.

Spatial Variations in Ground Water Quality

Data on ground water quality in the tailings were collected by two separate monitoring schemes: shallow hand-dug piezometers along the flanks of Blue Joe Creek, and auger-drilled piezometers within the body of the tailing pile. The quality of water in the shallow piezometers is believed to represent the average quality of ground water discharge to Blue Joe Creek from the tailings. The deeper auger-drilled piezometers are believed to monitor ground water both within and below the tailings.

Spatial variations in dissolved metal concentrations in the shallow piezometers are discussed first. Data from these stations are used to identify zones of high metal concentration coming from the base of the tailings along Blue Joe Creek. Water quality data from the auger-drilled piezometers are compared with the shallow piezometer data to help determine the nature of the sub-tailings or intra-tailings water quality. This can have useful implications with regard to the analysis of ground water flow systems.

Shallow piezometers (H1-H11) were installed along the flanks of Blue Joe Creek to monitor the quality of ground water discharge into the creek (figure 3; table 7). Seven piezometers were placed on the west side of Blue Joe Creek, and four were placed on the east side. Holes one to two feet deep were dug with a post hole digger, 4-inch PVC pipes were set in place, and the outer annulus of each hole was backfilled with the excavated material. The ranges of dissolved zinc, lead, and cadmium measured in these piezometers are shown in figures 14, 15 and 16.

Ground water discharge from the east side of Blue Joe Creek contains consistently higher concentrations of metal cations than similar discharge from the west side of the creek, with the exception of H9. Spatial variability in the metal cation concentration is thought to result primarily from mineralogic variability in the tailings, and/or spatial differences in the volume of ground water moving through the tailings.

Mineralogic variability in the ore deposit at the Continental Mine (i.e. pyrite content, gangue mineralogy and trace accessory minerals) should manifest itself as spatial variability in the composition of the mill tailings; spatial variation in the composition of the mill tailings is expected to produce spatial variations in the metal cation concentration of ground water in the tailings. It is not known to what extent metals are liberated from the solid phase by simple dissolution or more complex oxidation-reduction reactions. The relative abundance of a given

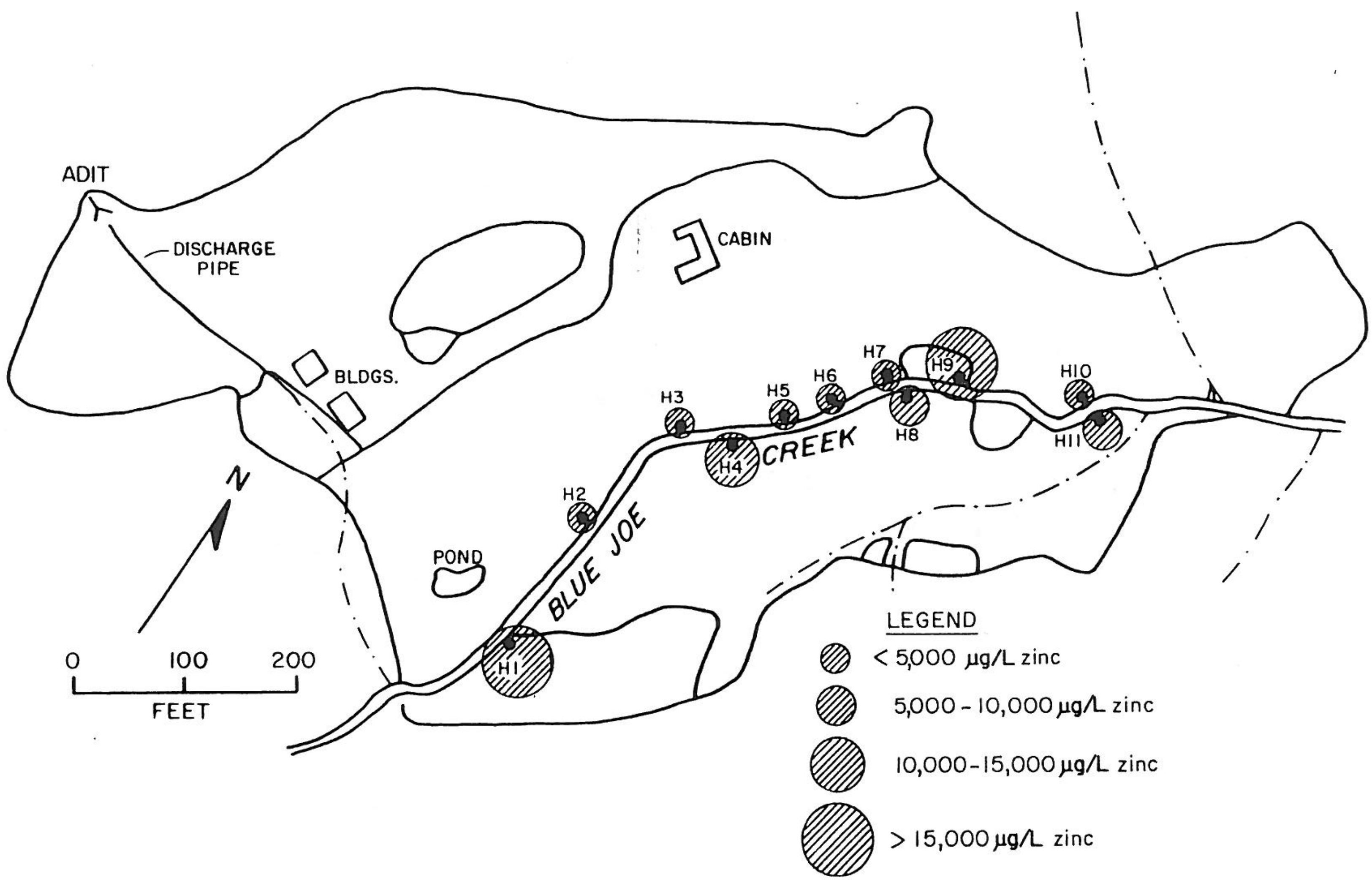


Figure 14. Spatial variation in dissolved zinc concentration from shallow piezometers along Blue Joe Creek (September 1985).

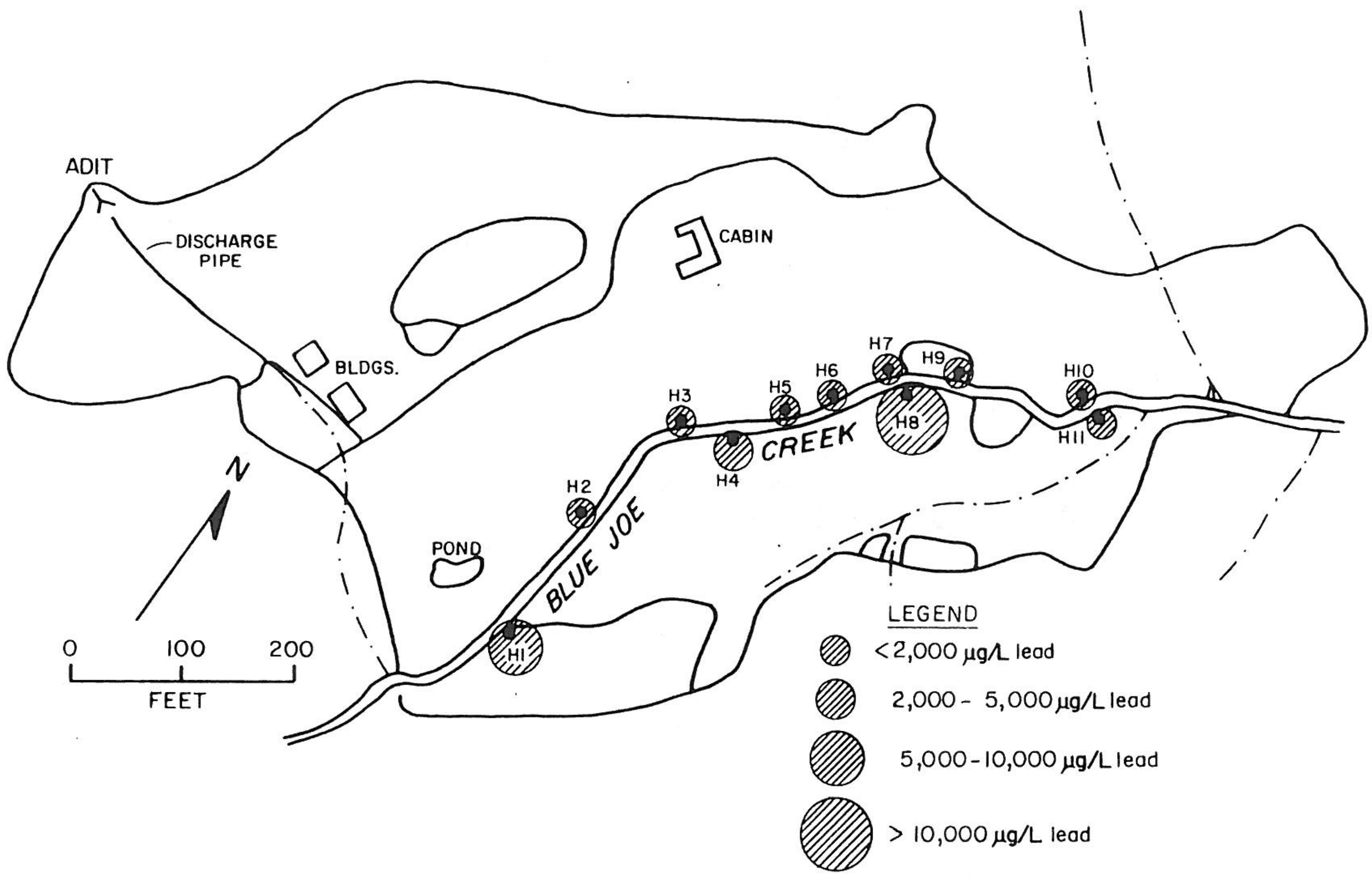


Figure 15. Spatial variation in dissolved lead concentration from shallow piezometers along Blue Joe Creek (September 1985).

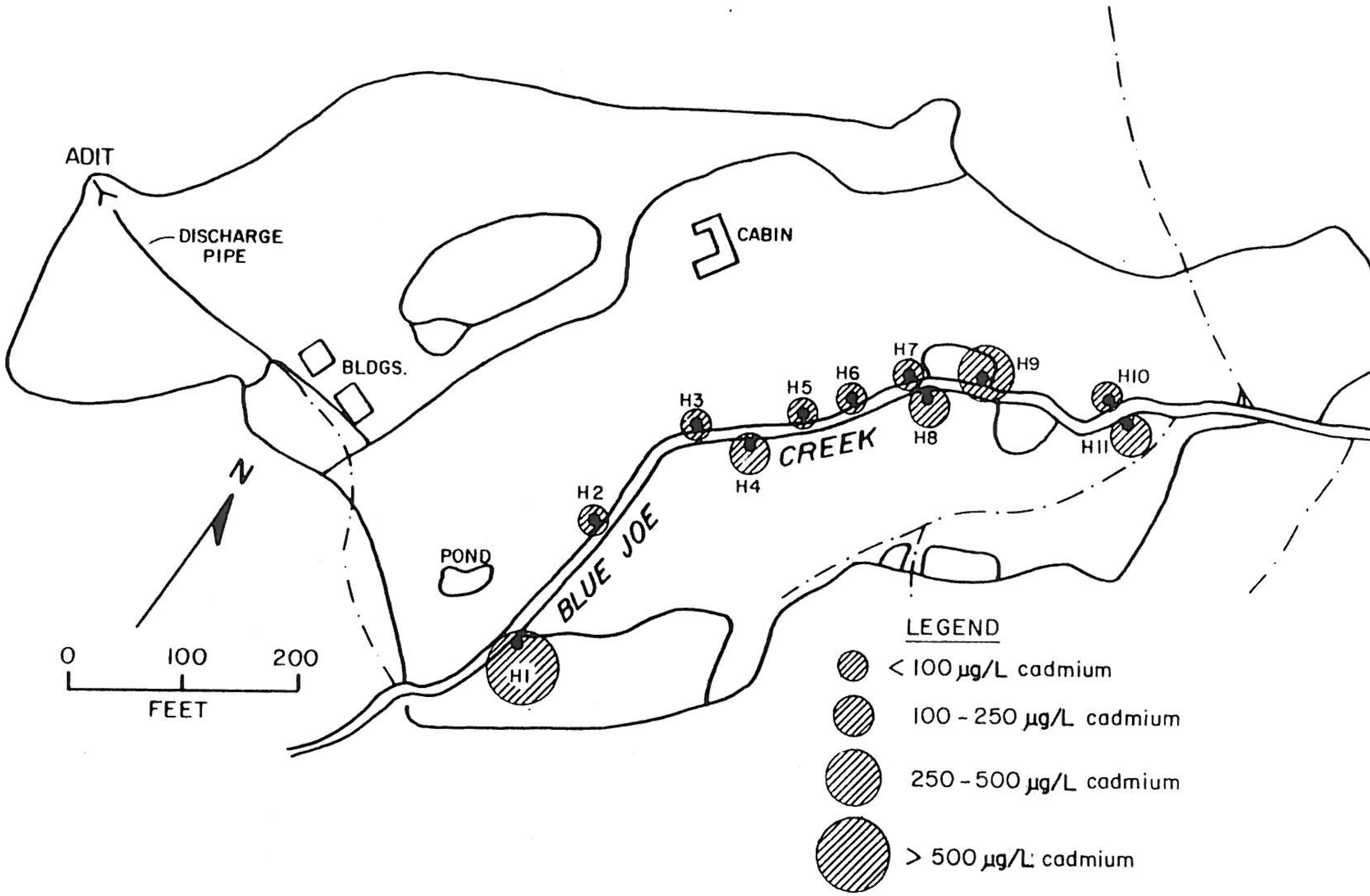


Figure 16. Spatial variation in dissolved cadmium concentration from shallow piezometers along Blue Joe Creek (September 1985).

mineral in tailings is related by solubility characteristics to the amount of that mineral brought into solution from the solid phase (Wai, 1987). Mineralogic species present in trace amounts may influence the ground water quality in the tailings to a much greater extent than the major ore minerals if the trace minerals display greater solubility. X-ray diffraction analysis of the tailings around each shallow piezometer would be required to arrive at a conclusive relationship between the tailings mineralogy and the observed water quality. No such analysis was conducted in this study.

