EPA-600/2-77-225
NOVEMBER 1977

Environmental Protection Technology Series

FEASIBILITY OF SILVER-LEAD MINE WASTE MANIPULATION FOR MINE DRAINAGE CONTROL

Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/2-77-225
November 1977

FEASIBILITY OF SILVER-LEAD MINE WASTE MANIPULATION FOR MINE DRAINAGE CONTROL

by

Montana Department of Natural Resources and Conservation
Engineering Bureau
Helena, Montana 59601

Grant No. S802122

Project Officer

John F. Martin
Extraction Technology Branch
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the pollutional impact on our environment and even on our health often requires that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-CI) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report discusses the feasibility and effectiveness of mine dump surface sealing for controlling acid mine drainage. The Block P Mine dump in north central Montana was selected for study. The information contained herein characterizes the study site, the current water quality, and recommendations for control of acid mine drainage. It is intended as a guide for future work, and is the planning document for use by the Montana Department of Natural Resources and Conservation in continuing the demonstration. For further information you may contact the Extraction Technology Branch of the Resource Extraction and Handling Division.

David G. Stephan
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

The purpose of this feasibility study was to examine the acid mine drainage (AMD) problems of the Dry Fork of Belt Creek in Montana and recommend abatement methods. The acidic water emerging from several old mine-tailings piles has not only destroyed the aquatic life in Galena Creek and the Dry Fork of Belt Creek but has ruined the overall aesthetic value of both creeks as well.

Recommendations to reduce the acidic wastes entering Galena Creek include a demonstration project to regrade and seal the surface of the Block P Mine dump and cover it with topsoil to allow revegetation. The bypass pipeline around the Block P Mine dump should be extended to prevent water in Galena Creek from creating seeps in the toe of the dump. Silver and Green Creeks should be rechanneled around the smaller tailings piles to prevent surface runoff from entering the tailings material.

This report was submitted in fulfillment of Grant No. S802122 by the Montana Department of Natural Resources and Conservation under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from March 15, 1973, to March 14, 1975, and work was completed as of September 1, 1976.

CONTENTS

FIGURES

TABLES

ACKNOWLEDGEMENTS

The Department of Natural Resources and Conservation would like to thank the following people for their contribution to the study.

Bondy, Richard L., P.E. — Project Manager
Water Resources Division
Department of Natural Resources and Conservation

Botz, Maxwell K., P.E. — Head of Planning and Surveillance
Department of Health and Environmental Sciences

Brown, Michael R. — Project Coordinator
Water Resources Division
Department of Natural Resources and Conservation

Crowner, Ann W. — Editor
Special Staff
Department of Natural Resources and Conservation

Diebold, Frank — Research Project
Chemistry Department
Montana Bureau of Mines and Geology

Ferris, Orrin A., P.E. — Project Manager
Water Resources Division
Department of Natural Resources and Conservation

Hill, Ronald D. — Project Officer
Resource Extraction & Handling Division
Environmental Protection Agency

Jankowski, Walter A. — Supervisory Water Quality Chemist
Department of Health and Environmental Sciences

Lambert, David W. — Editor
Water Resources Division
Department of Natural Resources and Conservation

Martin, John F. — Project Officer
Extraction Technology Branch
Environmental Protection Agency

McBeath, Melvin F. Water Resources Division Department of Natural Resources and Conservation	Planner and Stream-Gage Operator
McBride, Gwen Monarch, Montana	Weather Station Observer
Siroky, Laurence J. Water Resources Division Department of Natural Resources and Conservation	Project Coordinator
Smith, Robert W. Water Resources Division Department of Natural Resources and Conservation	Project Coordinator
Stevenson, Robert K. Cascade City-County Health Department	Field Investigator and Stream-Gage Operator
Wipperman, Al Department of Fish and Game	Biologist

PART I. INTRODUCTION

Scope

This report presents the feasibility of several methods of abatement for the acid mine drainage (AMD) problem in the Dry Fork of Belt Creek in Judith Basin and Cascade Counties, Montana. A general discussion of the chemistry of AMD and its effect on streams is contained in Appendix G. The specific scope of the investigation is:

1. Review the history of mining and AMD problems in the study area, and evaluate current mine drainage abatement measures being employed there.

2. Assess the jurisdictional framework through which a mine drainage abatement project may be carried out.

3. Inventory local topographical features, hydrology, water quality, social and environmental factors, and other elements influencing the value of AMD demonstration projects in the study area.

4. Discuss the feasibility of potential abatement methods to solve and AMD problem.

5. Recommend a course of action for future abatement of AMD.

Objectives

The major objective of the AMD feasibility study was to determine the influences of the acid mine water on the surface and ground-water systems in the upper Belt Creek drainage areas affected by the acid mine water and to formulate an approach to minimize their adverse effects.

Project Description

The project was divided into the following collection and testing sections:

1. Baseline Data Collection. The initial effort of the study was to establish a monitoring system for

surveillance of water quality in Galena Creek and its tributaries, discharges from springs and seeps, and surface runoff; interpretive graphs of these data are presented in Appendices C and D. Complete water quality data may be obtained from the Montana Department of Natural Resources and Conservation (DNRC). Thirty-two water sampling sites (Appendix B) were established throughout the study area. Water samples taken at the stations established the quality of both surface and ground water throughout the study area. The complete baseline water-quality studies will provide the standards against which the success of future demonstration projects can be measured.

Five stream-gaging stations (Appendix E) were constructed to record flows in Galena Creek above and below the project site, on Silver Creek, at Liberty Mine seep, and at the Block P Mine seep (see Figure 1). Numerous streamflow measurements were made at locations throughout the study area.

A weather station to record daily air temperatures, evaporation pan water temperatures, precipitation, evaporation, and wind velocity was constructed (Appendix F).

2. Diversion Pipeline Installation. A diversion pipeline was installed parallel to Galena Creek to transport the uncontaminated main flow of Galena Creek around the Block P tailing area. By bypassing this area the seepages, which are the major sources of the pollution problem, were isolated. Another major problem, that of having too large a flow to be handled by diversion or other treatment, was also solved by isolating the seepages.

3. Neutralization Testing. The effectiveness of various types of lime and limestone to neutralize the acid waters in Galena Creek was tested. The testing results show which materials are economically feasible to use in abatement of the AMD problem.

4. Dump Sealant Studies. Silicate and limestone kiln dust were studied to determine their effectiveness as surface sealants on the Block P Mine dump.

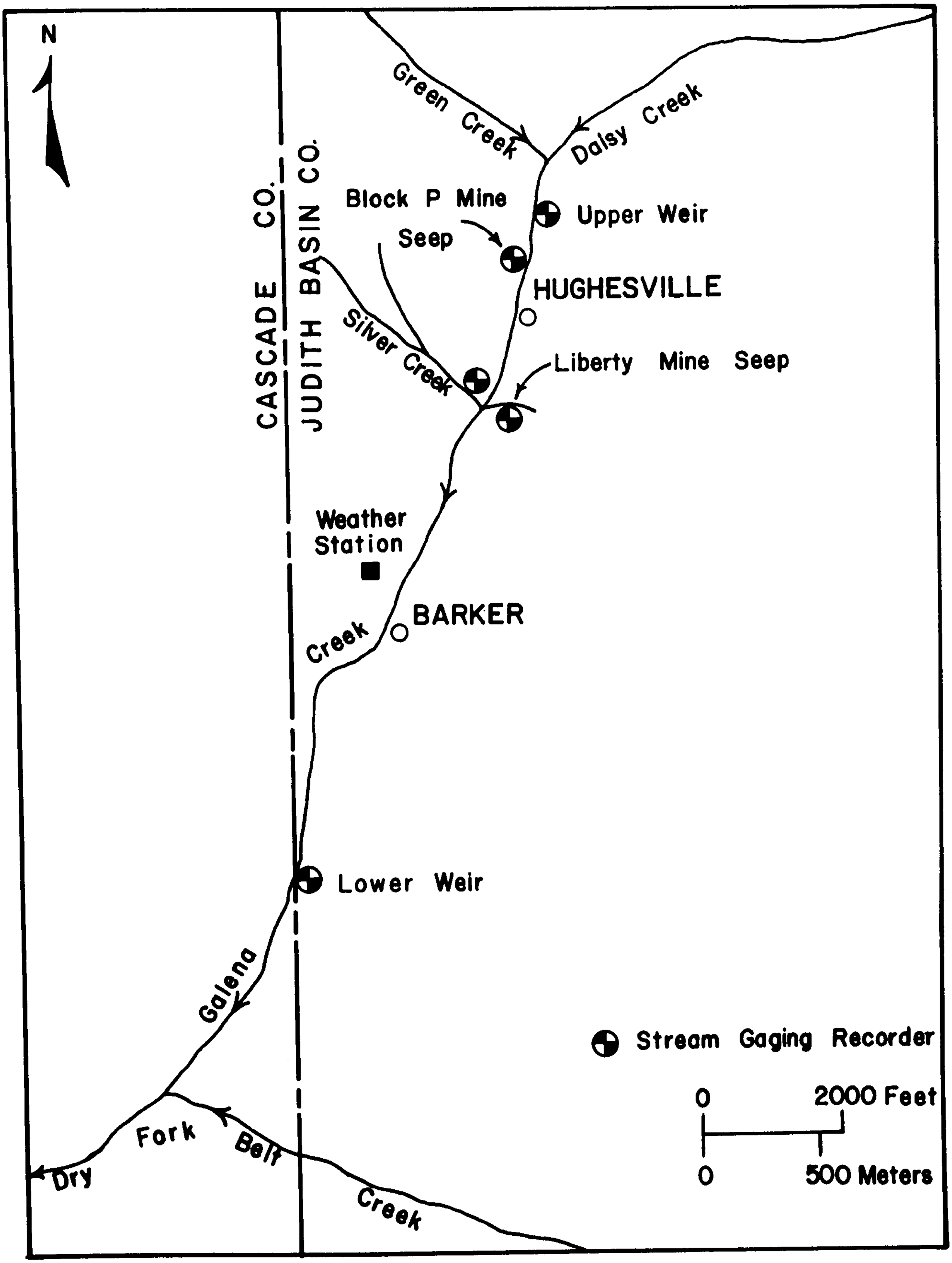

FIGURE 1. Galena Creek Drainage Map.

PART II. CONCLUSIONS AND RECOMMENDATIONS

Water quality in Galena Creek and the Dry Fork of Belt Creek is significantly influenced by AMD from old lead and silver mines. Water quality in this drainage area is extremely poor at the Liberty Mine seep, a spring at the Block P Mine, and a spring in Galena Creek near some abandoned mine cars. The quality is better in the Dry Fork of Belt Creek below Galena Creek and in Galena Creek above the mining area, but the water is still toxic to most aquatic life. Concentration of toxic metals in the streams is not significantly diluted by rainfall or melting snow.

In spring, the spring at the Block P Mine contributes from 20 to over 80 percent of the total metal load in Galena Creek leaving the project area. The spring at the abandoned mine cars in Galena Creek also contributes from 20 to over 60 percent of the total metal load leaving the project area. The total load in Galena Creek immediately below the Block P Mine dump varies from less than 40 to over 100 percent of the total load leaving the project area, which indicates that the Block P Mine dump is a major source of pollutants.

Silver Creek normally contributes a small portion of the total metal load leaving the project area, but at times it contributes in excess of 10 percent of the load. Liberty Mine seep, of poor quality but with low, intermittent flow, contributes a small percentage of the total waste load entering Galena Creek.

Several methods were considered for treatment and abatement of the study area's AMD problem. Surface manipulation of mine-waste dumps and streams in the area, one of the investigated methods, appeared feasible from the points of view of cost, effectiveness, and adaptability to the hostile climate.

Based on pilot tests, limestone neutralization reduced concentrations of iron and copper, raised pH, but did not significantly reduce loads of zinc, manganese, or cadmium in Galena Creek. Cottrell dust (a lime waste from cement plants) was tested for neutralization ability and significantly reduced loads of all metals investigated. A combination of limestone treatment and reaction with Cottrell dust appears to be the most economical alternative for neutralization. Neutralization was not recommended because of the high cost of annual maintenance and poor accessibility to the site in winter months.

Other methods of abatement investigated but not recommended because of high costs were removal of mine-tailings piles, ponding and aeration, evaporation, reverse osmosis, electrodialysis, ion exchange, and freezing.

A three-part AMD demonstration project is recommended for the Galena Creek Drainage in Judith Basin County, Montana. For reducing AMD pollution in Galena Creek, sloping the top of the Block P Mine dump and sealing it with bentonite is recommended. The bypass pipeline should also be extended from its existing inlet to the upper weir to prevent Galena Creek flows from recharging the spring above the Block P Mine dump. Rechanneling of Silver Creek and Green Creek around tailings piles will also reduce the acidic loads entering Galena Creek.

PART III. LEGAL FRAMEWORK

Authority

Montana statutory authority to conduct a feasibility study is found in Section 89-132, Revised Codes of Montana (R.C.M.) 1947. Subsections of that Section, among other things, broadly empower the Montana DNRC:

> (d) To accept from any federal agency grants for and in aid of the carrying out of the purposes of this Act and any Acts of Congress.
>
> ....
>
> (t) To make investigations and surveys of natural resources and of opportunities for their conservation and development and pay the costs of the same either from its own funds or cooperatively with the federal government....

The power of the Board of Natural Resources and Conservation to enter into contracts for studies or investigations with the federal government is clear and has been utilized on numerous occasions for studies on different problem areas.