The volume of ground water moving under and through the tailings also may affect the measured metal cation concentration. Areas showing significant ground water discharge (expressed as visible seepage faces or substantial gully discharge) may display relatively low dissolved concentrations because of dilution. No large seepage faces were observed along the stream bank; ground water discharge from gullies also was not significant during the low flow period when the piezometers were installed and sampled. Inconclusive evidence exists to hypothesize a primary cause for spatial variability in ground water quality in the shallow piezometers.

The data suggest that a definite relationship does exist between the ground water pH and the corresponding concentration of metal cations. The three lowest pH values (H1, H8 and H4) correspond with the three highest lead values, three of the four highest zinc values and three of the four highest cadmium values. Without x-ray diffraction data, the possible correspondence with pyrite content and mineralogy cannot be established, however.

Water from the three auger-drilled piezometers (PZ1-PZ3) was sampled and analyzed for metal cations (fig. 3; tables 8, 9, 10, and 12). Excess

Table 7. Water quality data for late September, 1985.

Number of Stations: 15
Trace metal samples filtered to 0.45 microns
EC values compensated to 25 °C.
'*' denotes value at or below detection limit
'.' denotes missing data

Site	Date	Cd (µg/L)	Cu (µg/L)	Fe (µg/L)	Pb (µg/L)	Zn (µg/L)	EC (µmhos/cm)	pH	Temp (°C)	Flow (cfs)
BJ1	9-21-85	.	.	.	.	.	.	.	.	0.4
BJ2	9-20-85	.	.	.	.	.	120	6.2	4.5	.
BJ3	9-21-85	.	.	.	.	.	115	6.6	4.5	0.2
MA1	9-21-85	.	.	.	.	.	.	.	.	0.1
H-1	9-21-85	720	2170	330	6800	59000	305	4.5	6.5	.
H-2	9-21-85	13	.	*	610	1200	125	6.1	5.0	.
H-3	9-21-85	31	*	170	600	2320	275	5.9	7.0	.
H-4	9-21-85	133	.	2250	3540	13300	150	5.5	4.5	.
H-5	9-21-85	9	.	*	110	534	105	6.3	6.5	.
H-6	9-21-85	70	.	30	340	2660	120	6.7	6.0	.
H-7	9-21-85	40	.	*	1150	1480	105	5.7	6.0	.
H-8	9-21-85	170	.	*	11800	9800	115	5.2	5.0	.
H-9	9-21-85	268	*	350	170	19000	310	6.0	6.0	.
H-10	9-21-85	87	.	*	680	2740	135	6.2	6.0	.
H-11	9-21-85	128	.	4810	1700	8000	150	5.8	7.0	.

Table 8. Water quality data for October, 1984.

Number of Stations: 17
Trace metal samples filtered to 0.45 microns; major metals unfiltered
EC values compensated to 25 °C.
All samples below detection limit for copper and arsenic
BJ6 and BJ7 below detection limit for chloride
'*' denotes value at or below detection limit
'.' denotes missing data

Site	Date	Cd (µg/L)	Fe (µg/L)	Pb (µg/L)	Zn (µg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	Sulfate (mg/L)	EC (µmhos/cm)	pH	Temp (°C)	Flow (cfs)
BJ1	10-11-84	18	*	210	1200	.	.	.	.	113	6.7	7.0	0.11
BJ2	10-11-84	11	50	170	880	.	.	.	.	111	6.1	7.0	0.10
BJ3	10-11-84	5	50	49	300	.	.	.	.	89	6.2	6.5	0.097
BJ4	10-11-84	*	50	*	26	.	.	.	.	45	6.5	6.0	0.041
BJ5	10-11-84	*	*	*	12	.	.	.	.	32	7.0	6.0	0.064
BJ6	10-11-84	*	*	*	*	*	*	0.7	7	20	7.4	4.5	0.003
BJ7	10-11-84	15	*	450	1100	13	2.3	0.8	14	96	.	4.0	0.11
BJ8	10-11-84	2	30	96	140	7	1.7	0.9	7	57	5.8	6.0	5.8
MA1	10-11-84	10	*	95	500	.	.	.	.	164	5.8	5.5	.
MD1	10-11-84	*	*	33	30	.	.	.	.	114	.	6.5	0.001
MD2	10-11-84	*	*	23	46	.	.	.	.	46	.	4.0	0.002
MD3	10-11-84	10	*	120	430	.	.	.	.	160	6.0	3.0	0.029
MD4	10-11-84	16	2200	72	1300	.	.	.	.	180	6.0	4.0	0.001
MD5	10-11-84	4	1050	230	340	.	.	.	.	53	6.0	4.0	0.002
MD6	10-11-84	5	*	1070	400	.	.	.	.	34	6.0	4.0	0.012
MD7	10-11-84	*	*	25	*	.	.	.	.	47	6.0	3.5	0.005
PZ1	10-11-84	*	*	*	25	.	.	.	.	178	6.0	7.0	.

Table 9. Water quality data for June, 1985.

Number of Stations: 24
Trace metal samples filtered to 0.45 microns; major metals unfiltered
EC values compensated to 25 °C.
Alkalinity as mg/L of calcium carbonate
Many pH values measured with litmus paper--read to nearest half a pH unit
'*' denotes value at or below detection limit
'.' denotes missing data

Site	Date	Cd (µg/L)	Cu (µg/L)	Fe (µg/L)	Pb (µg/L)	Zn (µg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Alk (mg/L)	EC (µmhos/cm)	pH	Temp (°C)	Flow (cfs)
BJ1	6-7-85	13	.	*	220	800	.	.	.	.	46	6.0	3.0	10
BJ2	6-7-85	12	.	*	180	720	.	.	.	.	48	6.0	3.0	11
BJ3	6-7-85	9	.	*	220	590	.	.	.	.	43	6.0	3.0	10
BJ5	6-7-85	*	.	*	*	11	.	.	.	.	16	6.8	2.0	10
BJ6	6-7-85	*	.	*	*	72	*	*	*	6	16	7.0	2.0	.
BJ7	6-7-85	6	*	*	120	410	0.7	*	*	9	31	6.0	3.0	20
BJ8	6-7-85	*	*	*	100	72	0.4	0.3	*	.	22	6.0	5.0	140
MA1	6-7-85	30	.	*	570	2010	.	.	.	.	84	6.7	2.0	0.55
MA2	6-7-85	*	*	*	*	12	.	.	.	.	80	6.0	4.0	0.001
MD1	6-7-85	*	.	*	*	65	.	.	.	.	54	6.7	3.0	0.001
MD3	6-7-85	32	30	*	380	2220	.	.	.	.	77	5.7	2.0	2.7
MD4	6-7-85	14	*	4940	51	1200	.	.	.	.	140	5.7	8.0	0.001
MD5	6-7-85	4	*	180	540	270	.	.	.	.	23	5.7	2.0	0.005
MD6	6-7-85	29	20	*	2300	1400	.	.	.	.	32	6.7	2.0	.
MD7	6-7-85	*	.	*	*	38	1.0	*	*	10	45	6.0	4.5	2.4
MD8	6-7-85	*	.	*	*	17	.	.	.	.	14	6.0	2.0	5.2
MD9	6-7-85	76	*	*	840	5000	.	.	.	.	190	5.5	4.0	0.06
MD10	6-7-85	72	220	*	4700	4000	.	.	.	.	66	5.5	2.0	0.02
MD11	6-7-85	27	20	*	540	1680	.	.	.	.	140	6.0	8.0	0.02
MD12	6-9-85	.	.	.	.	.	.	.	.	.	113	6.0	7.5	0.02
MD13	6-9-85	.	.	.	.	.	.	.	.	.	83	6.0	4.0	0.01
PZ1	6-7-85	*	*	*	*	15	.	.	.	.	.	.	.	.
PZ2	6-7-85	6	*	740	310	1780	.	.	.	.	62	6.0	2.5	.
PZ3	6-7-85	2	*	*	42	42	.	.	.	.	94	5.9	2.5	.

Table 10. Water quality data for July, 1985.

Number of Stations: 21
Trace metal samples filtered to 0.45 microns; major metals unfiltered
EC values compensated to 25 °C.
Alkalinity as mg/L calcium carbonate
Pb detection limit at 50 µg/L
All samples below detection limit for iron except MD5 (2.47 mg/L)
'.' denotes missing data
'*' denotes value at or below detection limit

Site	Date	Cd (µg/L)	Pb (µg/L)	Zn (µg/L)	Ca (mg/L)	Alk (mg/L)	Hard (mg/L)	EC (µmhos/cm)	pH	Temp (°C)	Flow (cfs)
BJ1	7-19-85	17	290	877	.	46	.	100	6.4	7.0	0.22
BJ2	7-19-85	15	210	844	.	.	.	111	6.9	8.5	0.20
BJ3	7-19-85	8	120	395	.	48	.	99	6.7	7.5	0.15
BJ4	7-19-85	*	*	10	.	26	.	.	.	.	0.02
BJ5	7-19-85	*	*	10	.	.	.	22	6.8	12.5	0.13
BJ6	7-19-85	*	*	*	*	8	8	11	6.4	9.0	0.006
BJ7	7-19-85	13	420	704	13	37	36	77	6.5	8.0	0.28
BJ8	7-19-85	3	60	134	6	24	24	51	6.3	11.5	5.9
MA1	7-19-85	12	130	510	.	78	80	.	.	.	0.11
MA2	7-19-85	*	*	12	.	.	.	85	6.5	5.5	0.001
MD1	7-19-85	*	*	22	.	.	.	89	6.5	5.0	0.002
MD2	7-19-85	2	*	62	.	.	.	39	6.3	12.0	0.008
MD3	7-19-85	14	190	526	.	.	.	147	6.8	5.5	0.11
MD5	7-19-85	2	160	109	.	.	.	36	6.3	6.5	0.002
MD6	7-19-85	13	1150	679	.	.	.	22	6.1	8.0	0.014
MD7	7-19-85	*	*	*	6	31	24	32	6.7	8.0	0.04
MD12	7-19-85	20	190	935	.	.	.	165	6.8	13.0	0.002
MD13	7-19-85	.	.	.	.	.	.	71	6.4	7.0	0.002
PZ1	7-21-85	*	*	12	.	.	.	148	6.1	10.0	.
PZ2	7-21-85	.	.	.	.	.	.	41	6.2	9.5	.
PZ3	7-21-85	.	.	.	.	.	.	82	6.2	9.0	.

Table 11. Water quality data for August, 1985

Number of Stations: 7
EC values compensated to 25 °C.
Alkalinity as mg/L of calcium carbonate
'.' denotes missing data

Site	Date	EC (µmhos/cm)	pH	Temp (°C)	Alk (mg/L)	Flow (cfs)
BJ1	8-26-85	118	6.5	12.0	40	.
BJ3	8-26-85	100	6.5	12.0	41	.
BJ5	8-26-85	25	7.2	11.0	12	0.033
BJ7	8-26-85	105	6.7	13.0	34	.
MA1	8-26-85	160	7.4	2.5	82	0.053
MD7	8-26-85	49	6.7	11.0	26	.
MD12	8-26-85	170	6.4	15.0	.	.

Table 12. Water quality data for early September, 1985

Number of Stations: 17
Trace metal samples filtered to 0.45 microns
EC values compensated to 25 °C.
'*' denotes value at or below detection limit
'.' denotes missing data

Site	Date	Cd (µg/L)	Fe (µg/L)	Pb (µg/L)	Zn (µg/L)	EC (µmhos/cm)	pH	Temp (°C)	Flow (cfs)
BJ1	9-5-85	30	*	270	1030	115	7.2	11.0	0.14
BJ3	9-5-85	12	30	150	490	92	7.2	7.0	0.09
BJ4	9-5-85	*	90	50	30	47	6.4	7.0	0.05
BJ5	9-5-85	*	*	*	*	25	6.5	6.5	0.13
BJ7	9-5-85	21	*	470	850	95	7.2	9.5	0.19
MA1	9-5-85	15	*	100	680	.	.	.	.
MD3	9-5-85	14	40	170	630	175	7.2	5.5	0.067
MD4	9-5-85	3	2060	30	500	160	6.5	9.0	0.001
MD5	9-5-85	20	170	270	990	55	6.6	7.0	0.003
MD6	9-5-85	9	*	960	520	34	7.1	12.0	0.007
MD7	9-5-85	*	*	*	*	45	7.4	8.0	0.035
MD9	9-5-85	50	*	530	2460	180	6.8	11.0	0.002
MD11	9-5-85	52	*	380	2630	205	6.9	10.0	0.001
MD12	9-5-85	14	*	120	800	155	7.2	11.0	0.009
MD14	9-5-85	19	100	60	1070	120	6.4	6.5	0.001
MD15	9-5-85	28	50	*	930	140	6.6	9.0	0.002
MD16	9-5-85	64	*	5400	3700	45	5.8	7.0	0.001
PZ1	9-5-85	*	*	*	*	150	7.0	7.5	.

quantities of suspended sediment and small borehole water yields prevented routine sampling from PZ2 and PZ3. The available data indicate low metal concentrations in PZ1 and PZ3. Water from PZ2 shows a much higher concentration of metal cations than the other two piezometers. Evidence from the drill logs and cross-sections (appendix 3; figs. 11-13), along with the water quality data, suggest that PZ1 and PZ3 were drilled through the base of the tailings, while the base of PZ2 is within the floatation tailings. Water samples taken from PZ1 and PZ3 may be more representative of sub-tailings ground water, whereas PZ2 may represent actual intra-tailings ground water. The low metal cation concentration and fairly stable water levels at PZ1 suggest that ground water in this area is recharged from sources other than local infiltration of precipitation or adit discharge.

Mine Adit Water Quality

Discharge from the no. 5 tunnel (MA1) is a perennial source of dissolved metals to Blue Joe Creek. The water from this portal represents the summation of ground water that seeped or dripped into the underground workings. Part of the discharge from the no. 5 tunnel is believed to originate as rainfall or snowmelt which infiltrates into the subsurface near the drainage divide. Natural and man-made pathways such as faults, joints, drill holes, shafts and other mining-induced disturbances are thought to channel some of this water to the underground workings (fig. 5). Water moving through the underground workings is believed to leach metals from the mineralized rock still present there.

Water quality data from the lower discharging adit were collected at two separate points: the portal (MA1) and the confluence of the adit discharge with Blue Joe Creek (MD3) (fig. 2; tables 8 through 12). The second portal (MA2) does not have a significant discharge, contains low dissolved metal concentrations, and is not thought to impact Blue Joe Creek to any extent. Temporal variations in metal cation concentration and load at MA1 and MD3 are discussed below.

The lower mine adit contributes a significant portion of the total dissolved metals measured in upper Blue Joe Creek (table 13). The highest metal loads were measured in early June. The discharge from the adit and the concentration of dissolved metals were highest during this period (fig. 17). The peak probably represents the flushing of dissolved metals from the mine workings which accumulate over the fall and winter as oxidation products of the metal ores (Gaillot, 1979). It is not known if the annual peak discharge of the adit was measured during the June sampling.

The discharge from the mine decreases abruptly from June to July. Dissolved metal concentrations also decline significantly from June to

Table 13. Percentage and amount of total mine site metal load (as measured at BJ7) coming from the lower mine adit (as measured at MD3)

Metal	Oct 84		Jun 85		Jul 85		Sept 85	
	(%)	(load)	(%)	(load)	(%)	(load)	(%)	(load)
Zn	10	31	72	15000	29	140	31	100
Pb	7	9	42	2500	18	51	15	28
Cd	17	0.7	64	210	42	3.8	28	2.3

NOTE: Metal load in grams/day

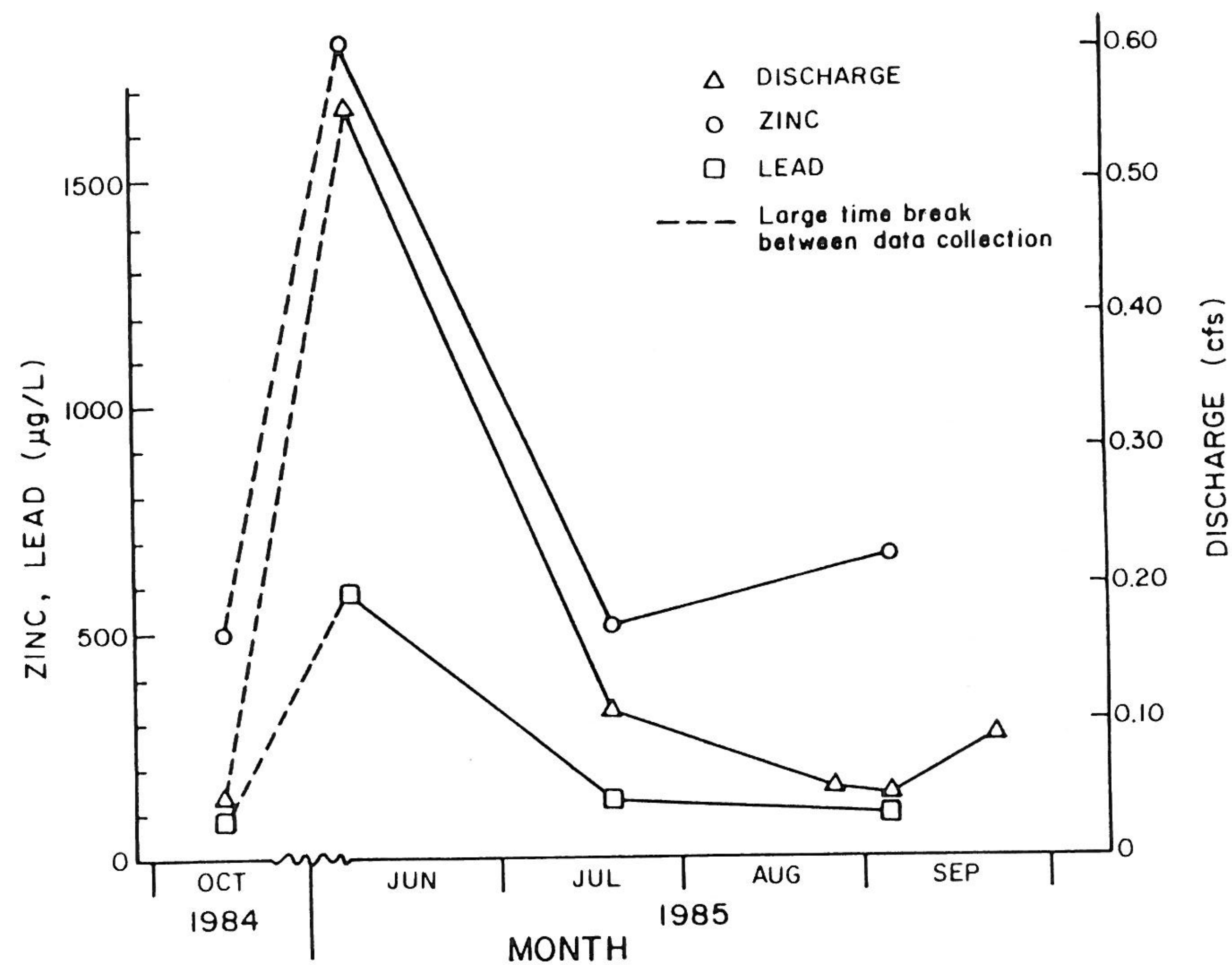


Figure 17. Temporal variations in the dissolved metal concentration and discharge from the lower mine adit.

July. Flow rates decline gradually from July to early September, and are accompanied by a slight rise in the concentration of zinc and cadmium. The concentration rise probably is related to the reduction in the volume of good quality inflow to the underground workings.

Two measurements of adit water alkalinity were made in July and August, with values of 78 and 82 mg/L respectively. These values are roughly twice the level of alkalinity measured in Blue Joe Creek at the mine site, over seven times the background levels from the headwaters of Blue Joe Creek, and up to seven times the levels measured in nearby drainages (appendix A). The adit alkalinity values are relatively high in relation to the water quality in Blue Joe Creek and adjacent streams, but still are fairly low in an absolute sense. Measurements of adit pH in August and September (July pH data were not collected) indicate neutral to slightly alkaline water. The local carbonate unit of the Wallace Formation may be the primary bicarbonate source contributing to the measured alkalinity and near neutral pH at MA1.

Spatial and Temporal Variations in Surface Water Quality

Water quality in Blue Joe Creek is the primary natural gauge by which environmental impacts from the mining activities are measured. Mining activity at the Continental Mine is responsible for both chemical and physical impacts to the stream. This section of the report is concerned primarily with the evaluation of spatial and temporal variations in dissolved metal concentration and metal load in Blue Joe Creek. This evaluation can help illustrate the degree to which stream quality is impacted, the primary non-point source areas responsible for these impacts, and the critical time periods when water quality is most degraded.

Metal cation concentrations in Blue Joe Creek show a marked increase with downstream distance through the mine site during all sampling periods. Changes in zinc and lead concentration from the headwaters to BJ8 are plotted for periods of peakflow and baseflow in figures 18 and 19. The concentration response of cadmium is very similar to zinc, only at much lower concentrations.

The following observations summarize the dissolved metal and discharge pattern for high flow along Blue Joe Creek (fig. 18).

1. The dissolved zinc concentration in Blue Joe Creek increases eight-fold between BJ5 and BJ3. The primary source of metals responsible for this sharp rise is the discharge from the adit (MD3). The lead concentration also rises noticably over this same interval.
2. Dissolved zinc concentration is highest at BJ1. Dissolved lead concentration remains fairly stable throughout the tailings reach of the stream (BJ3 to BJ1).
3. Concentrations of both zinc and lead drop about 50 percent between BJ1 and BJ7 in response to a doubling in creek discharge over the same interval. The two major sources of discharge which enter the creek between BJ1 and BJ7 (i.e. the diversion channel return flow (MD8) and water from a natural side tributary (MD7)) are low in dissolved metals.
4. Stream discharge increases approximately seven times from BJ7 to BJ8. The concentration of dissolved zinc drops roughly 80 percent over this same interval. The concentration of dissolved lead, in contrast, declines less than 20 percent over the five miles between BJ7 and BJ8.

The following observations summarize the dissolved metal and discharge pattern for low flow along Blue Joe Creek (fig. 19).

1. The largest increase in dissolved zinc occurs between BJ3 and BJ2. This differs from the high flow pattern, and indicates that a high

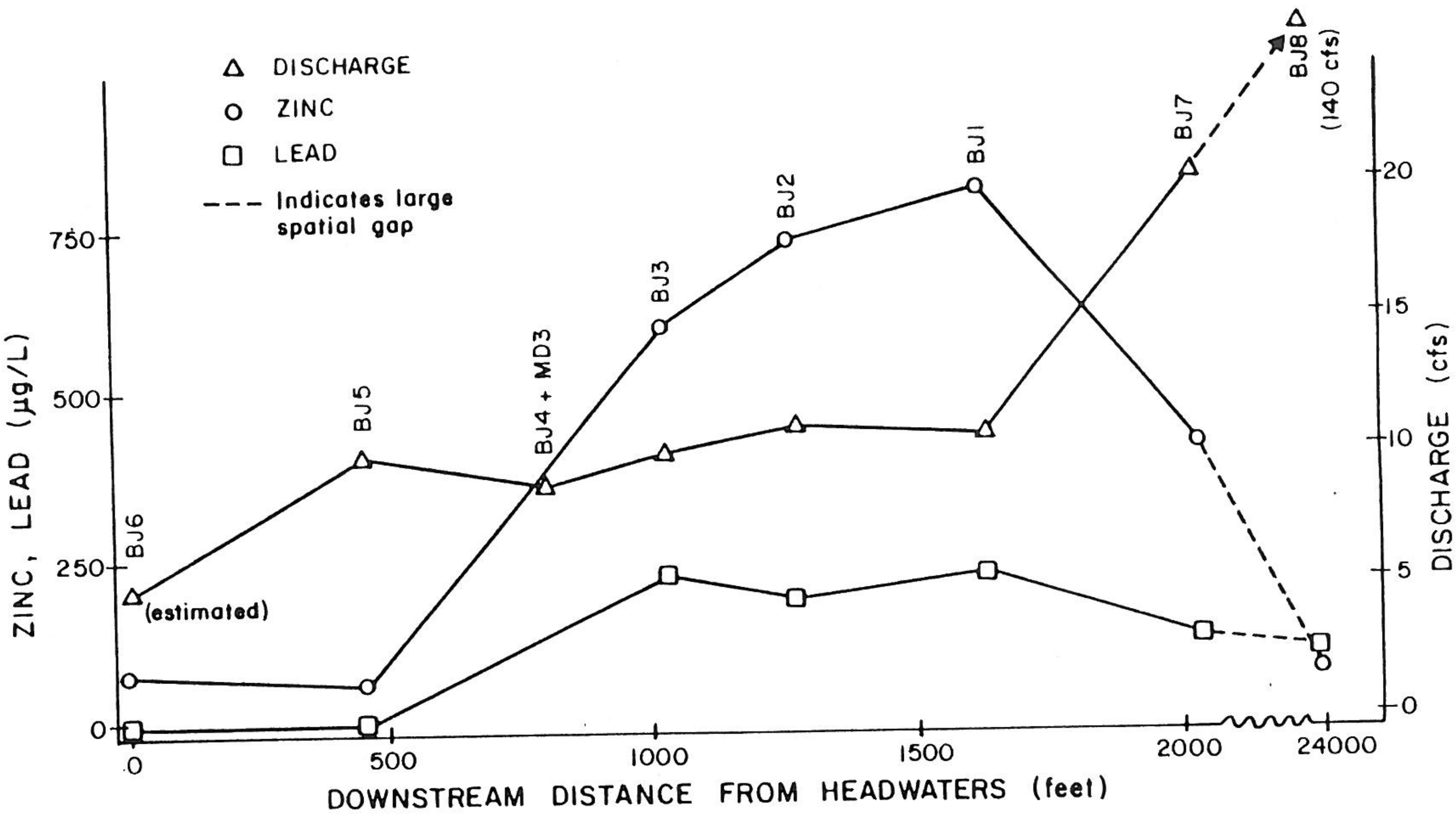


Figure 18. Spatial variations in the dissolved metal concentration in Blue Joe Creek during spring high flow (June 1985).

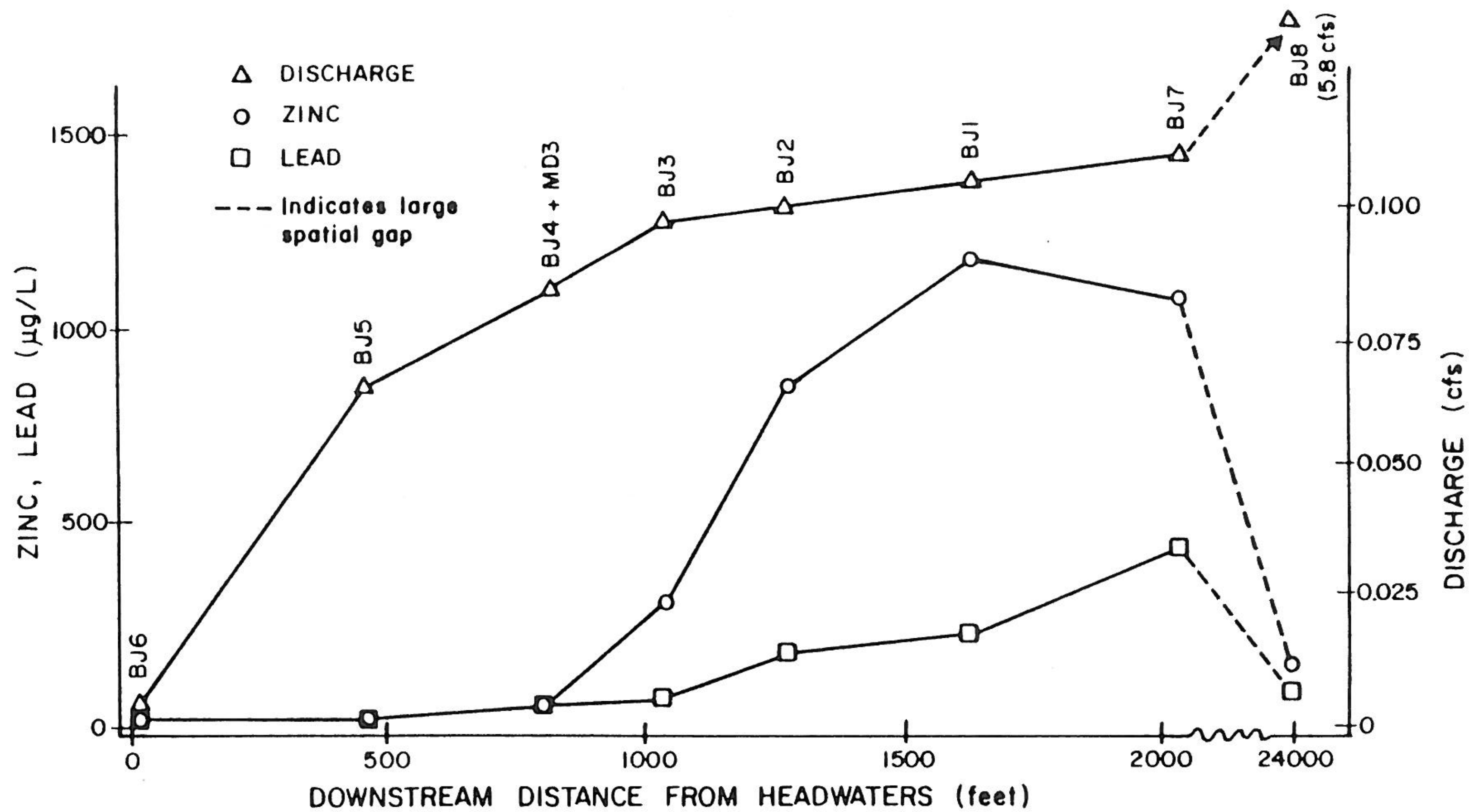


Figure 19. Spatial variations in the dissolved metal concentration in Blue Joe Creek during autumn low flow (October, 1984).

percentage of metals entering Blue Joe Creek at the mine site during low flow comes from tailings seepage.