Site and Mineral Right Acquisition

The Montana DNRC has statutory authority to acquire the necessary sites for project construction. Section 89-104, R.C.M. 1947, provides the power to acquire by purchase, exchange, or condemnation "any land, rights, water rights, easements, franchises, and other property considered necessary for the construction, operation and maintenance of works." Section 89-102, R.C.M. 1947, defines "works" very broadly and includes therein "all means of conserving and distributing water," including those for purposes of "irrigation, flood prevention, drainage, fish and wildlife, recreation...." Therefore, there is no question that the Board of Natural Resources and Conservation has ample authority to acquire such sites as might become necessary for project construction.

PART IV. ENVIRONMENTAL INVENTORY

Cultural Environment

MINING HISTORY

Buck Barker and Pat Hughes first discovered the silver-lead deposits near Barker, Montana, on October 23, 1879. Hundreds of claims were soon located, and a feverish mining activity resulted. Several of the mines became important producers of silver, copper, lead, and zinc. However, mining operations waned with the depletion of the rich, near-surface ore bodies. Lower grade ores, developed from deeper exploration, could not be mined and shipped at a profit. A drop in the market for silver in 1892 forced most of the mines to close. The only large-scale operations undertaken at later dates were developments of the Block "P" Mine between the years 1927 and 1930 and from 1941 to 1943. In recent years only sporadic mining has been conducted; most of the mines have been idle for many years.

CURRENT SOCIAL AND ECONOMIC CONDITIONS

The Dry Fork of Belt Creek drainage is located in Cascade and Judith Basin Counties, Montana, approximately 64 kilometers (km) (40 miles (mi)) southeast of Great Falls, Montana. The project lies in the northeast portion of the Lewis and Clark National Forest, which encompasses most of the Little Belt Mountains. Recreational areas within the national forest include a ski hill at Kings Pass, eight established camping sites, hiking trails, and fishing access sites. In the fall months, the national forest is heavily used by deer and elk hunters.

The drainages of Galena Creek and the Dry Fork of Belt Creek include no year-round residential areas. Hughesville and Barker are old mining towns, which presently have a few cabins occupied only in the summer.

Within the drainage basin of Belt Creek are the communities of Neihart, Monarch, and Belt. Neihart, in the upper drainage of Belt Creek, has a summer population of 170, many of whom live in Neihart only during the summer months for the recreation that the surrounding area offers. Monarch, located on Belt Creek at the mouth of the Dry Fork of Belt Creek, has a population of 160, again, many of whom live in Monarch only during the summer months. The city of Belt, the hub of farming and ranching activities to the north of the Little Belt Mountains, lies in the lower reaches of the Belt Creek drainage and has a population of 650.

The Little Belt Mountains are most heavily used by the people from Great Falls and Cascade County. Recent population trends for Cascade County indicate that the county's 1970 population will increase 32 percent by 1980, bringing the population to 108,000. The 1970 population of Judith Basin County was 2,667; population projections for the county indicate that by 1980 the population will be 2,200, a decline of 18 percent (U.S. Department of Commerce 1970; J. H. Nybo, Lt. Governor's Office, to M. R. Brown, Engineering Bureau, Water Resources Division, DNRC, Helena. Personal Communication, January 15, 1976.).

Considering these population trends, it seems likely that the recreational needs of Cascade County will increase. Since the Little Belt Mountains are the nearest forested recreation area to Great Falls, most of the increased population may rely on this area for fishing, hunting, hiking, and camping. It is possible that there is a need for more recreation areas in the Little Belt Mountains, which includes the Dry Fork of Belt Creek.

Physical Environment

STUDY AREA LOCATION, GENERAL HYDROGRAPHY, AND TOPOGRAPHY

Figure 2 shows the Belt Creek drainage basin. All of the AMD occurs in the Galena Creek watershed, which drains into the Dry Fork of Belt Creek. Galena Creek and the Dry Fork of Belt Creek below Galena Creek do not support aquatic life. The Dry Fork of Belt Creek empties into Belt Creek at the town of Monarch. Acidic waters of the Dry Fork are diluted by the waters of Belt Creek to such an extent that fish can thrive in Belt Creek below the Dry Fork. Belt Creek flows into the Missouri River approximately 16 km (10 mi) northeast of Great Falls.

As illustrated in Figure 3, page 10, the entire watershed of Galena Creek is rugged. Elevations of the Galena Creek Basin range from 1,652 meters (m) (5,420 feet (ft)) at the mouth of Galena Creek to 2,423 m (7,952 ft) at Mixes Baldy Mountain. Most of the watershed is forested with the exception of the lower watershed area near the mouth of Galena Creek.

Figure 4, page 11, is the plan and topographic map of the Galena Creek mine area at Hughesville. The map shows the location of the mines as well as all mine workings and dump areas. The Block P Mine dump is the largest mine-tailings pile in the study area, and is one of the contributors to the AMD problem. The weather station at Barker and the middle reaches of Galena Creek are shown in Figure 5, page 12; Figure 6, page 13, shows the mill tailings pond as well as Galena Creek and its confluence with the Dry Fork of Belt Creek.

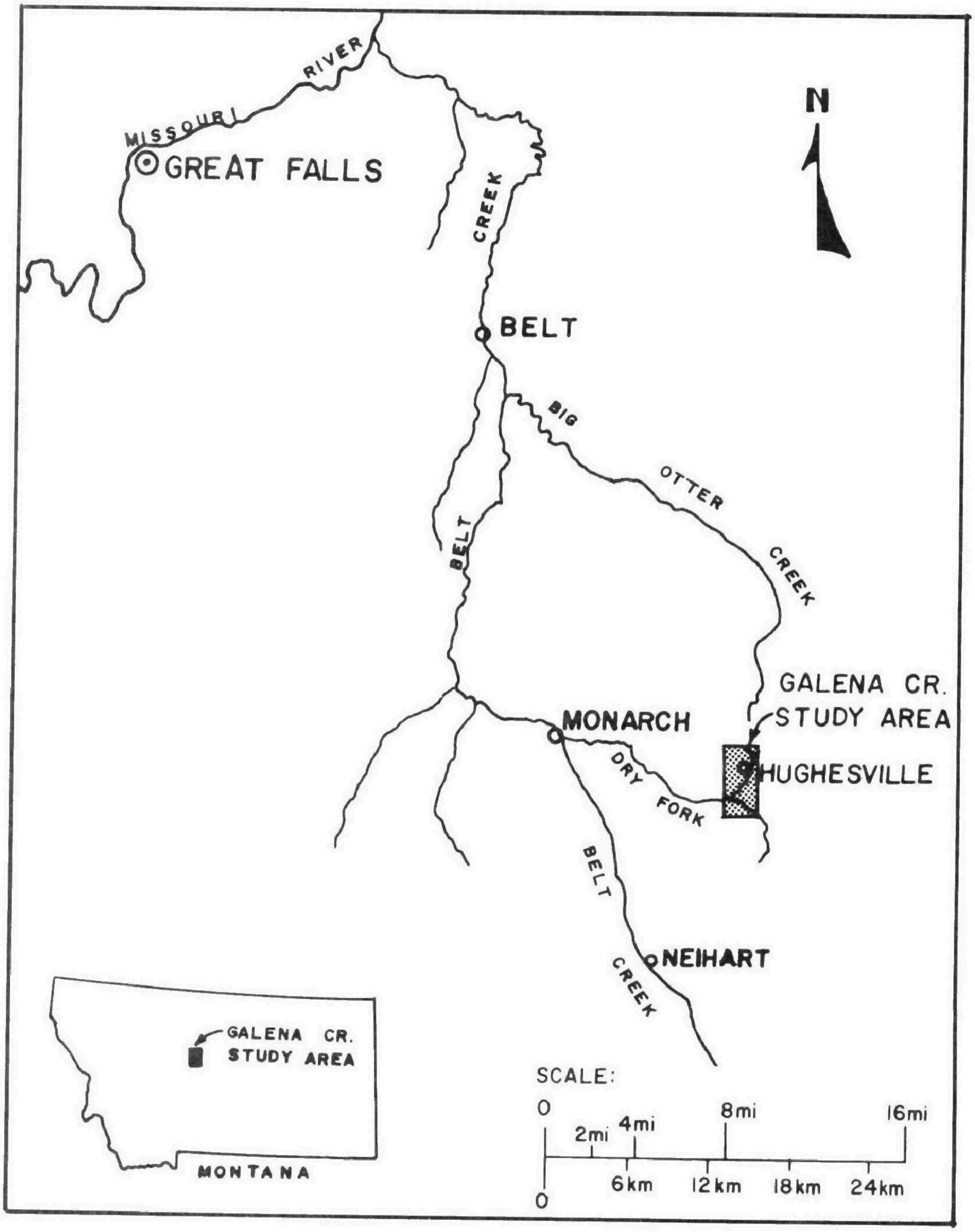

FIGURE 2. Galena Creek Study Area, Location Map.

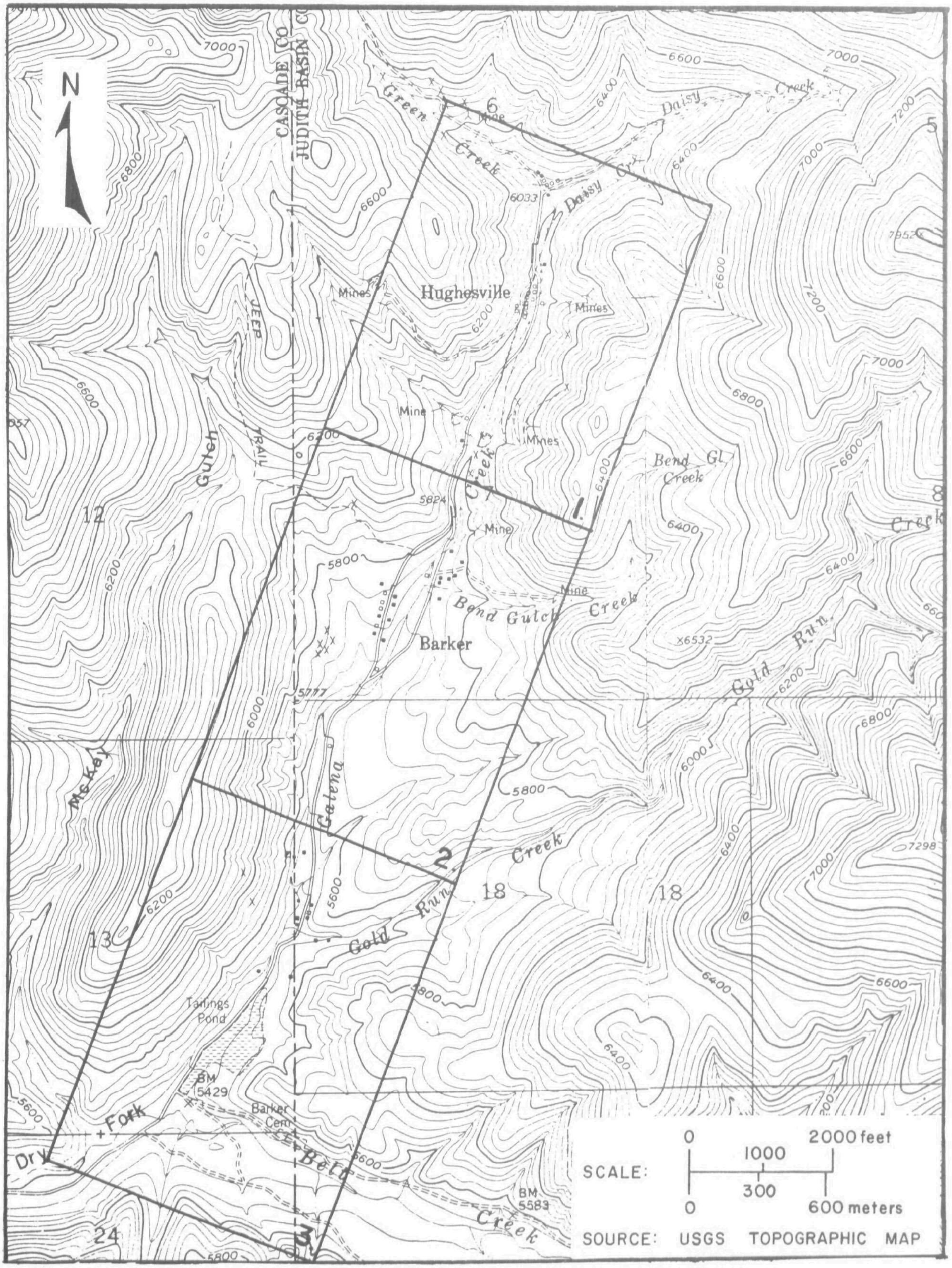

FIGURE 3. Galena Creek Study Area.

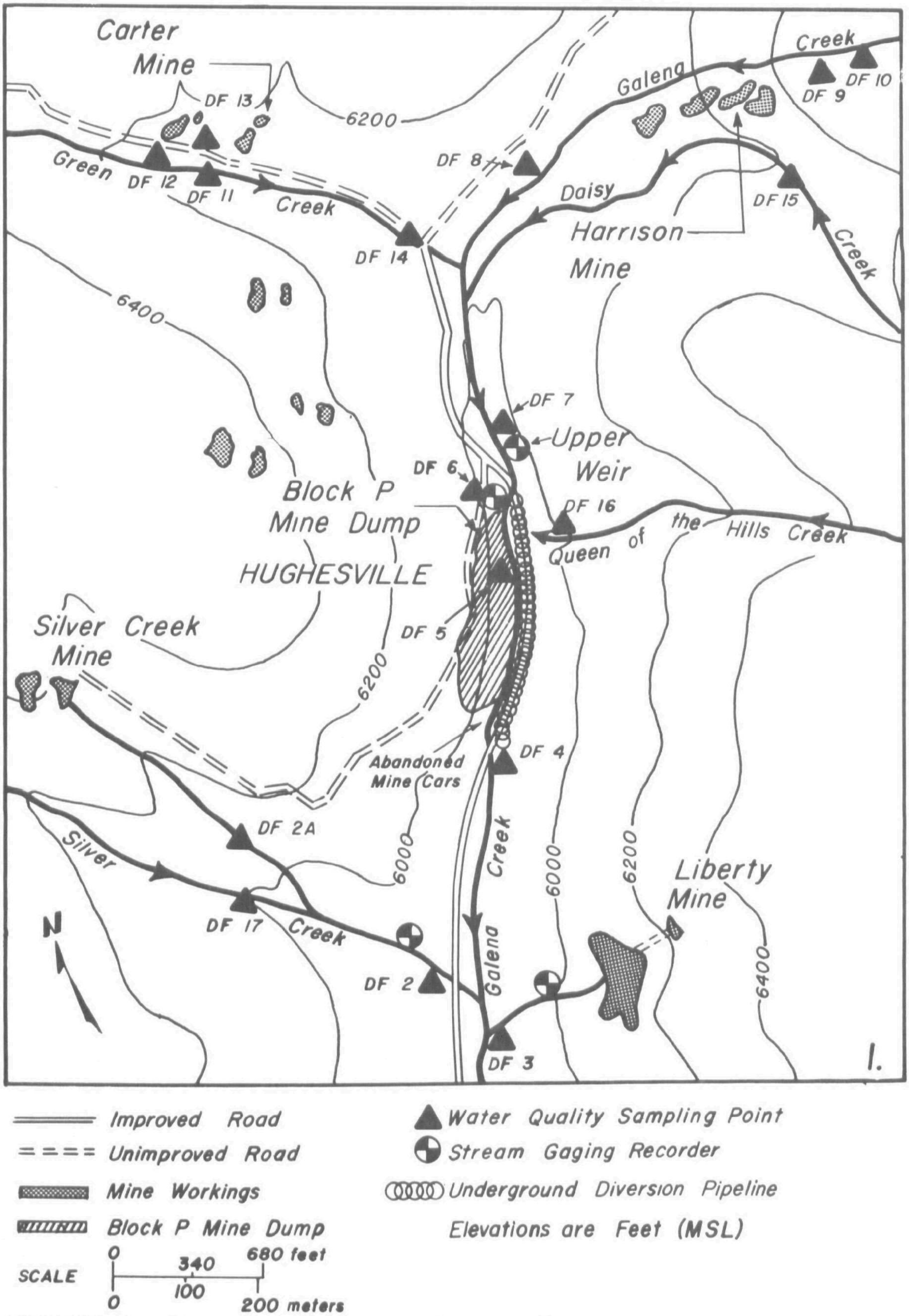

FIGURE 4. Plan and Topographic Map #1, Galena Creek and Block P Mine Dump.

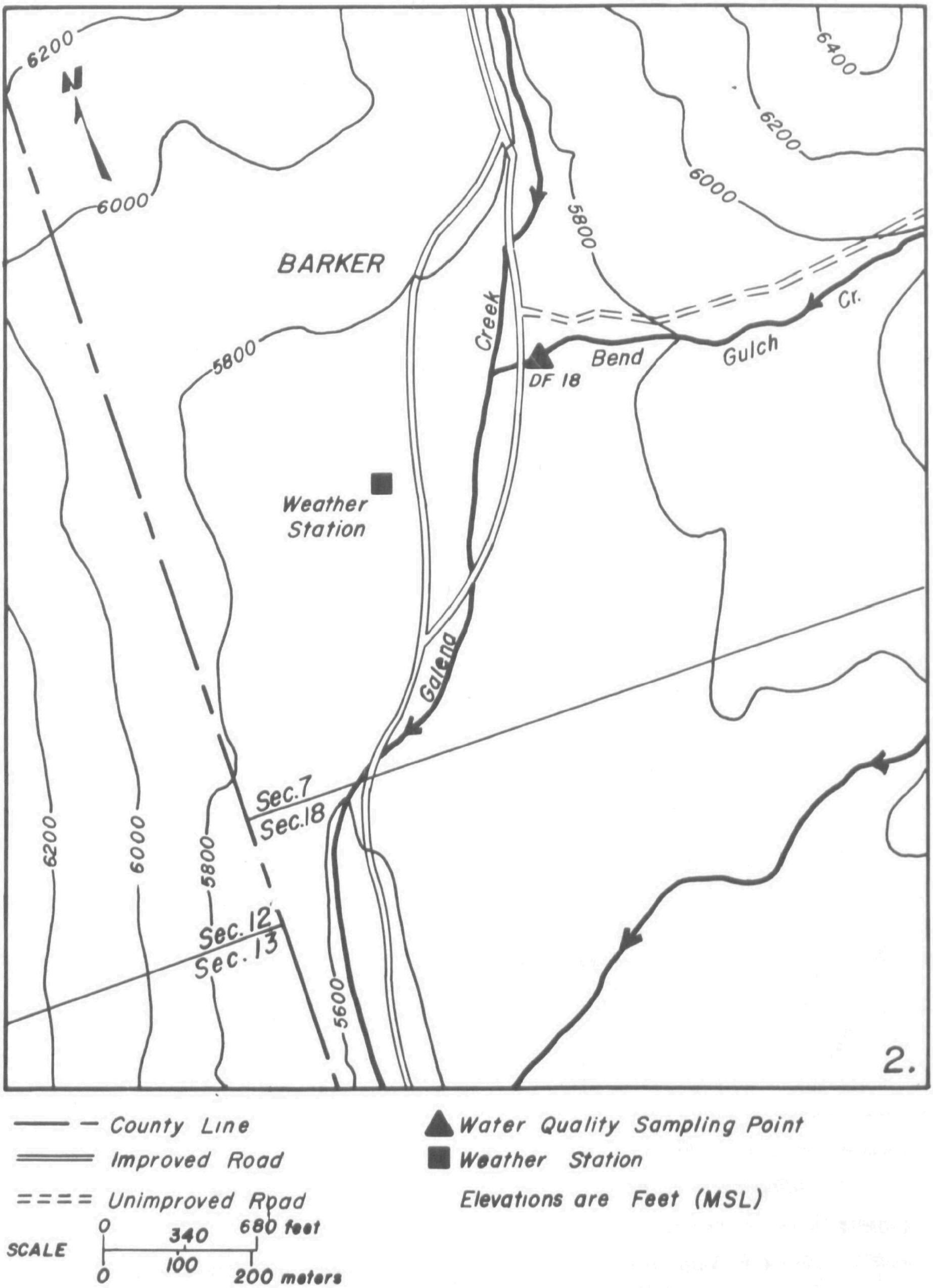

FIGURE 5. Plan and Topographic Map #2, Galena Creek and Weather Station.

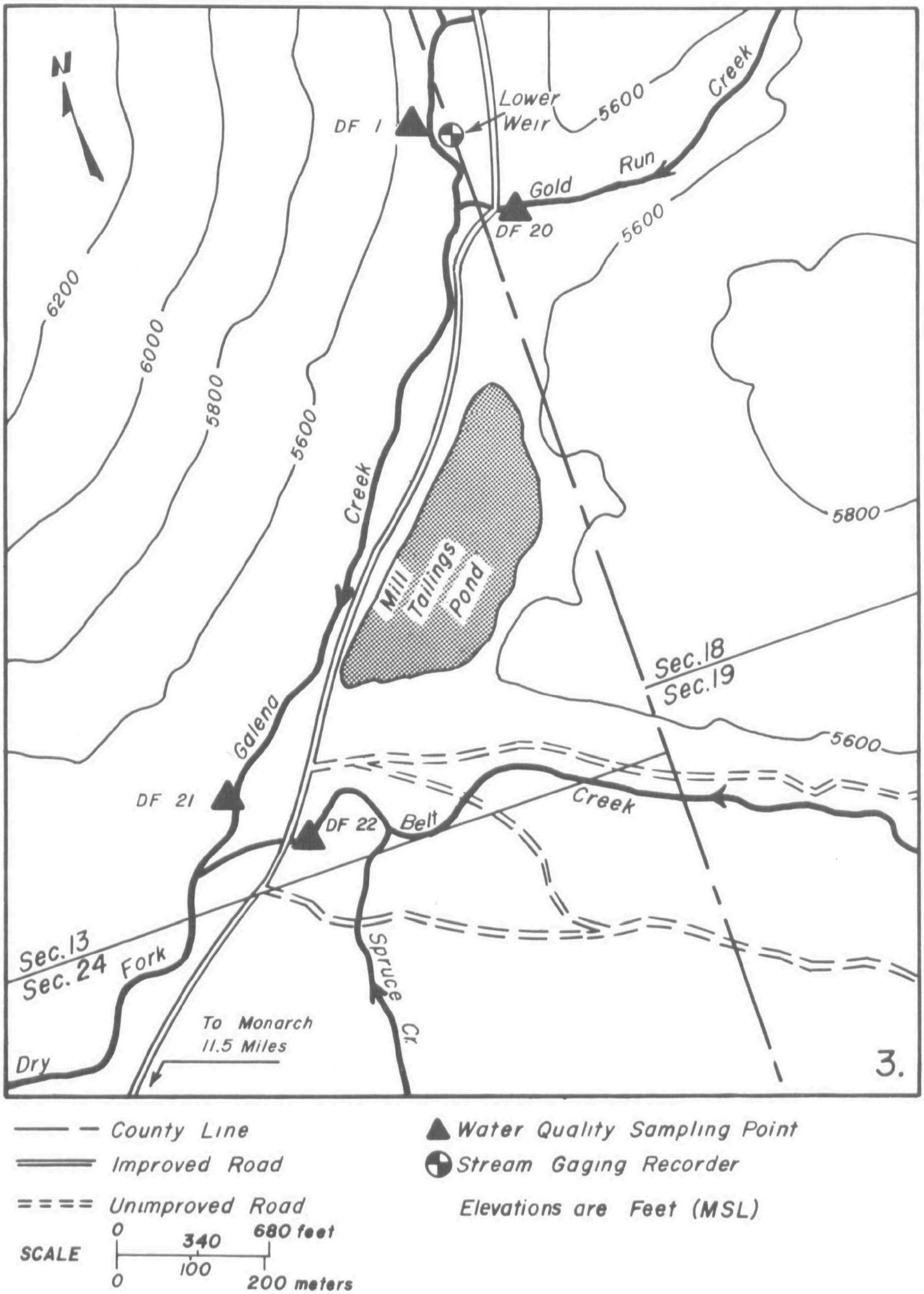

FIGURE 6. Plan and Topographic Map #3, Galena Creek and Lower Weir.

CLIMATE

A weather station was installed at Barker, Montana, to gather weather data for the study. Complete weather information is shown in Appendix F.

The climate has many features associated with the "continental" type. Daytime temperatures in the summer are usually hot, followed by pleasantly cool nights. The hot weather, when it does occur, is never accompanied by high humidity. Daytime high temperatures in July average about 24° C (+75° F).

Arctic air masses usually invade the area from a few to several times each winter. These cold air masses remain only for a few days before being moved aside by warm chinooks. Temperatures at this time of year may vary from a low of -40° C (-40° F) at night to highs of +7° C (+45° F) in midafternoon. In the study area, the chinooks are not usually accompanied by the strong winds that occur in the flatlands to the north and east; however, the warm temperatures prevail.

The study area has considerable sunshine throughout the year, but there are some cloudy days during the May and June wet season, and the clouds and snow generally accompany winter arctic air invasions. Following storms, clearing is rapid; wintertime chinooks are almost always accompanied by clear or nearly clear skies. Summer mornings are almost always clear, sometimes giving way to large (cumulus) cloud types near noon, with scattered thunderstorms from midafternoon to early evening.

Precipitation in the study area averages about 762 millimeters (mm) (30 inches (in)) per year. Average annual snowfall for the study area is 7,620 mm (300 in), with the heavier amounts of snow occurring in the months of January, February, and March. During the months of April and May, heavy wet snow showers occur with some drizzling rains increasing the water content of the snow. The latter part of May and early June is usually the period of highest precipitation, coming in the form of rain. It is during this period that temperatures are warm enough to cause snowmelt. Precipitation throughout the rest of the year (July-December) usually comes from thunderstorms and rain showers, with a few snow flurries occurring in November and December.

Maximum expected rainfall rates, as listed in Table 1, have been published by the National Weather Service of the U.S. Department of Commerce in the 1973 Precipitation-Frequency Atlas of the Western United States (Miller et al.).

TABLE 1. PRECIPITATION-FREQUENCY DATA

Frequency		Precipitation	
Year	Hour	Millimeters	Inches
2	6	33.0	(1.3)
5	6	40.6	(1.6)
10	6	48.3	(1.9)
25	6	58.4	(2.3)
100	6	68.6	(2.7)
2	24	55.9	(2.2)
5	24	71.1	(2.8)
10	24	81.3	(3.2)
25	24	101.6	(4.0)
50	24	104.1	(4.1)
100	24	119.4	(4.7)

Source: U.S. Department of Commerce 1973.