2. Dissolved zinc reaches a peak at BJ1 and declines slightly from BJ1 to BJ7. Dissolved lead in Blue Joe Creek rises steadily through the tailings. The largest lead concentration increase occurs between BJ1 and BJ7. The difference in the spatial pattern of zinc and lead between BJ1 and BJ7 is attributed, in part, to a surface discharge (MD6) which enters the creek below BJ1. MD6 contains a relatively high concentration of dissolved lead.
3. Discharge in Blue Joe Creek increases approximately 50 times between BJ7 and BJ8. The zinc concentration at BJ8 is reduced to less than 12 percent of its value at BJ7. The dissolved lead concentration at BJ8 is reduced to 20 percent of the low flow maximum measured at BJ7.

The metal cation concentrations at individual sites display distinct temporal variations. These changes are believed to be strongly influenced by seasonal changes in the hydrologic regime. Plots of time versus concentration are shown in figures 20, 21 and 22 for some selected sample sites. The following generalizations are suggested from the temporal variation plots.

1. Metal cation concentrations in Blue Joe Creek (BJ1 and BJ7) rise gradually throughout the summer as streamflow becomes increasingly dominated by baseflow.
2. The flushing event from the underground workings is evident in the response at MD3. The temporal pattern of MD6 is similar to the pattern at MD3. The pattern may suggest that flushing of accumulated oxidation products from the metal bearing minerals in the tailings is occurring. A seasonal flushing of metal ions from tailings deposits was observed by Marcy (1979) in his study of mine wastes in the Coeur d'Alene

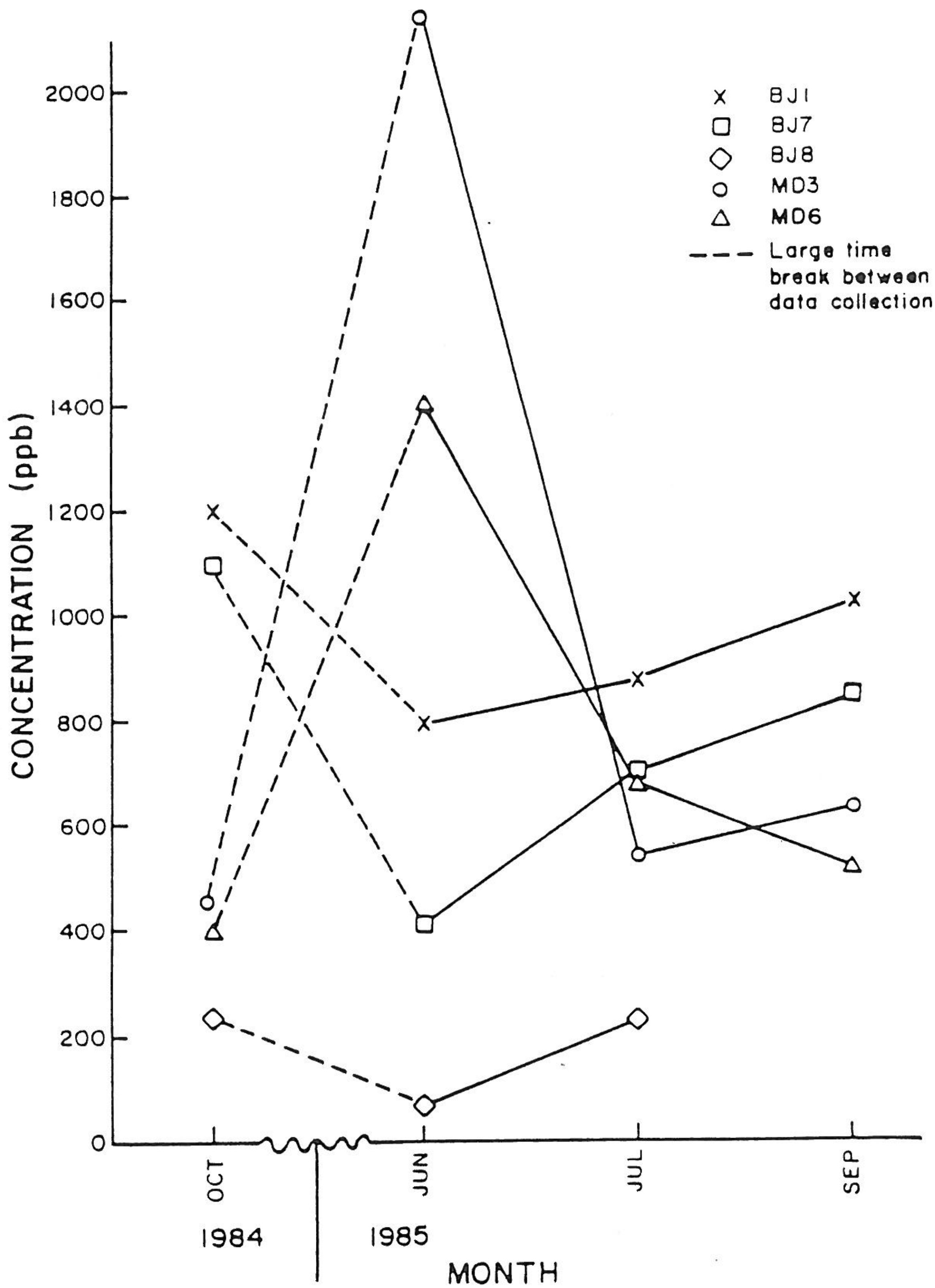


Figure 20. Temporal variation in the dissolved zinc concentration at selected sample sites.

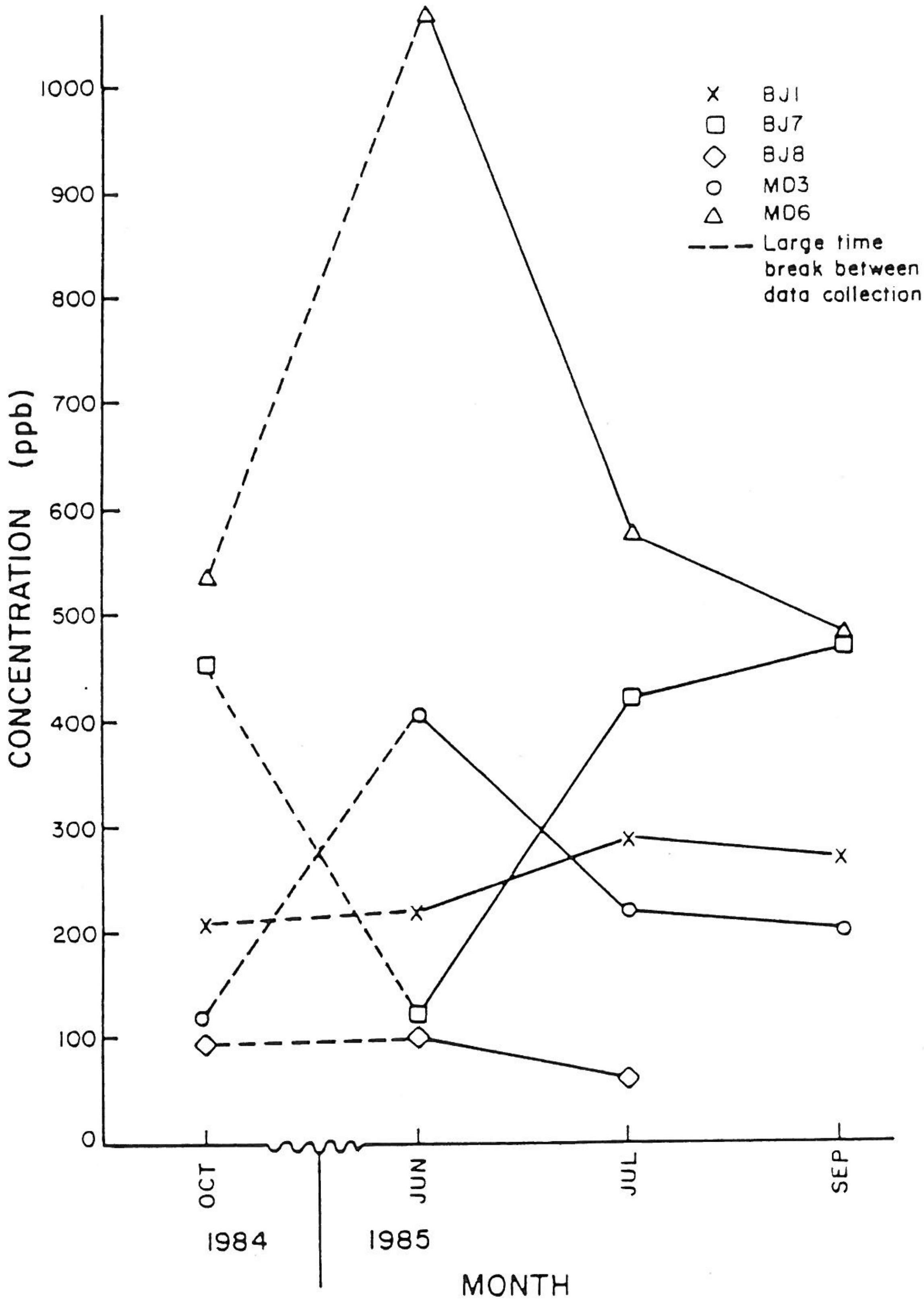


Figure 21. Temporal variation in the dissolved lead concentration at selected sample sites.

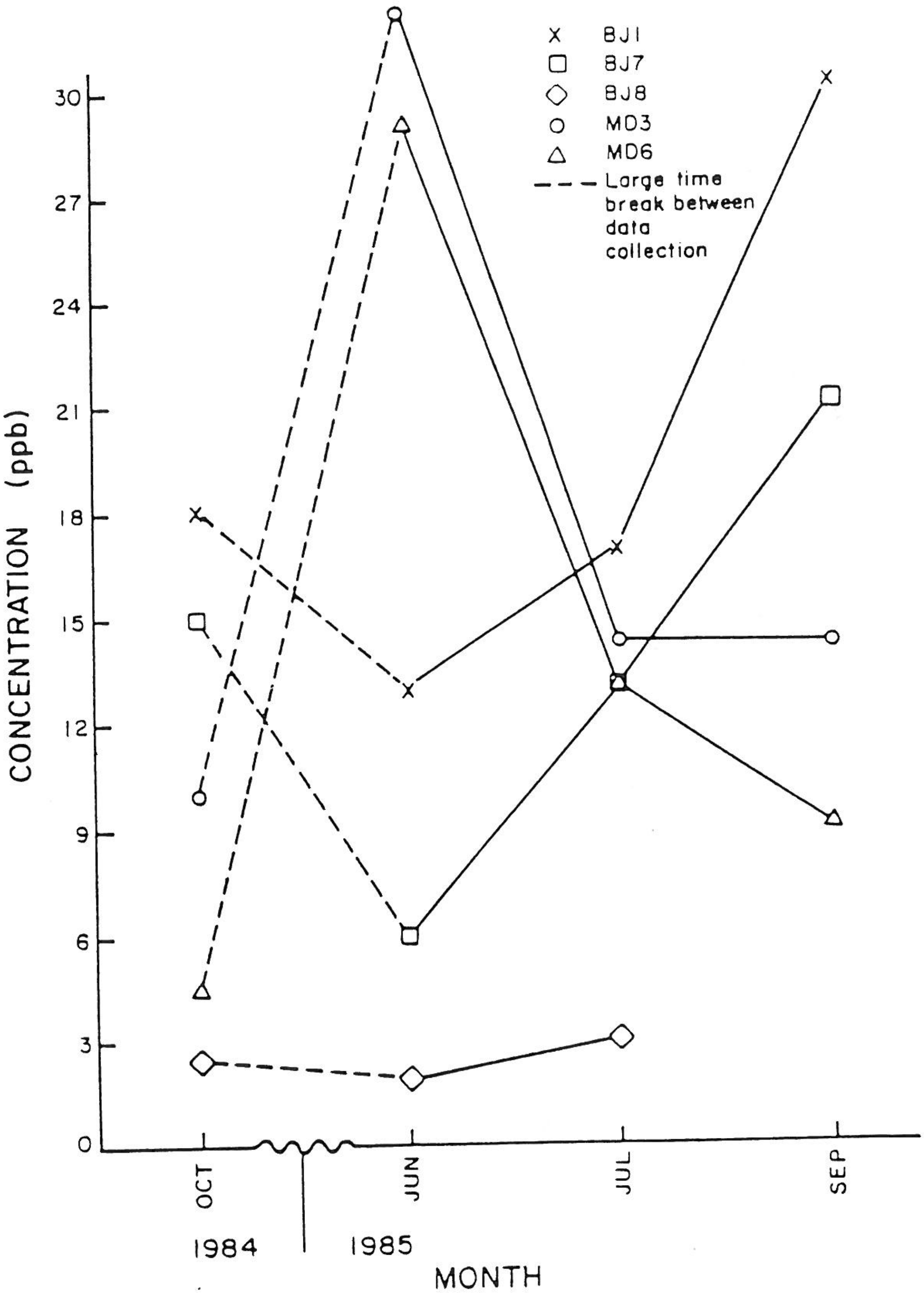


Figure 22. Temporal variation in the dissolved cadmium concentration at selected sample sites.

district, and by Gaillot (1979) in his study of tailings piles at the Jack Waite Mine.