Pan evaporation for the weather station at Barker for the months from June through September averages 360 mm (14 in). However, precipitation for the months from June through September averages about 250 mm (10 in) which yields a net evaporation from any open ponds or dams of 110 mm (4 in).

Severe storm types other than arctic air invasions include high winds, blizzards, and heavy rains, but these are not frequent. Thunderstorms in the summer may produce high winds and hail.

SURFACE WATER RESOURCES

Galena Creek is a perennial stream, getting most of its water in the springtime from snowmelt. During the rest of the year, streamflows come from surfacing ground water and mine seeps. Major tributaries to Galena Creek are Green Creek, Daisy Creek, Silver Creek, and Gold Run Creek, all of which are perennial streams. Queen of the Hills Creek and Bend Gulch Creek only contribute to Galena Creek during spring snowmelt and rain showers.

Quantity

Five stream-gaging stations were established at strategic points in the Galena Creek watershed. Daily flow values were gathered on Galena Creek at Hughesville, the Block P Mine seep at Hughesville, Silver Creek near Hughesville, the Liberty Mine seep near Hughesville, and Galena Creek near Barker above Gold

Run Creek. Daily streamflow records for each of the five stream-gaging stations are listed in Appendix E.

Streamflow data were gathered from August, 1973 to November, 1974. However, data were not gathered during the winter months, November through April, when the low flows occurred. High flows from snowmelt in late May and early June of 1974 washed out the five recording stations, and high streamflow data was not collected. Before the stations were destroyed, Galena Creek at Hughesville recorded a high flow of 223.29 liters per second (lps) (3,539 gallons per minute (gpm)) on April 26, 1974. Galena Creek near Barker recorded 688.18 lps (10,900 gpm) on April 26, 1974. Prior to their washout in the spring, the Block P seep station at Hughesville recorded a maximum flow of 5.07 lps (80 gpm) on June 19, 1974, and the Liberty Mine seep station near Hughesville recorded a high flow of 7.61 lps (120 gpm) on April 26, 1974. Silver Creek station near Hughesville recorded a maximum flow of 32.11 lps (508 gpm) on May 9, 1974.

Quality

Classification According to State Water Quality Standards. The Dry Fork of Belt Creek and its tributaries are classified by Montana Water Quality Standards (1974) as a B-D_1 stream. This classification states in part:

> Water-use description. The quality is to be maintained suitable for drinking, culinary and food processing purposes after adequate treatment equal to coagulation, sedimentation, filtration, disinfection and any additional treatment necessary to remove naturally present impurities; bathing, swimming and recreation; growth and propagation of salmonoid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply....

The Dry Fork of Belt Creek and its tributary, Galena Creek, do not meet Montana's water quality standards due to the impact of AMD. These streams have, therefore, been designated as "water quality limited" by the State of Montana. The complete Montana Water Quality standards are available from the Water Quality Bureau of the Montana Department of Health and Environmental Sciences.

Water Sampling Sites. A total of 32 stations were established in the project area (Appendix B). Of these, 17 stations were sampled quarterly or monthly and the remaining stations sampled once or twice during the project. In addition to sampling at fixed stations, water quality runs were conducted. In this technique, a number of points on the stream were sampled in a short period of time (usually one day). This intensive survey method showed the stream's chemical dynamics as the water moved downstream.

Sampling sites were chosen on the basis of accessibility and strategic location with respect to pollution loads. There were seven major stations, described as follows:

DF 1. Galena Creek at Lower Weir. This station measured all pollutants from the mining area except that some constituents, such as aluminum and iron, precipitated in the stream channel and were gone or partially gone before they reached this station. It was sampled monthly when accessible.

DF 2. Silver Creek at Road. This monthly sampling point was at the main canyon road until a flume was installed 60 m (200 ft) upstream from the road. The creek was then sampled monthly at the flume. Water quality at these two stations was assumed to be identical.

Upstream, Silver Creek splits into two forks--a clean fork and a polluted fork (see Figure 4, page 11). The polluted fork had surface flow during spring runoff, and subsurface flow most of the year. Station DF 2A was established on the polluted fork just above the confluence with the clean fork. Only a few samples were collected at DF 2A.

DF 3. Liberty Mine Seep. A flume located about 30 m (100 ft) up a steep hill on the east side of Galena Creek served as the sampling point. The water sampled at this station flowed from the Liberty Mine tunnel and was augmented by runoff in the gulch between the Liberty Mine and Galena Creek. The station was sampled monthly when accessible.

DF 4. Galena Creek Below the Mine Dump. This station was located in a rocky section just downstream from the end of the Block P Mine dump and about 30 m (100 ft) upstream from the road stream crossing. It was designed to measure the pollution contribution of the Block P Mine complex. The steep stream gradient and rock bottom made flow measurements difficult at this site. During high flows, the stream was very turbulent and difficult to wade and measure. The station was sampled monthly when accessible.

DF 5. Spring Along Galena Creek at Mine Cars. After the spring runoff in 1973, a small spring was observed entering Galena Creek about 30 m (100 ft) upstream from station DF 4. The perennial spring arose from an opening in the rocks on the east creek bank and was normally submerged. Flow was difficult to measure due to its nearness to the stream and submergence during the runoff period. It was sampled monthly when accessible.

DF 6. Spring at Block P Mine. An ephemeral spring was located about 23 m (75 ft) west of Galena Creek and just northwest of the old ore-loading facility. The spring was dry during the late fall and winter and had maximum flow in the spring. It was sampled monthly when accessible.

DF 7. Galena Creek at Upper Weir. The pollution load of the upper portion of Galena Creek was measured at this station. It was sampled when accessible.

These were the seven major sites. Others fell into three categories:

DF 8. to DF 20. Streams sampled in the drainage area to determine the extent of the water pollution problem. Most stations were sampled once; some were sampled several times during the project.

DF 21. to DF 29. Stations on Dry Fork of Belt Creek sampled to determine downstream changes in water quality. Most stations were sampled once during the project; DF 29 was sampled several times.

DF 30. to DF 32. Stations on Belt Creek sampled to determine concentration of pollutants above and below confluence with Dry Fork. Stations were sampled once, except DF 31, which was sampled several times.

Results of Water Sampling. Water quality in Galena Creek has been significantly influenced by AMD from old metal mines. The mechanism for producing acid involves interaction of pyritic minerals, oxygen and water. The acidic water condition produced from the reaction apparently causes other metals to become soluble and enter into the aquatic system. Toxic metals entering the Galena Creek system in this way include cadmium, zinc, iron, manganese, lead, copper, arsenic, and aluminum. Due to their toxicity, abundance, and persistence in the system, zinc, iron, and manganese were selected for detailed evaluation (see Figures 7, 8, and 9).

Table 2 (page 22) shows typical water quality from various

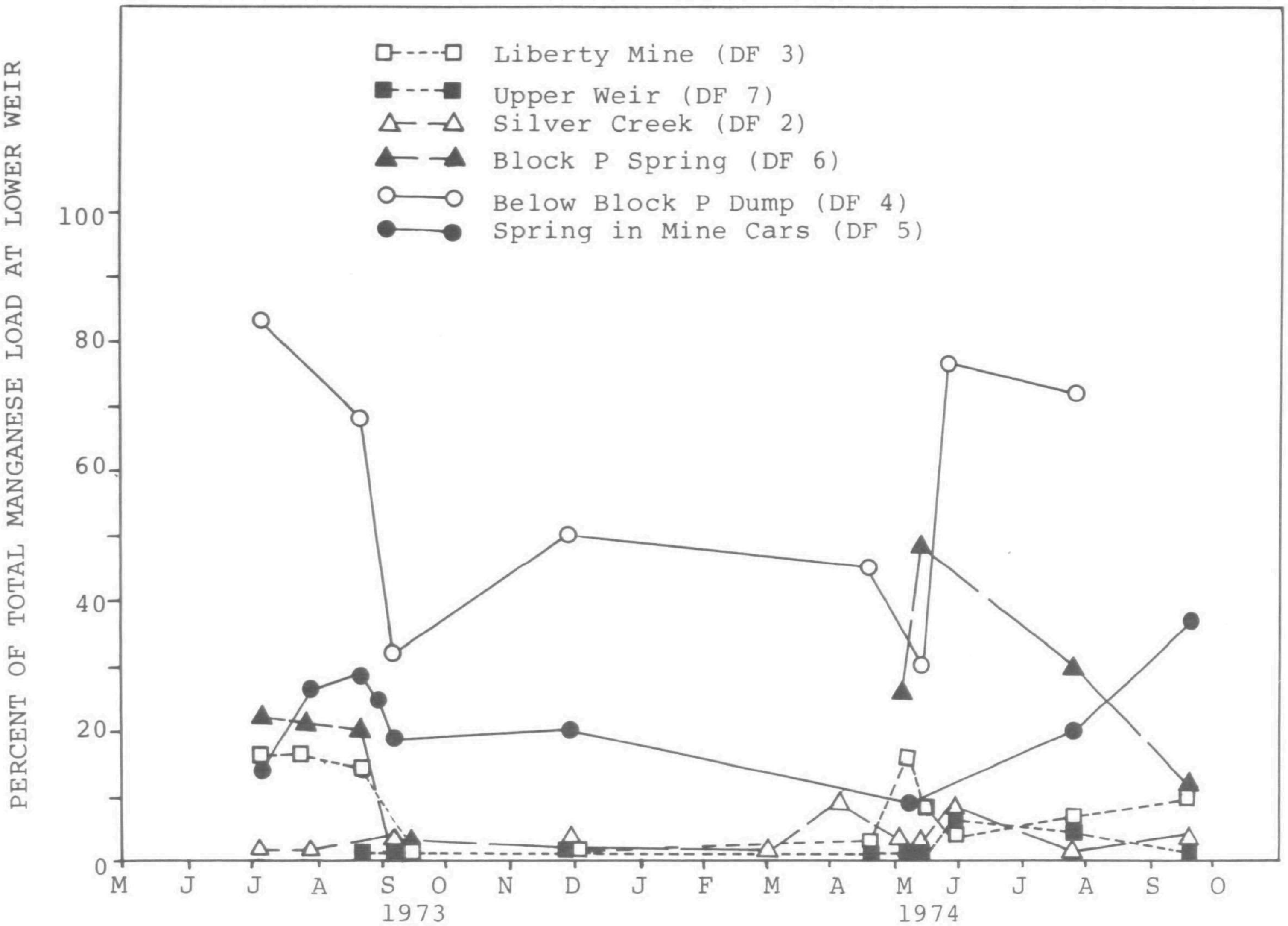

FIGURE 7. Manganese Load from Several Waste Sources Compared to Load at Lower Weir

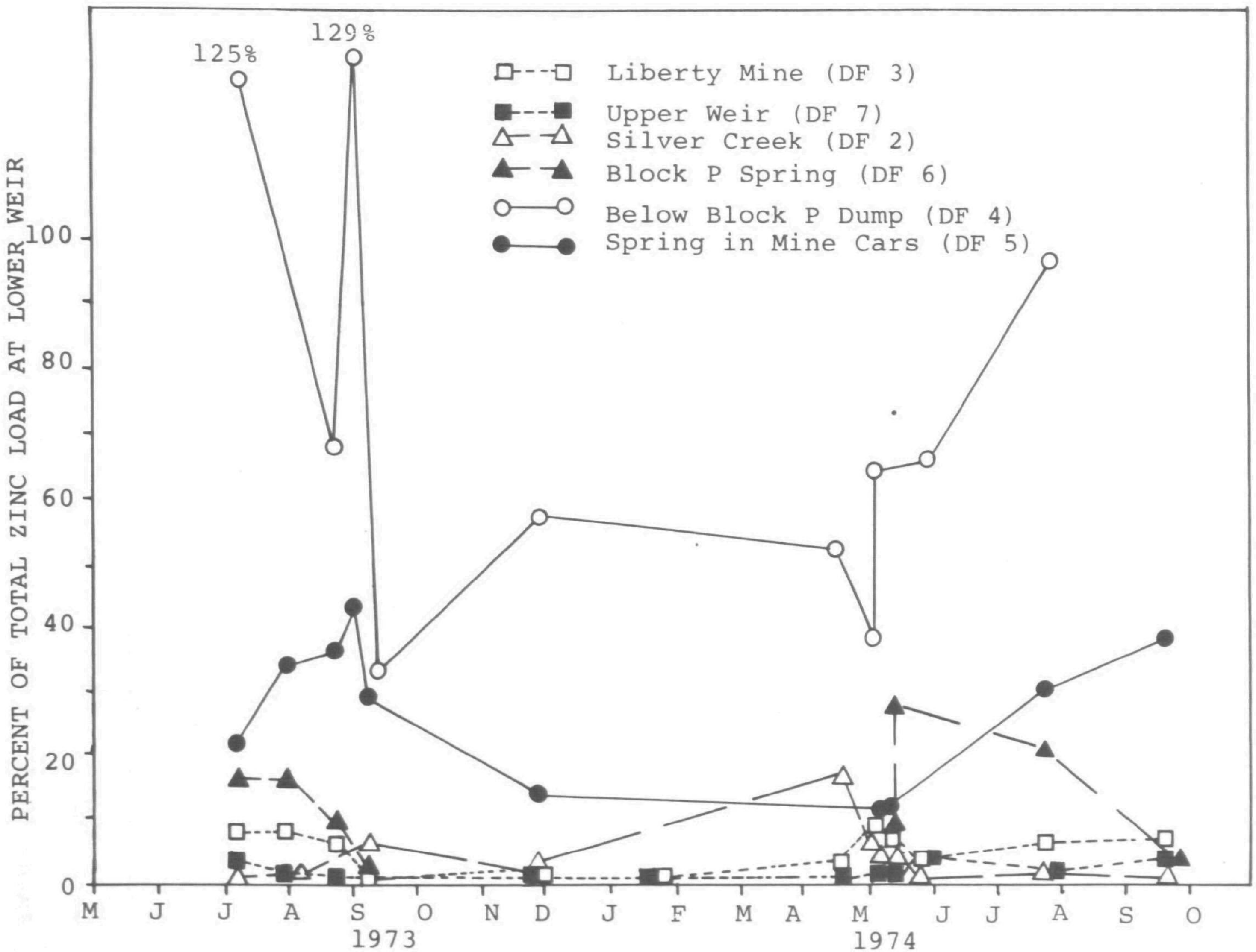

FIGURE 8. Zinc Load from Several Waste Sources Compared to Load at Lower Weir.