3. The temporal pattern of dissolved metals at BJ8 suggests that low and fairly stable concentrations are maintained at this location. Concentrations are not reduced downstream of the mine in proportion to the level of dilution from increasing stream discharge. This suggests that some metals are being contributed to Blue Joe Creek from sources other than the mine site.

Metal loads in Blue Joe Creek generally increase significantly below the mine site, particularly during low flow (October and July) (figs. 23 to 26). This pattern contrasts with the decline in metal cation concentrations observed between BJ7 and BJ8. The increase in dissolved metal loading between BJ7 and BJ8 suggests that a significant source of metal cations exists below the mine site. The source is believed to be mill tailings which are intermixed with the stream sediments. The percentage of total stream load coming from various sources is given in table 14. September concentration data at BJ8 were not collected, preventing the estimation of metal loads for this site.

A high percentage of the annual dissolved metals load is carried from the basin during spring peak flow periods (fig. 27). Peak flow metal loads exceed low flow metals loads by 30 times or more. An estimated 33 to 50 percent of the annual metal load in the creek is flushed from the basin each spring. This estimate is based on a two week duration for the peak flushing event, metal loads measured at BJ8 in June as average daily peak flow values, and metal loads measured in October as average daily values for the remaining 50 weeks.

Zinc and cadmium loads increase four to six times between BJ7 and BJ8 during low flow periods (i.e. October and July). During high flow, over 80

Table 14. Relative Source Loads and Percentages for Metal Cations (compared with metals load at BJ8).

SOURCE	OCT 84 (%)	OCT 84 (load)	JUN 85 (%)	JUN 85 (load)	JUL 85 (%)	JUL 85 (load)
Zn from Mine Adit	2	31	59	15000	7	140
Total Zn from Mine Site	15	300	83	20000	25	480
Zn gain between BJ7 and BJ8	85	2700	17	4000	75	1420
Pb from Mine Adit	<1	8.5	7	2500	6	51
Total Pb from Mine Site	9	120	18	6000	33	290
Pb gain between BJ7 and BJ8	91	1200	82	28000	67	580
Cd from Mine Adit	2	0.7	62	210	9	3.8
Total Cd from Mine Site	13	4.0	87	300	22	8.9
Cd gain between BJ7 and BJ8	87	27	13	40	78	31

NOTE: Metal load in grams/day

percent of the zinc and cadmium load measured at BJ8 comes from the mine site. The calculated zinc and cadmium load which is derived from stream sediments below the mine remains relatively constant throughout the year (i.e. 1420 to 4000 grams/day for zinc, and 27 to 40 grams/day for cadmium). Zinc and cadmium loads coming from the mine site are more variable temporally (i.e. 300 to 20,000 grams/day for zinc, and 4 to 300 grams/day for cadmium) (see table 14).

Lead increases markedly downstream of the mine site during both low flow and high flow periods. Sixty-seven to 91 percent of the total lead load in Blue Joe Creek (as measured at BJ8) is gained between BJ7 and BJ8. Assays and x-ray diffraction analysis of the stream sediments would be required to establish a link between the mineralogy and metal content of the stream sediment and the observed metal load patterns. No stream

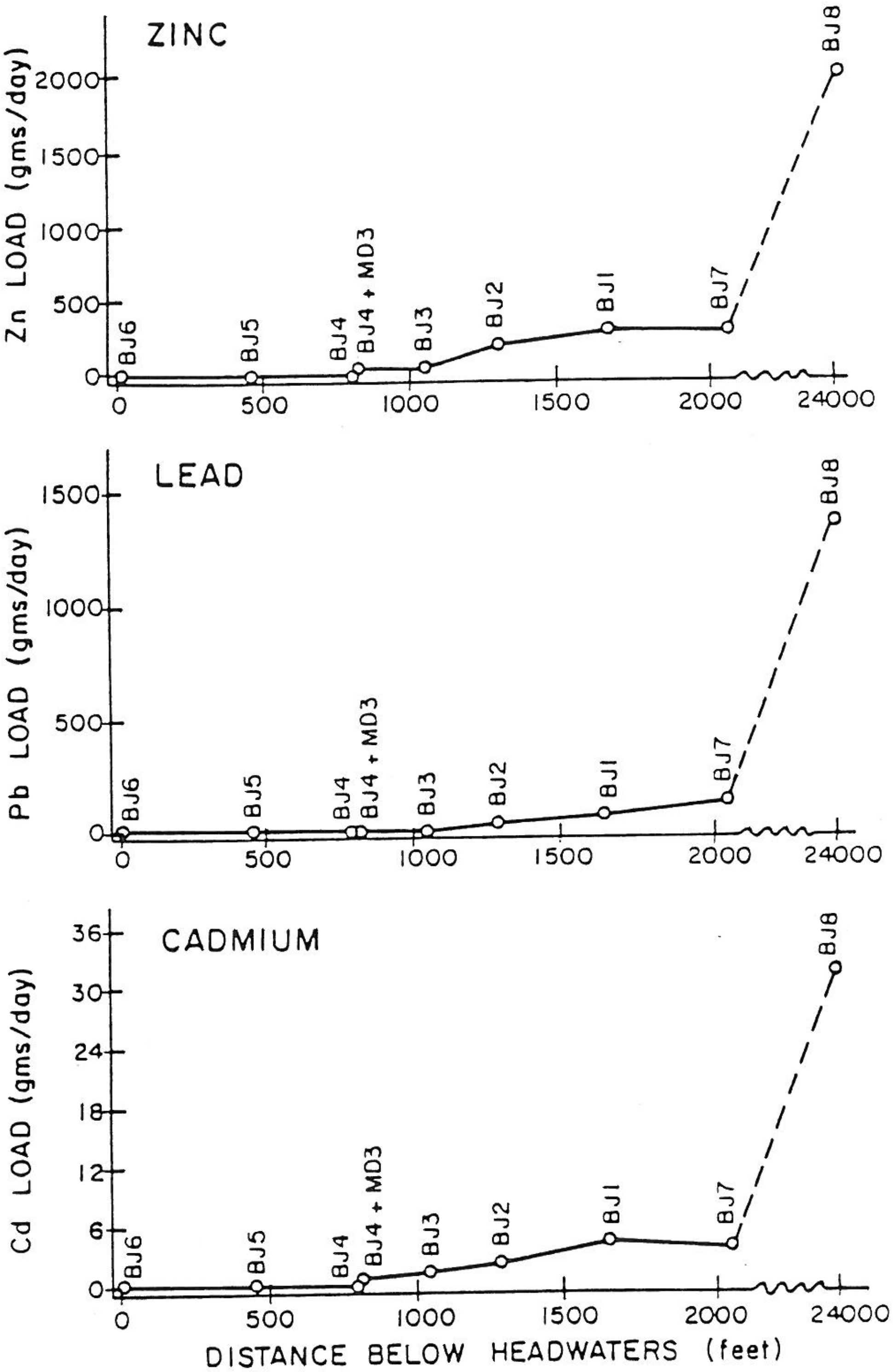


Figure 23. Metal load in Blue Joe Creek versus distance for October, 1984. Dashed lines indicate a large spatial break between sample stations.

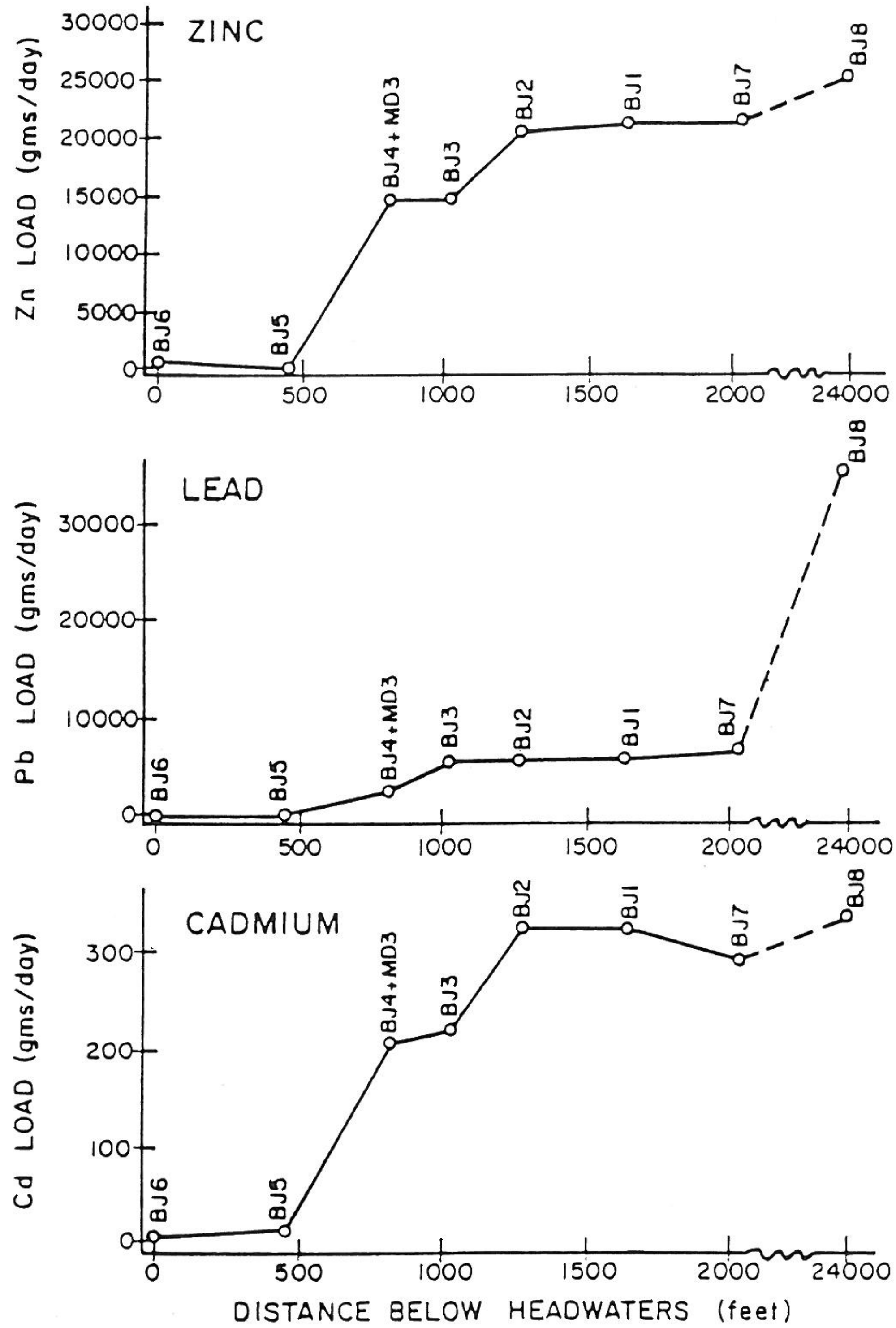


Figure 24. Metal load in Blue Joe Creek versus distance for June, 1985. Dashed lines indicate a large spatial break between sample stations.

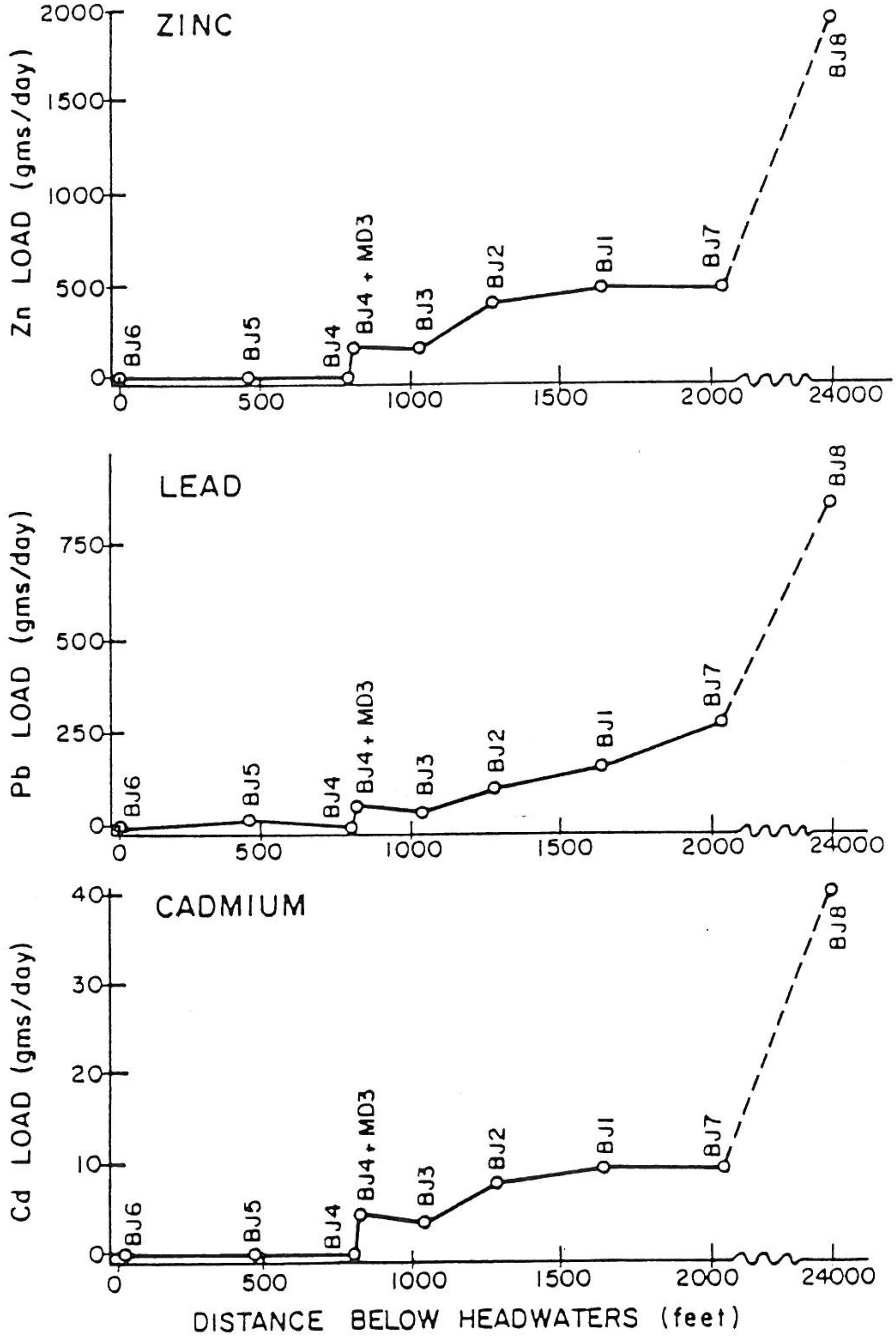


Figure 25. Metal load in Blue Joe Creek versus distance for July, 1985. Dashed lines indicate a large spatial break between sample stations.