21

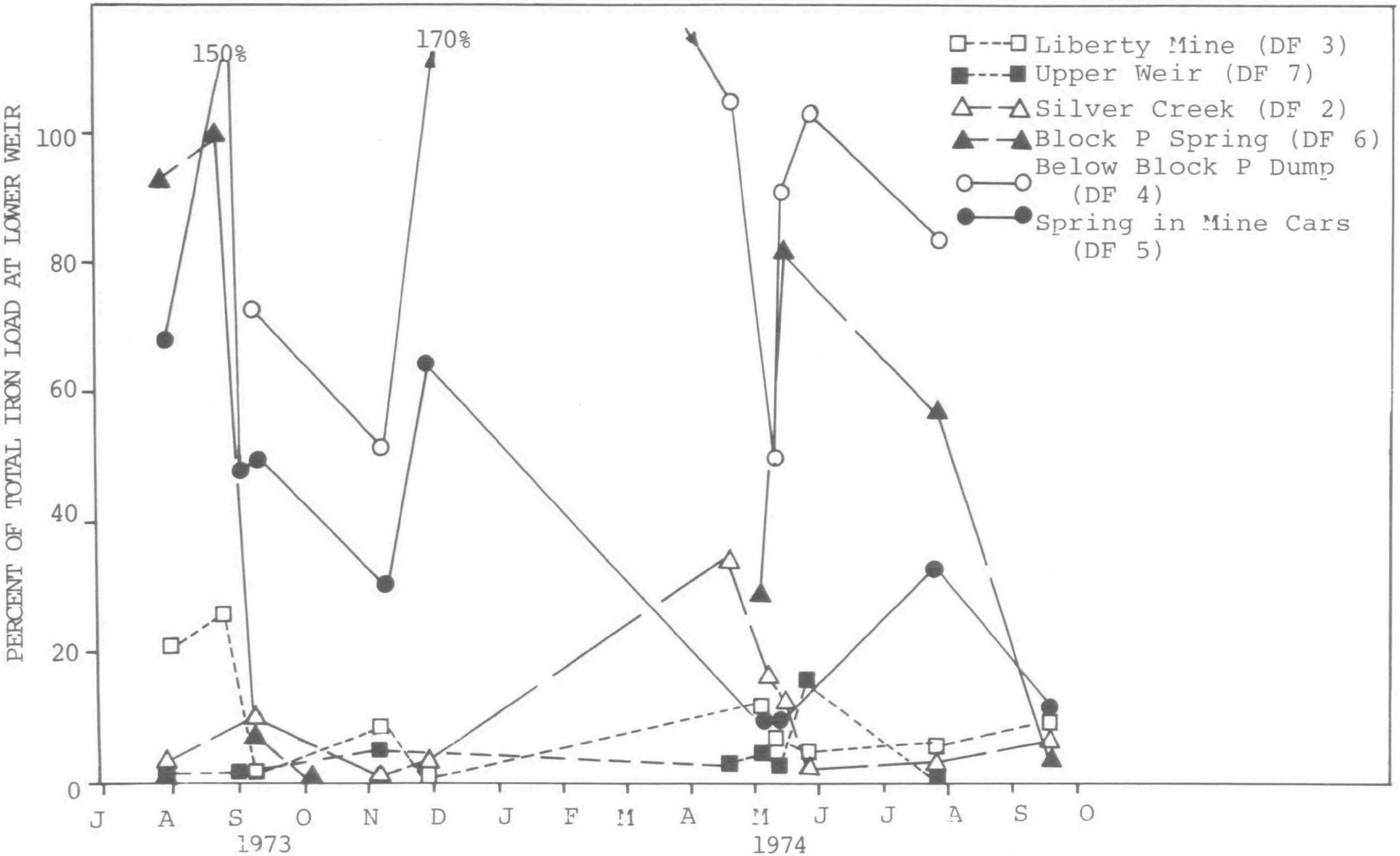

FIGURE 9. Iron Load from Several Waste Sources Compared to Load at Lower Weir.

TABLE 2. TYPICAL WATER QUALITY FROM WASTE SOURCES IN THE GALENA CREEK DRAINAGE

Station	DF 1	DF 2	DF 3	DF 4	DF 5	DF 6	DF 7	DF 8	DF 21	DF 4
Date sampled	8-21-73	7-28-73	9-06-73	8-21-73	8-21-73	8-21-73	8-21-73	8-21-73	7-06-73	5-27-74
Acidity as $CaCO_3$	94.*	6.9	1,120.	77.8	1,320.	1,070.	ND**	ND	3.5	5,870.
Alkalinity	0.	0.	0.	0.	0.	0.	71.	78.	81.	0.
Hydroxide	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Bicarbonate	0.	8.	0.	0.	0.	0.	86.	95.	98.	0.
Carbonate	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
Arsenic	.01	ND	ND	$<$.01	$<$.01	$<$.01	$<$.01	$<$.01	ND	ND
Cadmium	.08	ND	.09	.03	.6	.14	$<$.01	$<$.01	ND	ND
Calcium	80.	35.	60.	40.	164.	330.	42.	72.	27.	205.
Chloride	1.8	2.	ND	1.5	3.3	1.3	0.3	0.6	0.1	37.
Copper	.4	.07	1.2	.2	3.5	.4	.05	.06	.03	26.
Flow (lps)#	13.	.74	.06	11.	.63	.32	9.1	2.5	ND	2.2
Hardness Total	282.	97.	310.	174.	657.	1,038.	167.	283.	96.	1,294.
Iron	9.5	5.4	278.	20.	ND	400.	.10	.35	.49	720.
Lead	.19	ND	ND	ND	ND	ND	ND	ND	ND	ND
Magnesium	20.	3.8	39.	18.	60.	52.	15.	25.	7.2	190.
Manganese	26.	2.9	267.	22.	160.	225.	.17	1.1	.8	592.
pH	3.8	6.9	2.5	3.9	2.7	2.7	7.9	7.7	7.8	2.4
Sodium	6.	2.2	15.	5.2	19.	9.2	ND	ND	ND	ND
Spec. Con. (μmhos/cm)	755.	245.	3,293.	683.	3,150.	3,360.	356.	574.	218.	7,040.
Sulfate	333.	95.	1,966.	251.	2,069.	2,226.	97.	206.	22.	7,710.
Temperature ($^{\circ}$C)	19.2	13.	5.1	13.5	ND	ND	11.	9.5	ND	7.
Zinc	19.	3.1	130.	16.	146.	73.	.17	.83	.35	700.

*Concentrations are in milligrams/liter (mg/l). **No data. #Liters per second (lps).

streams and springs in the area. The quality varies from extremely poor in some of the waste sources to fair in the Dry Fork of Belt Creek below Galena Creek and in Galena Creek above the mining area. Water in the system can be characterized as calcium-bicarbonate type containing significant concentrations of metal and sulfate ions.

Table 3 illustrates the concentrations of metals in hard water that are thought to be considered safe for aquatic life.

TABLE 3. SAFE METAL CONCENTRATIONS IN HARD WATER

Element	Concentration (mg/l)
Arsenic	1.0[a]
Cadmium	0.003[b]
Copper	0.03[c]
Iron	0.2[c]
Lead	0.03[b]
Manganese	1.0[a]
Zinc	0.003[a]

Source: [a]Botz and Pedersen 1976; [b]U.S. EPA 1972; [c]McKee and Wolf.

When comparing the concentrations of elements found in the Galena Creek system (Table 2, page 22) with those in Table 3, the concentrations shown in Table 2 clearly exceed those considered safe for aquatic life. Waste sources that are particularly poor in quality are the Liberty Mine seep, the spring at the Block P Mine, and the spring at the mine cars. These waste sources exert a siginificant influence on the overall quality of water in Galena Creek.

RELATIVE IMPORTANCE OF POLLUTANT SOURCES

To compare the contribution of various pollution sources, the zinc, iron, and manganese loads from each source were calculated as to their percentage contribution to the total load at Station DF 1 (lower weir). It was assumed that the load at the lower weir was a 100 percent load. Due to processes of deposition and erosion of sediment, chemical reaction, and precipitation, loads at the lower weir seldom equal the sum of loads from the various waste sources. Figures 7, 8, and 9 (pages 19-21),however, do show the relative importance of each pollution source.

Sources Upstream from the Upper Weir

Mine wastes enter Galena Creek from a variety of sources upstream from the upper weir (measured by stations DF 7 through DF 15). The wastes entering the system in the upper weir area have, in comparison with the load at the lower weir, a small impact on stream water quality (Figures 7, 8, and 9, pages 19-21). During the spring runoff season, some acid waters enter the system above the upper weir; however, their contribution to the total pollution load seldom exceeds a few percent.

Sources Between the Upper Weir and the Lower End of the Block P Mine Dump

A comparison (Table 2) between the quality of water at stations DF 4 (Galena Creek below the Block P Mine complex), DF 1 (Galena Creek at the lower weir), and DF 7 (Galena Creek at the upper weir) will reveal that the majority of pollutants in Galena Creek enter the stream between DF 7 and DF 4. Station DF 4 measures metal loading in water from the spring at the Block P Mine, from the spring near the abandoned mine cars, and from seepage along the dump, in addition to that already in Galena Creek and measured at DF 7. This indicates that the dump and the associated underground works in the mine are the main pollutant source to Galena Creek. The waste load at the end of the Block P Mine dump is at its maximum in the fall, summer, and spring and at its minimum during the cold-weather months, from October until April (Figures 7, 8, and 9). The contribution of this area to pollution in Galena Creek varies from less than 40 percent to well over 100 percent of the load at the lower weir. The occurrance of a load at the end of the Block P Mine dump in excess of 100 percent of the load at the lower weir indicates that, between the downstream end of the Block P Mine dump and the lower weir, there is some loss of metals due to precipitation, settling, or other causes, which is to be expected in an acid mine drainage system of this type.

The spring near the Block P Mine, measured by station DF 6, appears to be ephemeral in that it responds to precipitation, and goes completely dry during cold winter weather. When flowing, it is a waste source that contributes metals to Galena Creek. The period of peak contribution of this spring is during the middle of the runoff period in May and June, when the spring may contribute from 20 to 80 percent of the entire load measured at the lower weir.

The spring in Galena Creek near the abandoned mine cars (DF 5) contributes a significant load to the stream and is one of the major toxic metal inputs to Galena Creek. The source of this spring is unknown, but it is probably related to water in the Block P Mine dump or water from the underground mines. The spring is exposed only during low water in Galena Creek. In the spring of 1975, the spring was entirely washed out and could be observed only as a bubbling area on one side of Galena Creek. Water flows from this spring year-round; however, the flow is difficult to measure because of its proximity to and periodic submergence by Galena Creek. During low streamflow, this spring characteristically contributes from 20 to over 60 percent of the total load at the lower weir. Iron loadings from this spring contribute an especially large percentage of the stream's total load. Another significant source of pollution during the snowmelt is seepage along the Block P Mine dump, a result of precipitation infiltrating the dump and dissolving metal-bearing materials there before escaping into Galena Creek. This seepage was particularly evident during the spring, when snowmelt on the dump face was observed entering the dump and exiting as springs along the west bank of Galena Creek. Development of rills and erosion on the dump face has been minimal, and a number of times snow was observed melting on the dump face with no runoff down the face from the snowpack, indicating that the snow was infiltrating directly into the dump. During the heavy snowmelt runoff period of May 1974, substantial snowmelt occurred on the dump, and a large seep estimated to be flowing at the rate of 2.21 lps (35 gpm) was observed flowing from the toe of the dump into Galena Creek. The quality of this seep (Table 2, page 22) was very poor and contributed a significant load of metals and acidity to the stream.

Sources Between the Block P Mine Dump and the Lower Weir

During the spring snowmelt, precipitation enters mine tailings and mine dumps on Silver Creek and contributes a metals load to Galena Creek. The period of maximum loading from Silver Creek is during the spring snowmelt (Figures 7, 8, and 9, pages 19-21). Silver Creek contributes at times in excess of 10 percent of the load at the lower weir. Normally, however, Silver Creek contributes a smaller percentage of the total pollution in the creek. After the snowmelt, Silver Creek rapidly reduces in flow, particularly the fork containing the mine tailings. This "bad" fork usually ceases flowing in summer and does not become a significant pollution source until the next spring runoff.

Acid mine wastes exit the Liberty Mine drift and flow down a small gully into Galena Creek. In the gully, there are also tailings from the mines that react with the acid mine waters. As shown in Figures 7, 8, and 9, the Liberty Mine seldom contributes a significant load to Galena Creek. The Liberty Mine is of the most significance in the late spring, summer, and early fall. Typically, the flow in the Liberty Mine area drops to zero during the cold portion of the year.

FACTORS INFLUENCING CONCENTRATION OF MINE WASTES

Concentrations and loads in sampled streams (Appendix D) show considerable variation in time. Concentrations and loads of mine wastes are influenced by several factors including:

1. Flow. Generally, higher flows are characterized by lower concentrations of dissolved metals. Spring runoff and other runoff events generally dilute the base flow and tend to lower metal concentrations.

2. Rate of change of flow. Concentrations of metals tend to be greater when streamflow is increasing and less when streamflow decreases. This is attributed to a "flush out" of the stream channel.

3. Suspended sediment. Increased flows, streambank disturbances, and other factors can increase concentrations of suspended sediment in streams. This in turn increases total metals concentrations due to the presence of suspended metal precipitates and adsorbed metals or sediment.

The correlation with flow for iron, manganese, and zinc concentrations at the spring at the Block P Mine is fairly good, showing a distinct downward trend of concentration with increased flow. The change in concentration, however, is small compared to the change in flow; consequently, higher flows tend to create significantly higher loads in the system. The correlation between concentration and flow at the upper weir is poor; the data suggest that the concentration of metals in the water increases with increasing flow. From these data it is clear that the concentration of metals in the streams is not greatly affected by the dilution effects of melting snow or rainfall.

PART V. POTENTIAL ABATEMENT METHODS

Treatment of Acid Waters

A number of factors should be considered in the comparison of alternate abatement techniques:

1. Galena Creek itself has a fluctuating flow and a relatively good water quality. It would be impractical to treat the entire flow of Galena Creek due to the large volume of water involved.

2. Individual waste sources in some cases have small flows of very poor water quality. Such streams may be amenable to some type of treatment.

3. The Galena Creek area, a high-mountain area with poor accessibility, is subject to severe problems of failures of power and mechanical systems. Any method selected for improvement of water quality must be compatible with the hostile climate.

4. Water in Galena Creek and the Dry Fork of Belt Creek is not used for industrial, domestic, or agricultural purposes. Any efforts at treatment or pollution abatement will probably not be compensated by a large increase in the value of the water. Abatement of the AMD in Galena Creek would result in an improved aquatic habitat and a more aesthetically pleasing stream. Property in the Dry Fork of Belt Creek and Galena Creek canyons would probably increase in value if the stream were improved in appearance.

5. Treatment alternatives must be considered in view of the seasonal variation in pollution flow and quality. Variation in the acidity of the water at several locations throughout the project is shown in Table 4; Table 5 shows the range in flow observed for three important waste sources. It is plain from this data that flow and water quality in the study area vary widely over time, a factor that increases the difficulty of choosing a method of treatment.

6. The method of treatment should be as cost-effective as possible.

TABLE 4. VARIATION IN ACIDITY OF ACID MINE WATERS IN GALENA CREEK

Station	Acidity (mg/l as $CaCO_3$) (DF 1)	(DF 2)	(DF 3)	(DF 5)	(DF 6)	(DF 7)
Maximum	126	142	2,258	2,560	1,139	25
Minimum	46	2.1	301	1,040	545	2
Mean	83	83	1,026	1,543	982	7
Number of determinations	15	14	15	9	8	5

TABLE 5. VARIATION IN FLOWS FROM MAJOR ACID MINE WASTE SOURCES

Waste Source	Flows (lps) Maximum	Minimum	Median
Spring in the abandoned mine cars	1.3	.6	1. *
Bubbling spring at Block P Mine	5.1	0.	1. *
Liberty Mine seep	7.6	0.	.6*

*Estimated

Potential treatment methods or abatement measures include:

1. Neutralization using limestone or lime.
2. Block P Mine dump surface manipulation.
3. Block P Mine dump removal.
4. Aeration and settling.
5. Evaporation.
6. Reverse osmosis.
7. Electrodialysis.
8. Ion exchange.
9. Freezing.

There are no acceptable sites for major water storage within the Galena Creek area; therefore, a treatment system must either partially treat wastes at high flows or handle the maximum expected waste flow. The potential treatment methods involving forced evaporation, reverse osmosis, electrodialysis, ion exchange, and forced freezing (methods 5 through 9 above) all require significant capital investment in a treatment plant, continuous operation, and disposal of sludge or brine from the system. All of these systems are significantly more expensive than the first four methods listed above. In view of the high initial cost, high annual maintenance cost, and waste disposal problems, these methods were not considered feasible as treatment or abatement measures. Methods 1 through 4 above (neutralization using limestone or lime, Block P Mine dump surface manipulation, Block P Mine dump removal, and aeration and settling) were considered more extensively and are discussed below.

Recommendations for abatement of AMD in the study area resulted from examination of these potential methods and are presented in Part II, Conclusions and Recommendations.

NEUTRALIZATION

Neutralization of AMD is a widely used technique, commonly using lime and limestone either alone or in combination to treat acid waters. Lime/limestone neutralization is often the most economical solution to acid mine waste problems. Due to its wide usage and potential for use in the Galena Creek area, neutralization was investigated to determine its effectiveness and cost.

On August 21, 1973, a sampling run was made at eight sites along Galena Creek. Duplicate samples were collected at these sites, refrigerated, neutralized in the lab, and analyzed for selected residual heavy metals (iron, manganese, zinc, and copper). The original and residual concentrations and quantities of base required for neutralization are shown in Table 6. The neutralization procedure consisted of titration of a 300 milliliter (ml) aliquot of sample with 0.10 N sodium hydroxide (NaOH) to a pH 11 endpoint. Samples were stirred continuously; pH readings were made 1 minute after adding each increment of base. A final reading was made 15 minutes after the last addition of base. An altered procedure was used for the mine-seep samples: after pH 11 was reached, 1 ml of 30 percent hydrogen peroxide (H_2O_2) was added to convert most of the remaining ferrous iron to the ferric form. Additional base was added to return the pH to 11, and a final reading made after a 15-minute period. The neutralized samples were filtered, acidified, and run for dissolved metals.

Neutralization curves were prepared from samples collected in December, 1973, to determine the response of wastes to neutralization. Due to ease of handling and good correlation with lime and limestone neutralization, 0.02 N sodium hydroxide was used to neutralize the wastes. The results of the tests (Figures 10 and 11) confirm the results of other studies; that is, neutralization is an effective treatment for acidity.

In addition to the laboratory neutralization tests, the stream system was sampled at eight locations from Galena Creek to the mouth of the Dry Fork of Belt Creek. These tests showed the response of metals in the stream system to neutralization by stream waters. Loads of metals decreased greatly (Table 7). Apparently, the metals precipitate from the stream.

TABLE 6. NEUTRALIZATION TESTS OF ACID WASTES IN GALENA CREEK

Test procedure	Sampling Station							
	DF 1	DF 3	DF 4	DF 5	DF 6	DF 7	DF 8	DF 16
pH								
in field	3.8	2.8	4.4	2.7	2.9	8.2	7.7	3.8
after H_2O_2	9.9	9.7	NA*	10.2	9.4	NA	NA	NA
after last titration	11.2	11.	11.	11.	11.1	11.1	11.	11.
after fifteen minutes	11.2	10.8	10.9	10.9	11.	11.1	11.	11.
Field Temperature, ^{o}C	19.2	15.7	13.5	8.	9.5	11.	9.5	10.6
ppm Fe, initial	1.4	200.	15.	280.	320.	.05	.01	<.01
final	.05	<.01	.2	<.01	<.01	<.01	.01	<.01
ppm Zn, initial	18.	108.	14.	125.	73.	.14	.75	1.
final	.02	.01	.19	.03	.03	.01	.01	.03
ppm Cu, initial	.32	1.5	.13	3.3	.4	<.01	<.01	.01
final	.01	.01	<.01	<.01	.01	<.01	<.01	.01
ppm Mn, initial	23.	275.	20.	130.	210.	.13	1.	.25
final	.01	.01	.51	.01	.03	.01	.01	.05
NaOH added before H_2O_2, ml	13.9	92.1	13.2	113.1	103.2	6.8	7.1	4.2
Equivalence in $CaCO_3$, mg/l	231.	1536.	220.	1886.	1721.	113.	118.	70.
NaOH added after H_2O_2, ml	3.1	8.4	NA	6.1	13.9	NA	NA	NA
Equivalence in $CaCO_3$ of all NaOH added, mg/l	284.	1676.	220.	1988.	1953.	113.	118.	70.

*Not applicable, H_2O_2 was added only to the mine-seep samples.

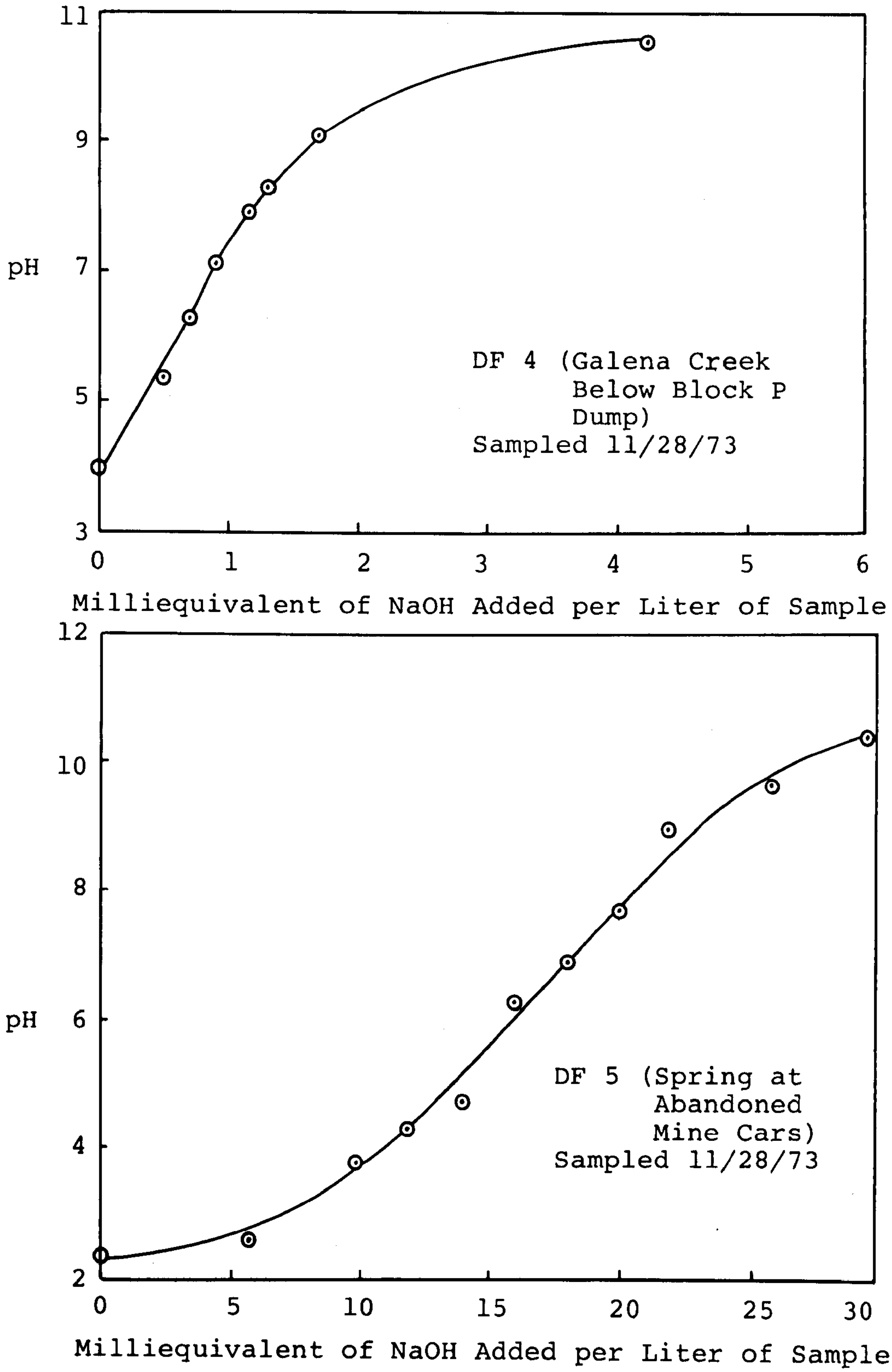

FIGURE 10. Neutralization Tests of Acid Mine Wastes from the Galena Creek Drainage: Stations DF 4 and DF 5.