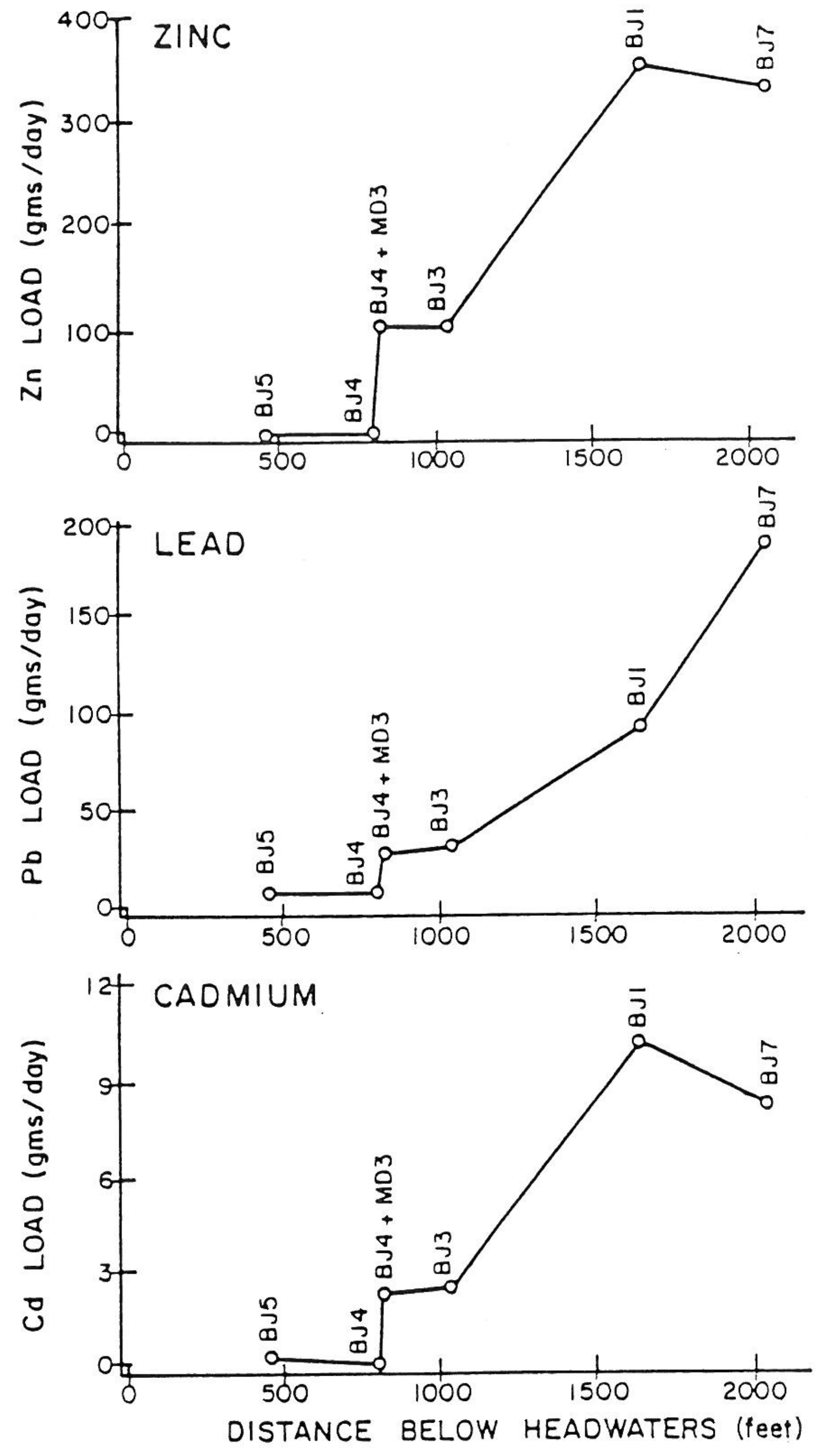


Figure 26. Metal load in Blue Joe Creek versus distance for September, 1985. Dashed lines indicate a large spatial break between sample stations.

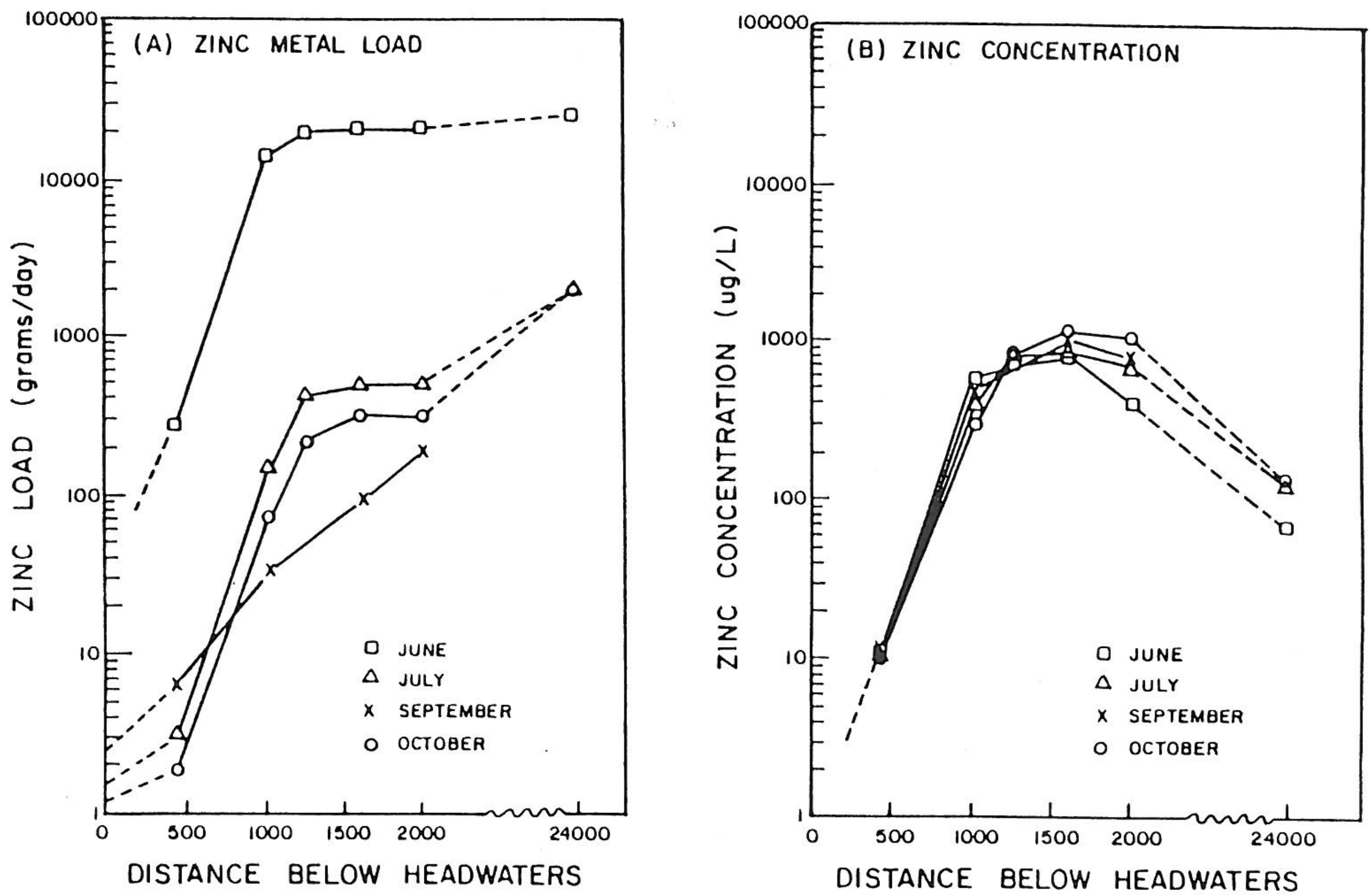


Figure 27. Comparison of zinc load and zinc concentration over time and space. Dashed lines indicate a large spatial break between sample stations.

sediment data were collected in this study.

The main findings of the water quality data analysis are summarized below.

1. Water quality problems in Blue Joe Creek are tracable to three primary metal ion source areas: the tailings pile, the mine adit (MA1), and tailings material intermixed in stream sediments below the mine site.
2. The concentration of dissolved metals in Blue Joe Creek appears to peak near the mine site, declining 20 to 80 percent downstream to BJ8 depending upon the time and constituent.
3. Tailings-enriched stream sediments annually contribute the bulk of the dissolved lead load in lower Blue Joe Creek. These sediments also contribute the bulk of the total zinc and cadmium load measured in lower Blue Joe Creek during low flow periods. High zinc and cadmium loads are contributed to the creek from mine adit discharge during spring high flow periods.

The water quality analysis results imply that reclamation efforts targeted solely at the mine site will not significantly abate the chemical water quality impacts to the drainage of Blue Joe Creek. Much of the chemical problem presently is derived from tailings material downstream of the mine site, and discharge from the mine adit. The tailings in the stream channel will be flushed gradually from the drainage with time, assuming upstream sources of sediment are stabilized. Sediment impacts to the creek system, though not specifically addressed in this study, may be mitigated to some degree by appropriate reclamation measures.

CHAPTER VI

CONCEPTUALIZED HYDROLOGIC MODEL AND RECLAMATION ALTERNATIVES

Introduction

Mined land rehabilitation is an attempt to return disturbed land to a form and productivity that conforms with a prior or desired land use plan. Such a plan should promote a stable ecological state which minimizes environmental deterioration and harmonizes with surrounding aesthetic conditions (Wahlquist, 1976). From experience at the Continental Mine, the final adoption and implementation of reclamation plans for an inactive mine site is the culmination of a multi-step process that can involve:

(1) the initial recognition and documentation of environmental impacts

(2) the identification of parties which share responsibility in evaluating and mitigating the problems

(3) the collection of historical and/or scientific field data pertinent to the understanding of the problem

(4) analysis and synthesis of the data base to delineate problem pollutants, their primary source areas and probable sinks

(5) the gestation of feasible and practical reclamation alternatives based upon the data analysis results, a review of pertinent reclamation practices, budgetary constraints, the availability of manpower and equipment, and the long-term intended land use and appearance.

Chapters two through five of this study pursue steps 3 and 4 above. A discussion of seasonal changes in the hydrologic regime of upper Blue Joe Creek is presented in this chapter as a preamble for step 5, the presentation of reclamation alternatives for the Continental Mine Study Area.

Conceptualized Hydrologic Model

The physical transport of mine wastes and the chemical leaching of metals from them are influenced greatly by seasonal changes in the hydrologic regime. The magnitude of chemical and sediment impacts on Blue Joe Creek varies seasonally as the local hydrologic conditions change. Hydrologic conditions which govern the physical processes of metal lixiviation and the erosion and transport of mineral wastes may be controlled to some extent by carefully planned reclamation activities. Reclamation proposals must be tempered with the recognition that many aspects of the hydrologic system are beyond human control. A conceptualized hydrologic model of upper Blue Joe Creek watershed is presented below, divided into three climatically and hydrologically distinct periods.

Late Fall/Winter

The frequency of precipitation events is greater during the late fall than during the summer months. Streamflow may increase in response to greater surface runoff. Ground water levels may rise somewhat in response to the infiltration and subsurface recharge. As the weather cools, snowfall predominates. Fine, sulfide-rich dust particles can become incorporated in the snowpack by blowing winds. Contamination of the snowpack also can occur by capillary suction of metal ions into the snow/ice matrix at the snow/ground interface (U.S. Forest Service, 1979). During the cold winter months, creek flow in the upper watershed is maintained primarily by ground water discharge at the valley bottom and from the adit discharge. Ground water levels in the tailings are expected to decline only slightly during the winter months. Dissolved metals are believed to be contributed to the creek primarily from adit discharge and tailings seepage.

Spring

The advent of spring is accompanied by several changes in the hydrologic regime. Melting of the snowpack can be coupled with extended and/or high intensity rainfall events. Surface runoff in Blue Joe Creek, tributaries, and small gullies increases significantly, ultimately reaching a peak spring discharge. Initial flushes of snowmelt water may contain high concentrations of metallic ions liberated from the ripe snowpack overlying the tailings piles (U.S. Forest Service, 1979). Seasonally high metal loads are flushed from the underground workings, whose discharge reaches its annual peak in response to high levels of rainfall/snowmelt along the drainage divide. High discharge rates result in a high dissolved metal load, and low to moderate dissolved metal concentrations in the creek. High sediment loads are contributed to the creek from rill and gully erosion, stream bank erosion and bank sloughing. Recharge produces a rise in the potentiometric surface. Ground water discharge from the mine wastes increases, but is a small percentage of the total stream discharge.

Summer/early Fall

Hydrologic conditions during the summer are much dryer than the spring months. Baseflow conditions in Blue Joe Creek are reached when melting of the snowpack is complete and monthly precipitation rates decline. Water levels in most of the tailings decline throughout summer as ground water discharge exceeds recharge. Discharge from the underground workings also declines through the summer. This discharge may account for up to 50 percent of the streamflow in upper Blue Joe Creek during mid-summer. Dissolved metal concentrations increase in upper Blue Joe Creek as the adit discharge and tailings seepage constitute a greater percentage of total creek flow.

Presentation of Reclamation Alternatives

Introduction

Reclamation efforts are needed to mollify the physical sedimentation and chemical leaching impacts to Blue Joe Creek attributable to the Continental Mine. No attempt is made here to differentiate the degree to which each process debilitates the stream system as a whole. Prior sections of this report examine the primary source areas of chemical and physical impacts through an examination of spatial and temporal variations in the local hydrochemistry near the mine. The following sections outline various reclamation alternatives for the Continental Mine. Each option is critiqued with regard to: (1) its long-term effectiveness at reducing physical and chemical impacts to the watershed, (2) its long-term effects on local aesthetics, (3) the relative economic costs involved, and (4) possible legal ramifications.

Reclamation alternatives for the Continental Mine discussed in this chapter focus on the immediate mine site. Tailings mixed with stream sediments downstream from the mine site represent a significant, but secondary problem. Of necessity, reclamation of the Blue Joe Creek drainage must start at the top of the watershed. Data presented in table 14 illustrate that an elimination of the mine site problems will not achieve mitigation of all water quality problems in the drainage. A follow-up study probably will be necessary to map the downstream tailings deposits and identify reclamation alternatives.

Reclamation alternatives proposed by Gaillot (1979, pp.110-117) for the abandoned Jack Waite Mine (whose characteristics are similar to the Continental) provide guidance for the Continental Mine site. Gaillot's study suggests that reclamation targeted at existing tailings piles may provide a significant reduction in the dissolved metal and sediment load to affected watercourses. Five of his alternatives for reclamation of tailings piles at the Jack Waite Mine are pertinent to the Continental Mine. These include: (1) removal of the tailings from the drainage for reimpoundment, (2) removal and redeposition of the tailings within the underground workings, (3) placement of the tailings into a new on-site impoundment designed to minimize erosion and metal leaching, (4) regrading and stabilizing the piles by physical, chemical and/or vegetative means, and (5) leaving the tailings as they are. Another option which presents itself at the Continental is the placement of the tailings into the surface workings near the drainage divide. These six options are discussed below.

Reimpoundment of Tailings Off-Site

The tailings at the mine site can be hauled by truck to an established tailing pond or mine pit with sufficient capacity to accept them. The estimated volume of tailings on site is approximately 40,000 cubic yards. For a 13 cubic yard truck, this will amount to over 3000 truck loads. The nearest large capacity tailings ponds are in the Coeur d'Alene district, approximately 100 miles to the south. The largest open pit site would be the Berkeley Pit at Butte, Montana, approximately 350 miles southeast.

Moving the tailings out of the drainage will reduce both the chemical and physical impacts associated with these wastes. The metal load from the adit will continue to impact Blue Joe Creek, as will the tailings mixed with stream sediments downstream of the mine site. Removal of the tailings pile, a primary sediment source, will reduce the sediment load of the creek. Much of the remaining tailings-rich stream sediments will be flushed from the basin over a number of years through the action of peak flow discharge events. Improvements in water quality and channel stability in the lower stream reaches should be gradual. Immediate aesthetic improvements will be noticed at the mine site by the removal of the tailings pile.

Gaillot (1979) states that it is highly unlikely that any mine would be willing or able to accept wastes from another mine. The cost to load, transport and dispose of the tailings in this manner would be very high. Severe road impacts from heavy truck traffic are likely. Legal complications may arise from high traffic volume near a wildlife management area, and transportation of chemically toxic mineral wastes.

Placement of Tailings into the Underground Workings

The tailings can be placed into the underground workings, eliminating their exposure to surficial processes. This option would require piping the tailings in dry or slurry form into the lowermost adit (no. 5 tunnel), or the no. 4 tunnel approximately 300 feet higher in elevation. A pipeline would have to be built and equipped with large enough pumps to overcome the effects of distance and head differential. If the tailings are piped into the no. 5 tunnel, seals would be required at the portal to prevent the tailings from being transported back out the adit by mine discharge.

Physical sedimentation problems from the unprotected tailings pile would be reduced by this option, assuming the lower adit is sealed. The overall effect on chemical leaching is not known. Sealing the lowermost adit would raise the water level in the mine, saturating the emplaced tailings. As the pressure head increased, dispersed seepage from natural flow conduits such as joints, faults and fracture zones would be expected. The combined metal load from these sources may equal or exceed the current adit metal load entering Blue Joe Creek. Placing the tailings into the underground would remove them from sight, and improve the visual aesthetics of the upper watershed.

For safety reasons the underground workings may require retimbering and clearing of undesirable debris before a pipeline could be installed. The structural soundness of the underground is not known. Localized caving may have occurred because of age and lack of maintenance. The occurrence of a high intensity rainfall event during the emplacement process could induce a large flux of sediment into the creek from the underground workings. Similarly, a failed seal could produce a catastrophic outpouring of sediment and water from the adit into Blue Joe Creek. The environmental repercussions from a failed seal may rival the impacts from the original failure of the tailings pond. Sealing the portal would prevent any reopening of lower mine levels.

The economic costs of implementing this option would be high. The major expenditures would include the necessary materials, equipment, labor costs, and consulting fees for a mining engineer.

Construction of a New On-Site Impoundment

The tailings could be placed into a new surface impoundment somewhere on the mine property. The impoundment should be designed to eliminate erosion, limit surface infiltration, and minimize seepage and leakage. The bottom and sides of the impoundment could be lined with a low permeability material such as clay, to reduce leakage and seepage. The outside of the embankments could be protected from erosion with coarse grade rip-rap. Once the tailings are in place, they could be covered with a clay layer to reduce surface infiltration. To minimize the potential for erosion, the impoundment should be located on fairly level ground away from larger tributaries and rivulets. Impoundment of 40,000 cubic yards of tailings to a depth of 12 feet, for example, would require an area of just over two acres.

Placement of the tailings into a new impoundment is expected to reduce both the sedimentation and the chemical problems currently contributed from the mine site. Erosion of unstable tailings would be minimized by proper design and maintenance. Provisions made to reduce the volume of water moving through the tailings would reduce associated chemical impacts. A two-acre impoundment would not enhance the visual aspect of the upper watershed, but would be an improvement over the current situation.

Construction of a new impoundment affords the opportunity of designing the facility from the ground up. The engineering, equipment, labor and material costs for building a new impoundment facility would be high. The lack of adequate level ground may complicate the engineering design. Routine maintenance would be required to preserve the integrity of the structure.

Placement of Tailings into Surface Workings

Depressions left near the drainage divide by surface mining activities could be utilized for impoundment of at least a portion of the tailings. A linear trench approximately 600 feet long, 60 feet wide and 15 feet deep could be made available for tailings disposal with excavation of some of the rip-rap grade rock in the workings. A facility with these dimensions has a storage volume of 20,000 cubic yards, or roughly half the current estimated volume of tailings on site. The tailings could be transported by truck or pipeline. The lower end of the trench may require some barricading with medium grade waste rock and rip-rap to prevent erosion and downslope movement of the fine tailings. The excavated rip-rap material could be placed over the top of the tailings to minimize surface exposure and improve physical stabilization. Revegetation also is a possibility.

Placing a portion of the tailings in the surface workings may be an efficient and cost effective method of reducing some of the stream sediment impacts from these materials. Surrounded on two sides by bedrock, barricaded on the downhill end, and stabilized at the surface, the tailings could be made relatively safe from surface erosion. Effects on chemical leaching are not as well defined. Moving the tailings to the surface workings may increase the lixiviation of metals from these wastes. The surface workings are directly interconnected to the subsurface workings. Water which percolates through the tailings probably would discharge from the lowermost adit. The metal load from the adit may increase. Aesthetic conditions at the tailings pile should improve with the removal of a portion of the wastes. Reclamation activities still would be required for the tailings not placed into the surface workings trench.

Implementation of this option would require fairly little in the way of engineering design or materials. The largest expenditures would be equipment and labor costs such as the operation of dump trucks, excavators and bulldozers. No legal complications are foreseen.

Regrading, Stabilizing and Channel Reconstruction

The tailings pile could be regraded, followed by physical, chemical and/or vegetative stabilization. These activities would need to be coupled with stream channel and adit channel restoration work. The tailings would require regrading to reduce slope gradients and minimize surface ponding. Erosion and sloughing could be expected on oversteepened slopes; depressions and flat areas should be eliminated to reduce chemical leaching and infiltration to the tailings. Regraded slopes should be protected from erosion by appropriate short-term and long-term stabilization methods. Chemical and/or physical means could be required in the short-term to stabilize the newly regraded tailings if long-term vegetative stabilization is desired. Visual aesthetics could be enhanced greatly with the establishment of a vegetative cover.

Effects of stabilization on chemical water quality would be less certain. Stabilization practices which minimized the contact between oxidized tailings and surface waters (i.e. overland and gully flow), could reduce surface leaching of metals from the mineral wastes. Dissolved metal contributions from sulfide-rich dust particles in the snowpack, or uptake of metal ions into the snowpack at the snow/ground interface may be minimized where the tailings surface is covered with rock, mulch or vegetation. Establishment of a vegetative cover on the tailings may increase evapotranspiration and decrease the volume of ground water discharge. Reducing the volume of ground water discharge from the tailings could reduce the metal load going to the creek from this source. Stream quality could be improved locally.

The long-term stability of the tailings at the Continental Mine is influenced greatly by the character of flow in upper Blue Joe Creek and the channel below the discharging adit. Restoration in upper Blue Joe Creek needs to focus on two primary problem areas: the diversion channel and the stream channel through the tailings. Blue Joe Creek should be directed back into its original channel instead of being routed into the diversion channel. Breaches along the upper third of the diversion channel promote tailings erosion and localized saturation. The upper two thirds of the channel should be filled in or blocked off to help minimize tailings erosion and the potential for increased chemical leaching. The lower third or so of the diversion channel is part of a natural drainage channel. This portion should be preserved to route discharge from the east side of the drainage to Blue Joe Creek.

The channel of Blue Joe Creek cuts directly through the tailings pile, resulting in steep, unstable stream banks which are susceptable to erosion and sloughing. The condition of the channel can be improved by: (1) removing excess debris from the channel, (2) reducing bank slopes by regrading, (3) reconstructing the channel with a more hydraulically stable streambed configuration, (4) stabilizing the channel banks with rip-rap, and (5) installing appropriate energy dissipation devices. Reconstruction of Blue Joe Creek in this manner would be most effective at reducing physical sedimentation impacts to the creek. The effect on chemical leaching is less direct. Dissolved metals are known to enter the creek from tailings-rich stream sediments downstream from the mine. Channel reconstruction which reduces the sediment load also would be expected to reduce downstream leaching problems over time. Debris removal and bank stabilization should improve noticably the visual aesthetics of the upper watershed.

The channel which routes discharge from the mine adit may be responsible for localized tailings saturation and erosion problems, based on visual observations of high suspended sediment at MD3, and high ground water levels in the southwest end of the tailings pile. The potential for stream quality impacts could be reduced somewhat by constructing a new channel between the adit and the creek. The channel should be designed to accomodate annual peak flow from a combination of snowmelt, rainfall and adit discharge. A discharge high of 2.7 cfs was measured near the confluence in June, 1985. The return period of this discharge event is unknown.

For safety purposes some sort of barrier should be constructed at the portal which prevents entrance to the underground, but permits drainage to occur. Backfilling with large diameter waste rock could accomplish this goal. Large waste rock is available within the open pit surface workings, and could be used for blocking both the no. 4 and 5 tunnels, and for rip-rapping channels and unstable banks.

The cost of regrading and stabilizing the tailings and reconstructing the channels will depend primarily upon the availability of equipment and manpower. Material and engineering costs should be relatively small. Stream channel work should be conducted during summer low flow periods to reduce sediment impacts.

Maintain Current Conditions

Left as is, the mine site will remain a primary contributor of sediment and dissolved metals to Blue Joe Creek for many decades. Eventually the tailings pile will be reduced by erosion and mass failure. Native vegetation gradually may encroach upon areas where the original soil layer is exposed. The metal load into Blue Joe Creek from the mine adit is not expected to change over time. Physical sedimentation impacts to the entire watershed will continue to occur as long as the tailings are present at the mine site or are intermixed with stream sediments downstream of the mine. Chemical water quality impacts are expected to decrease in the upper watershed as less tailings are available for leaching. A portion of the tailings eroded from the mine site will be deposited as sediment throughout the stream channel, prolonging the channel instability and metals contamination of lower stream reaches.

Exercising this option is by far the least expensive in terms of short-term economic costs. Aesthetic conditions are expected to improve gradually as vegetation slowly takes hold. The legality of this option is not certain. Failure to initiate some form of remedial action may violate state and federal regulations and acts designed to address the environmental consequences of mining activities.

CHAPTER VII

CONCLUSIONS

Chemical leaching and physical sedimentation impacts on Blue Joe Creek watershed are created from mill tailings at the mine site, discharge from the underground workings and tailings-enriched sediments below the mine site. The specific conclusions of this report are presented below.

1. Estimates of original and remaining tailings at the Continental Mine suggest that 40 to 60 percent of the tailings have been removed from the mine site by erosional processes. An undetermined amount of these tailings remain within Blue Joe Creek watershed intermixed with stream sediments downstream of the mine site.

2. Ground water discharge from the base of the tailings along Blue Joe Creek contains maximum concentrations of 59 mg/L zinc, 11.8 mg/L lead and 0.72 mg/L cadmium. Consistently higher dissolved metal concentrations were measured on the east side of the creek.

3. Dissolved metal contributions to Blue Joe Creek from the mine adit are highest during the spring and lowest during mid-summer. The zinc and cadmium load issued from the adit during spring high flow can account for over 50 percent of the total dissolved metal load measured 5 miles downstream of the mine site.

4. The concentration of dissolved metals in Blue Joe Creek tends to peak near the downstream end of the tailings pile during both low and high flow periods. Maximum dissolved metal concentrations of 1.2 mg/L zinc, 0.47 mg/L lead and 0.03 mg/L cadmium were measured during low flow periods.