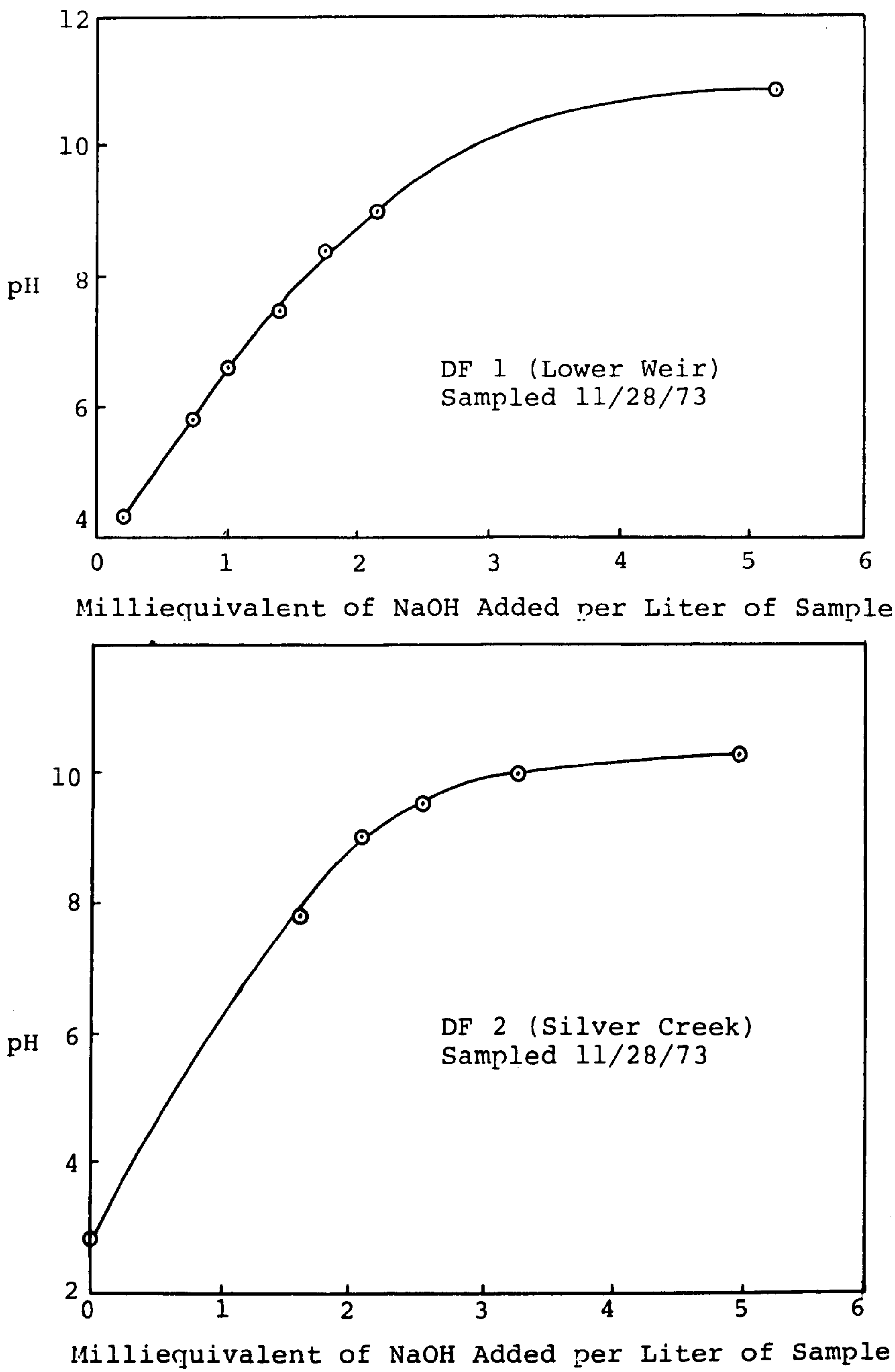

FIGURE 11. Neutralization Tests of Acid Mine Wastes from the Galena Creek Drainage: Stations DF 1 and DF 2.

TABLE 7. HEAVY METAL LOADS IN THE DRY FORK OF BELT CREEK: AUGUST 22, 1973

Sampling Station	DF 21	DF 23	DF 24	DF 25	DF 26	DF 29	DF 30	DF 31
Field pH	6.6	7.8	8.1	8.2	8.4	7.6	7.4	7.4
Metals:								
Iron								
D*	9.7**	.66	< .3	< .3	< .22	< .03	ND#	1.1
	(4.4)	(.3)	(.09)	(.09)	(.1)	(.01)	ND	(.5)
T*	102.	66.	25.	8.	.22	.07	1.1	4.3
	(46.3)	(29.9)	(11.3)	(3.6)	(.1)	(.03)	(.5)	(2.)
Manganese								
D	65.	105.	78.	42.	.88	< .03	ND	1.1
	(29.5)	(47.6)	(35.4)	(19.1)	(.4)	(.01)	ND	(.5)
T	70.	115.	81.	50.	.88	.07	1.1	1.1
	(31.8)	(52.2)	(36.7)	(22.7)	(.4)	(.03)	(.5)	(.5)
Zinc								
D	46.	32.	19.	15.	2.	.1	ND	54.
	(20.9)	(14.5)	(8.6)	(6.8)	(.91)	(.05)	ND	(24.5)
T	51.	69.	29.	16.	2.8	.17	81.	89.
	(22.7)	(31.3)	(13.2)	(7.3)	(1.3)	(.08)	(36.7)	(40.4)
Cadmium								
D	.16	< .3	< .3	< .3	< .22	< .03	ND	< 1.1
	(.07)	(.09)	(.09)	(.09)	(.1)	(.09)	ND	(.5)
T	.32	< .3	< .3	< .3	< .22	.03	< 1.1	< 1.1
	(.15)	(.09)	(.09)	(.09)	(.1)	(.09)	(.5)	(.5)
Copper								
D	.05	< .3	.34	.42	< .22	< .03	ND	< 1.1
	(.02)	(.09)	(.15)	(.19)	(.1)	(.09)	ND	(.5)
T	1.5	1.6	.68	.84	.22	.03	2.2	1.1
	(.68)	(.73)	(.31)	(.38)	(.1)	(.09)	(1.)	(.5)

*D=Dissolved, T=Total
**Units are pounds/day and, in parentheses, kilograms/day.
#No data

Using limestone and Cottrell dust (a cement waste product similar to lime) a field test was conducted to determine the cost and feasibility of neutralization. A continuous flow, rotary reactor was employed to test the neutralization effects of these tested materials on acid mine water from the spring at the abandoned mine cars in Galena Creek.

Conclusions of this field test were that limestone treatment reduced concentrations of iron and copper and raised pH but did not significantly reduce loads of zinc, manganese, or cadmium. Cottrell dust significantly reduced loads of all five metals investigated. A combination of limestone treatment followed by reaction with Cottrell dust appears to be the most economical alternative for neutralization.

Costs for neutralization facility, based on pilot tests, are shown in Table 8.

TABLE 8. COST OF NEUTRALIZATION OF ACID MINE WATERS*

	Installation Cost	Maintenance Cost per year
Limestone treatment	$26,483	$ 9,818
Cottrell dust treatment	24,133	77,040
Combination treatment (Limestone followed by Cottrell dust)	31,083	29,206

*Based on a flow of 0.299 million liters per day (0.079 million gallons per day) of acid water similar in composition to that of the spring at the abandoned mine cars in Galena Creek. Cost estimates are based on January 1, 1975 prices.

BLOCK P MINE DUMP SURFACE MANIPULATION

The Block P Mine dump, which is situated next to Galena Creek, is shown in Figure 12. A major reason that the dump is one of the main sources of acid discharge to Galena Creek is that the waters of Galena Creek pass along the toe of the dump and wash materials from the dump into the creek. To partially remedy this problem, in July of 1974, a bypass pipeline was installed parallel with Galena Creek for the entire length of the Block P Mine dump. During the low flows in the fall and winter, the pipeline diverts all of the flow from Galena Creek around the toe of the Block P Mine dump. During high flows in the springtime, excess flows from the pipeline spill into Galena Creek. Figures 12 and 13 show the relative location of the diversion pipeline, Galena Creek, and the Block P Mine dump.

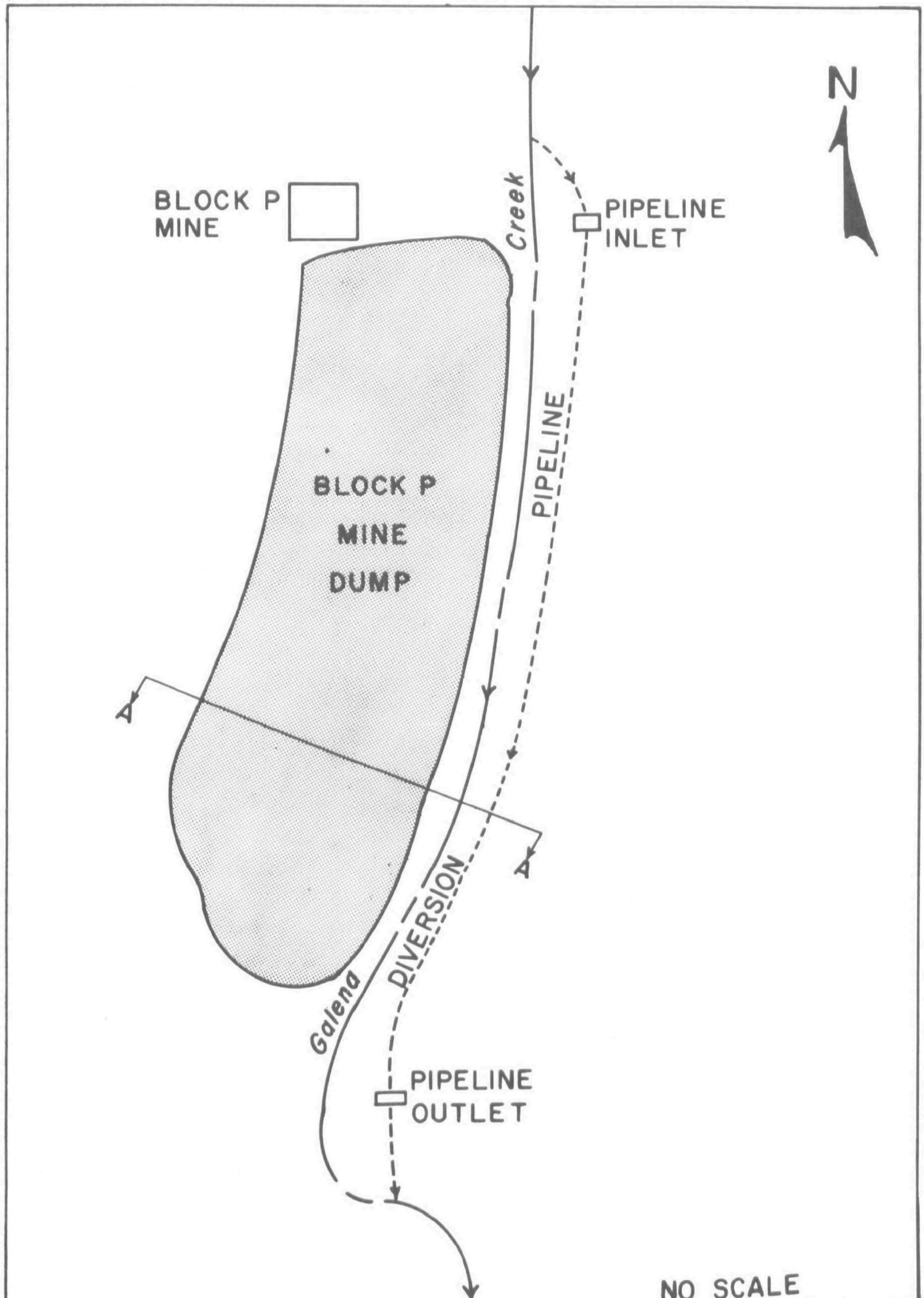

FIGURE 12. Block P Mine and Dump--Plan View.

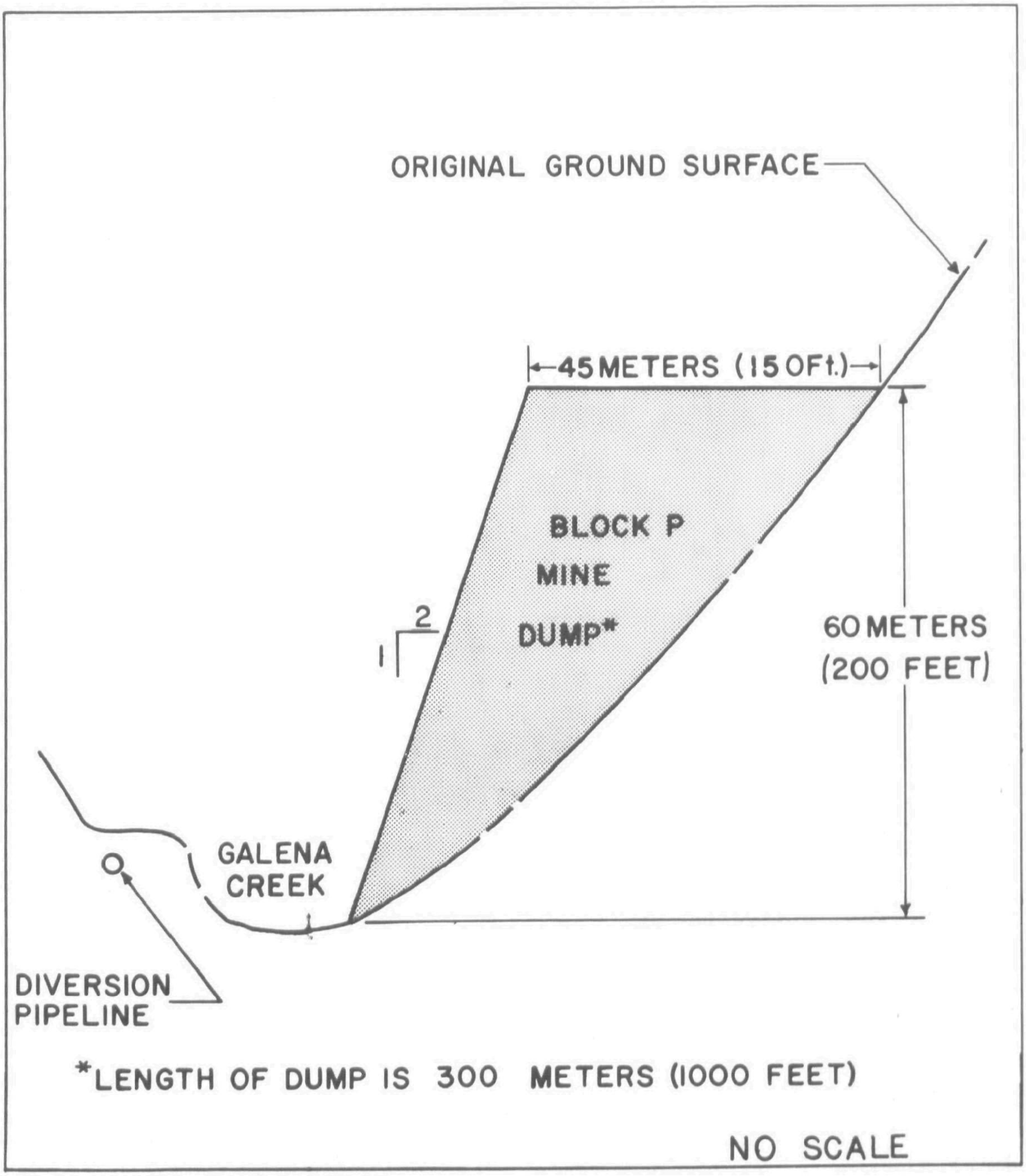

FIGURE 13. Block P Mine and Dump--Cross Section A-A.