5. The dissolved metal load in Blue Joe Creek increases from 20-90 percent between the downstream end of the tailings pile and the lower reaches of the drainage, depending upon the season and constituent. Tailings-enriched stream sediments are believed to be the source of metals brought into solution downstream of the mine site. In lower Blue Joe Creek, the dissolved metal load during spring high flow was measured as high as 25,000 grams/day zinc, 34,000 grams/day lead and 340 grams/day cadmium.

6. Reclamation alternatives are proposed which try to address the problems of chemical leaching and physical sedimentation from erosion. Alternative proposals for the Continental Mine include:

   (1) removal of tailings from the drainage for reimpoundment.

   (2) placement of the tailings into the underground workings.

   (3) placement of the tailings into a new on-site impoundment.

   (4) placement of the tailings into the surface workings.

   (5) regrading and restabilizing the tailings in combination with channel reconstruction.

   (6) leaving the tailings as they are.

The fifth alternative is favored from a consideration of relative costs, anticipated reduction in chemical and physical impacts, aesthetic improvements and legal complications.

RECOMMENDATIONS

Some additional considerations pertaining to the Continental Mine and the proposed reclamation work are presented below:

1. A study of the distribution of tailings in stream sediments below the mine site should be conducted prior to, or in consort with any reclamation work at the mine site. Reconnaissance sampling in Blue Joe Creek every half mile or so below the mine for dissolved zinc, lead and cadmium would help isolate primary metal source areas. Discrete stream reaches which are found to contribute the greatest amount of dissolved metals to the stream could be evaluated for their reclamation potential. Studies also should be undertaken to evaluate the downstream impacts from sediment and dissolved metals on Boundary Creek. Cooperation with Canadian agencies may be necessary to orchestrate such a study.

2. Post-reclamation water sampling in Blue Joe Creek should be implemented periodically to help evaluate any changes in water quality. Provisions should be made for long-term maintenance of reclaimed areas to preserve and upgrade the effectiveness of the original reclamation efforts.

3. Biological survey data on macroinvertebrate diversity and abundance should be collected before reclamation, and periodically thereafter. This analysis, coupled with the water quality data, should help better define the effectiveness of reclamation work.

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APPENDIX A. SELECTED HISTORICAL WATER QUALITY DATA

Water Quality Data for Blue Joe Creek from Gerhardt (1981)

Ion concentrations expressed as total rather than dissolved metals
'*' denotes value at or below detection limit
'.' denotes missing data
All samples below detection limits for As (0.01 mg/L) and Cr (0.05 mg/L)
Sample sites are listed below as the inferred equivalents to the current study's site designations

Site	Date	Cd (µg/L)	Cu (µg/L)	Fe (µg/L)	Pb (µg/L)	Zn (µg/L)	Alk (mg/L)	Hard (mg/L)	EC (µ mhos/cm)	pH	Flow (cfs)	Sus.Sed. (mg/L)	Turbid (JTU)
BJ5	5-15-80	*	*	20	*	24	18	8	16	7.0	3.5	3.75	0.40
	8-21-80	*	*	20	*	2	8	10	23	7.3	0.1	1.34	0.30
BJ7	5-15-80	14	30	840	1185	682	8	14	45	6.8	3.3	40.18	2.50
	8-21-80	24	10	20	870	1626	14	38	100	7.0	0.3	1.09	0.25
BJ8	5-15-80	*	*	660	390	79	4	10	19	6.8	146.	6.77	0.60
	8-20-80	*	*	30	80	173	18	20	48	7.1	7.9	3.85	0.20
MA1	5-15-80	42	140	60	920	3575	.	.	.	.	.	.	.
	8-21-80	13	*	10	70	808	.	.	.	.	.	.	.

Ranges in Water Quality Data for Selected Drainages, Smith Creek Planning Unit, USFS (1976)

Sampling sites assumed to be the mouths of Blue Joe and Grass Creeks and in Boundary Creek above confluence with Blue Joe Creek.

Site	Alk (mg/L)	Nitrate (mg/L)	Tot. P (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Iron (mg/L)	Flow (cfs)	Sus. Sed. (mg/L)	TDS (mg/L)
Blue Joe	10 - 20	.03 - .09	.03 - .13	.83 - 1.1	2.0 - 5.0	.04 - .45	7 - 300	8 - 91	10 - 24
Upper Boundary	15 - 31	.02 - .04	.01 - .15	.83 - 1.3	4.0 - 5.0	.02 - .31	12 - 600	4 - 62	20 - 35
Grass	8 - 10	.02 - .06	.02 - .13	.83 - 1.5	-----	0 - .18	10 - 490	11 - 20	6 - 9

APPENDIX B

SAMPLE SITE DESCRIPTIONS

BJ1 - approximately 90' upstream from diversion channel mouth
BJ2 - 150' S 60° E of SE corner of cabin
BJ3 - 240' due east from south corner of "garage"
BJ4 - 50' upstream of confluence between adit discharge and creek
BJ5 - intake side of culverted mine road crossing (USFS Route 2546)
BJ6 - 400' upstream of BJ5 in SE fork of headwaters
BJ7 - 200' downstream of NE end of tailings pile
BJ8 - at lower bridge crossing of USFS Route 2546
MA1 - lowermost adit (no. 5 tunnel) 250' west of shaker building
MA2 - adit about 1000' N 40° E of cabin along logging/mining road
MD1 - seep near junction of mine roads, approx. 300' SW of shaker bldg.
MD2 - small intermittent tributary approx. 75' SW of BJ5
MD3 - at mouth of mine adit discharge with Blue Joe Creek
MD4 - tailing seep 25' due west of BJ3
MD5 - tailing seep in gully 125' due south of BJ3
MD6 - tributary/surface channel 80' S 10° E of BJ1
MD7 - tributary at junction with mine road approx. 300' N 30° E of cabin
MD8 - in diversion channel 200' S 20° E of BJ1
MD9 - tailing seep in large gully 100' S 35° E of SE corner of cabin
MD10 - surface flow from deep narrow gully 70' S 40° W of BJ1
MD11 - surface flow from gully along creek, 200' S 15° E of cabin
MD12 - surface flow from gully along creek, 250' S 10° E of cabin
MD13 - intermittent tailings seeps 100' SE of cabin
MD14 - surface flow from small gully 60' S 20° W of BJ3
MD15 - discharge from wooden pipe below pond, 65' S 50° W of BJ3
MD16 - surface flow/tailing seepage from gully, 60' S 20° E of BJ3
PZ1 - auger drilled piezometer 235' due south of SE corner of cabin
PZ2 - " " " 50' S 55° E of BJ3
PZ3 - " " " 120' S 50° W of BJ1
H1 - shallow piezometer on east bank of creek, directly across from BJ3
H2 - " " " west " " " , 10' SE of MD11
H3 - " " " " " " " , 90' upstream of BJ2
H4 - " " " east " " " , 50' " " "
H5 - " " " west " " " , directly across from BJ2
H6 - " " " " " " " , 75' downstream from BJ2
H7 - " " " " " " " , 125' " " "
H8 - " " " east " " " , 170' " " "
H9 - " " " NW " " " , 150' upstream of BJ1
H10 - " " " NW " " " , 50' " " "
H11 - " " " SE " " " , 30' " " "

APPENDIX C

PIEZOMETER CONSTRUCTION DETAILS AND DRILL LOGS

BOREHOLE CONSTRUCTION AND MATERIALS:

Three piezometers were installed in the tailings pile at the Continental Mine in October of 1984. A portable auger-type Mobile Drill with three foot flights was used to drill a vertical four inch diameter hole in the tailings. The piezometers were constructed with one inch polyvinyl chloride (PVC) pipe, capped on the bottom. The lowermost foot was slotted with a hack saw and then covered with fiberglass screening to help minimize the movement of fines into the pipe. The annulus around the slotted interval was filled with pre-washed pea gravel to promote higher hydraulic conductivities near the slotted interval and minimize the movement of fines into the pipe. A foot of bentonite clay was added on top of the pea gravel to help seal the perforated interval from downward migration of water from upper levels. Drill cuttings then were added to fill the remaining annular space, and the top of the piezometer capped.

PIPE LENGTHS:

PZ1 (13.3 ft.); PZ2 (7 ft.); PZ3 (11.5 ft.)

DRILL LOG DETAILS:

PZ1

0'-3'	tan moderately coarse tailings
3'-4.5'	brownish-grey, clayey-pebbly material
4.5'-6'	brown clayey material, some water
6'-9'	tan to brown pebbly-clayey material
9'-12'	medium greenish brown clay, wet

PZ2

0'-2.3'	fine, layered reddish-brown tailings
2.3'-4.2'	medium greyish-brown clayey tailings
4.2'-4.8'	medium brown clayey tailings, some pebbles, wet

PZ3

0'-3'	fine medium brown tailings
3'-9'	medium grey tailings, somewhat wet
9'-10'	fine brown material with intermixed pebbles, wet

APPENDIX D

ANALYSIS OF METAL AND NUTRIENT UPTAKE BY BARLEY PLANTS GROWN IN THE TAILINGS AND LOCAL SOILS FROM THE CONTINENTAL MINE

Sample	Cd	Cu	Cr	Pb	Ni	As	Zn	Mn	Al	Fe	B	Na	Ca	Mg	K	P	S
TS1	25	10	2.9	260	6.0	0.5	570	230	20	71	28	0.09	0.55	0.46	2.8	0.15	0.66
TS2	28	20	3.3	240	6.6	0.3	1200	450	30	64	40	0.11	0.81	0.46	1.4	0.22	0.94
TS3	66	30	3.5	180	8.0	0.5	2200	160	20	80	21	0.13	0.67	0.38	1.3	0.24	0.92
TS4	18	6	2.6	21	12.0	0.5	290	390	49	90	33	0.14	0.57	0.35	2.9	0.45	0.44

NOTE: first 11 parameters in parts per million; last 6 parameters in percent
Samples analyzed in 7/86 by A&L Agricultural Laboratories, Inc., Omaha, Nebraska
TS1 and TS2 represent intermixed jig and floatation tailings
TS3 represents floatation tailings
TS4 represents sub-tailing soil

APPENDIX E

WATER QUALITY CRITERIA AND BRIEF HYDROCHEMISTRY FOR SELECTED DISSOLVED METALS

Zinc

[Much of the material presented on zinc is taken from U.S. EPA (1980a)].

Zinc is readily transported in most natural waters and is one of the most mobile of the heavy metals. Sphalerite (ZnS) is thought to be the primary zinc source at the Continental Mine. In aqueous solution, zinc always has a valence of +2. The K_{sp} of ZnS is 1.6×10^{-24}. Water quality standards suggest an upper limit of 5 mg/L for domestic supplies. The threshold concentration of total recoverable zinc in freshwater aquatic systems is the value given by:

$$e^{\{0.83[\ln(\text{hardness})]+1.95\}}$$

where hardness as $CaCO_3$ at values of 50 and 100 mg/L corresponds to threshold values of 180 and 320 µg/L, respectively. Copper can act in synergy with zinc, producing toxic effects at sub-threshold levels. Hardness, as a function of the calcium concentration, acts antagonistically toward zinc toxicity.

Zinc forms complexes with a variety of organic and inorganic ligands. Generally the complexes display fairly high solubilities, and are not important below pH 7 (Baes and Mesmer, 1976). Most zinc introduced into the aquatic environment is partitioned into stream sediments by sorption onto hydrous iron and manganese oxides, clay minerals, and organic materials. Variables affecting zinc mobility include the concentration and composition of suspended and bed sediments, dissolved and particulate iron and manganese concentrations, pH, salinity, concentration of complexing ligands, and zinc concentration.

Dissolved zinc in soil water at levels as low as 1.3 mg/L can be phytotoxic to some plant species by interfering with iron metabolism. Total soil concentrations in the order of 1 percent zinc are limiting to normal plant populations (Williamson et al., 1982).

Lead

Lead is present in the Continental Mine ore as galena, PbS. The solubility product of lead sulfides is low. The mobility of the lead ion is limited in natural systems by adsorption by ferric hydroxide or precipitation as the sulfide or carbonate (U.S. EPA, 1980b). The principal dissolved inorganic form under neutral pH and oxidizing conditions is Pb^{+2}. A threshold level of 0.05 mg/L has been set for domestic water supplies. The threshold concentration of total recoverable lead in freshwater aquatic systems is the value given by:

$$e^{\{1.22[\ln(\text{hardness})]-0.47\}}$$

where hardness as $CaCO_3$ at values of 50 and 100 mg/L corresponds to threshold values of 74 and 170 µg/L, respectively (U.S. EPA, 1980b). The solubility of lead compounds in water increases markedly with decreasing pH. Calcium in solution acts antagonistically toward lead toxicity (Martin and Mills, 1976).

Plants vary widely in their tolerence to lead. The phytotoxicity of lead generally is greater than zinc, but less than copper (Williamson et al., 1982). Total concentrations of 1-2% residual lead are limiting to normal plant populations (Williamson et al., 1982).

Cadmium

Cadmium is believed to be present in the Continental Mine ore as greenockite, CdS, or proxies for zinc in the crystal lattice of sphalerite. The concentration of this element in the tailings is not known. Like the sulfide of lead, CdS is very insoluble. Oxidation of the sulfide can liberate and mobilize cadmium as the divalent cation, Cd^{+2}.

The drinking water standard for cadmium is 0.01 mg/L (U.S. EPA, 1976). The threshold concentration of total recoverable cadmium in freshwater aquatic systems is the value given by:

$$e^{\{1.05[\ln(\text{hardness})]-3.73\}}$$

where hardness as $CaCO_3$ at values of 50 and 100 mg/L corresponds to threshold values of 1.5 and 3.0 µg/L, respectively (U.S. EPA, 1980c). Cadmium acts synergistically with zinc and copper to increase toxicity, whereas calcium acts antagonistically.

Cadmium is relatively mobile in the aquatic environment, and may be transported in solution as hydrated cations, or as organic or inorganic complexes. Cadmium ions exhibit a strong affinity for adsorption to clays, muds, humic and organic materials, and some hydrous oxides. Increases in pH enhance sorption processes which can lead to the accumulation of cadmium in streambed sediments (U.S. EPA, 1980c). Phytotoxicity of sensitive plant species can occur at low concentrations, particularly when in synergy with other elements such as copper (Williamson et al., 1982).