Many seeps and springs were found along the toe of the dump and in Galena Creek after the diversion pipeline was installed; most of them were caused by water moving down through the dump and emerging at the toe in Galena Creek. The top of the dump, relatively flat with a few concave spots, causes water from snowmelt and rainfall, as well as any runoff from the hill above the top of the dump, to pond. To prevent this ponded water from seeping into the dump, there are at least three alternatives:

<u>Alternative 1</u>

This alternative would involve sloping the top of the dump away from the existing hillside (Figure 14). Precipitation falling on the top of the dump and runoff coming from the hillside would run off into the stream, thus preventing most seepage. This alternative is an effective means of removing the water from the top of the dump, however, water would still run over the toxic dump top, and some would seep into the unsealed dump. In addition, water running off the dump would create severe erosion problems on the steep side of the dump next to Galena Creek so that some of the dump material would still be washed into Galena Creek. Cost of this alternative is calculated to be $16,800.

<u>Alternative 2</u>

This alternative includes sloping the dump as in alternative 1 and sealing the top of the dump with bentonite. Topsoil will be placed on the bentonite and planted with a grass mixture suitable to the area. This alternative effectively removes the water from the top of the dump and prevents water from seeping into the dump, but the severe erosion of the steep side of the dump will still wash toxic material into Galena Creek. Cost of this alternative is calculated to be $44,150.

<u>Alternative 3</u>

This alternative would slope the top of the dump toward the hillside as shown in Figure 15. The top of the dump would then be sealed with bentonite, 0.3 m (1 ft) of topsoil placed on the bentonite, and grass planted on the topsoil. A gravel drain in the swale between the hillside and the dump, as shown in Figure 15, would catch all water running off the hillside and dump and carry it to a pipe that would convey it to Galena Creek. This alternative effectively removes water from the top of the dump and prevents erosion, as well as prevents water from seeping through the dump. Alternative 3 is calculated to cost $50,650.

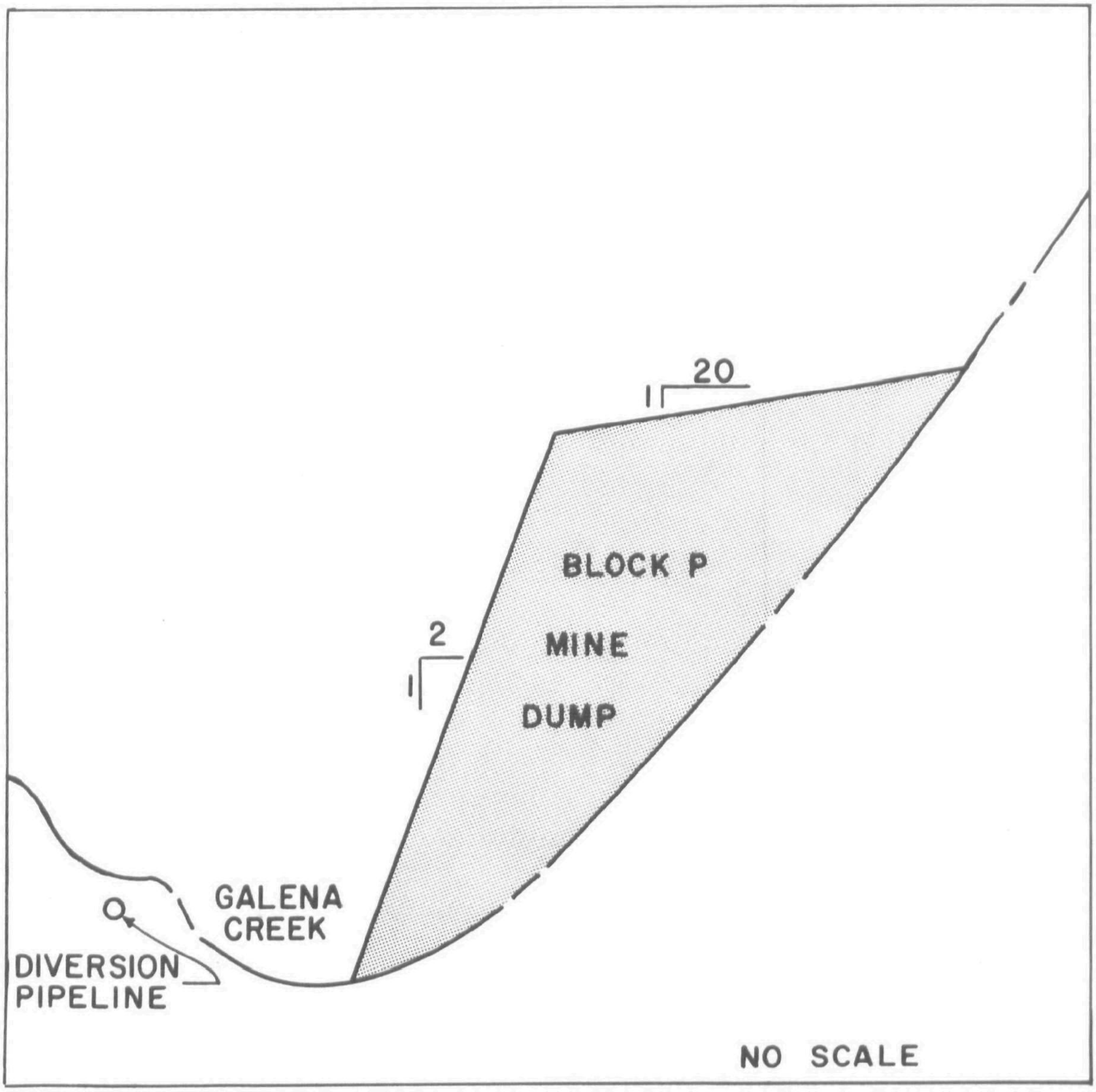

FIGURE 14. Block P Mine and Dump--Dump Sloping Away from Hillside.

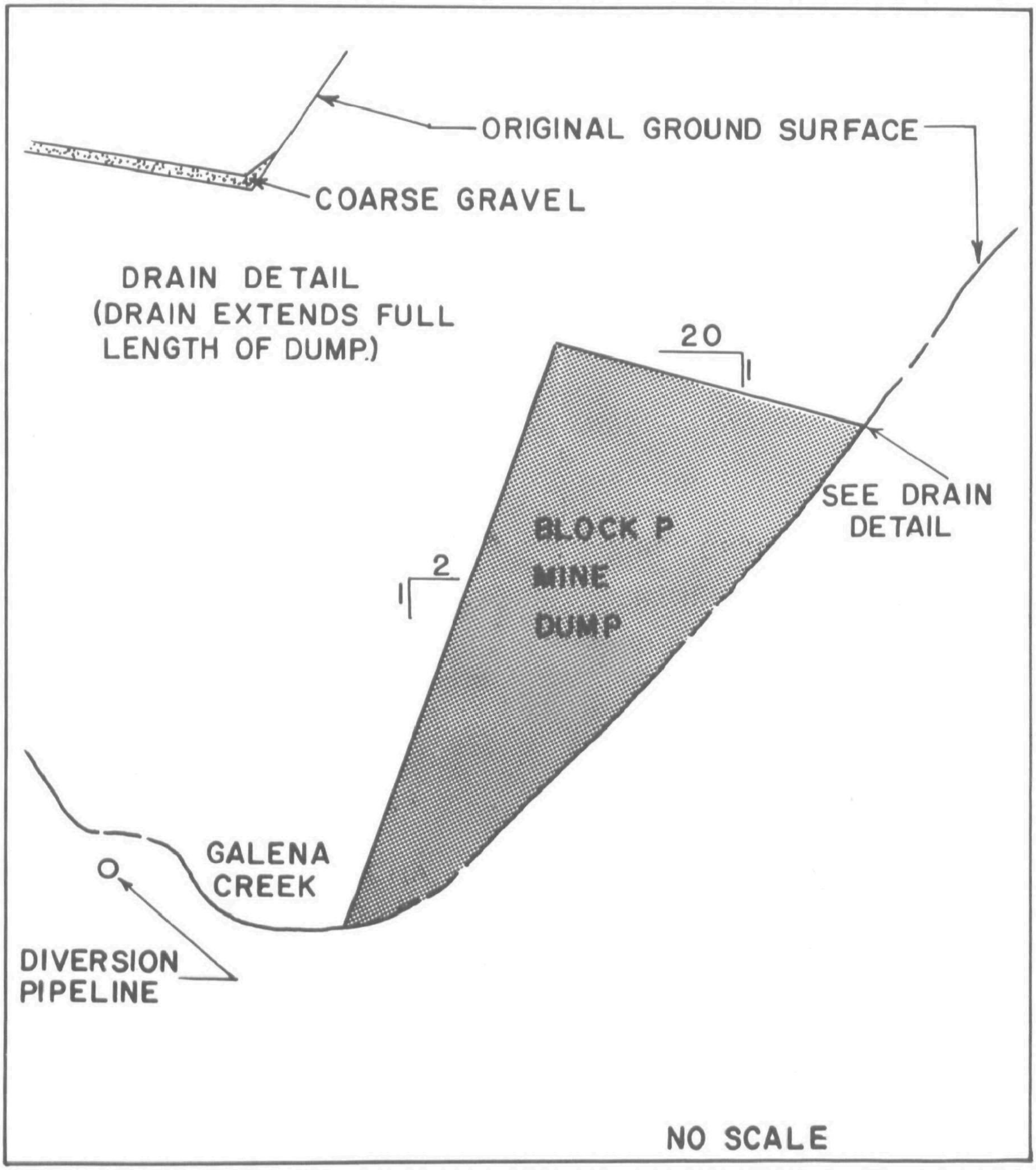

FIGURE 15. Block P Mine and Dump--Drain and Dump Sloping Toward Hillside.

Manipulating the surface of the Block P Mine dump is probably not a complete solution to the AMD problems in Galena Creek because all acidic wastes do not come from the Block P Mine dump. Ground water, as well as water seeping from underground mine workings, contributes to the AMD, as explained in Part IV.

REMOVAL OF BLOCK P MINE DUMP

One method for solving the AMD problem is to remove the Block P Mine dump, which is calculated to contain 142,000 cubic meters (185,000 cubic yards) of mine-tailings material.

The dump material could be hauled approximately 8 km (5 mi) south to the mill tailings ponds located near the mouth of Galena Creek. Sealing the ponds beforehand would prevent seepage. The cost of moving the Block P Mine dump and sealing the tailings ponds is calculated at $256,340.

Another alternative for removing the dump is to haul it to the nearest smelter (Anaconda, Montana), where the minerals would be removed from the tailings material. This alternative solves the present problem of tailings material at Hughesville, but moves the problem of storing the tailings material to a different location. The cost of this alternative, including only excavation and hauling since smelting costs would be offset by sale of the minerals, is $3,790,000.

Removal of the dump, like surface manipulation of the dump, would be only a partial solution to the AMD problem, since some of the pollution comes from sources other than the Block P Mine complex.

AERATION AND SETTLING

Another treatment option examined was subjection of the waste-laden water to natural aeration and settling in a pond. To test this method, a laboratory test of aeration and settling was conducted on samples from the major waste sources. Procedures for each of the studies are given below:

1. Settling Study. Two sample bottles from each of the five sampling sites were uncapped and loosely covered with foil to allow evaporation to occur. They were stored at room temperature in the laboratory (25^{o} C) (77^{o} F). After one week of settling, water was decanted from one of the bottles from each site, filtered through a 0.45 micron filter, and analyzed immediately for dissolved iron, manganese, zinc, and copper. After standing for four weeks, water from the remaining bottles was decanted, filtered, and analyzed for the same constituents.

2. <u>Aeration Study.</u> Air was bubbled through five samples for one week at the flow rate of 1.25 liters per minute (0.33 gpm). To minimize the effect of water carryover as the air passed from one sample to another, the bottles were arranged in ascending order of metal concentrations: stations DF 7, DF 1, DF 2, DF 4, DF 5. After one week of aeration, the samples were filtered and run for dissolved iron, manganese, zinc, and copper.

The results, summarized in Table 9, indicate that there would be some lowering of iron concentrations due to oxidation; however, zinc, manganese, and copper concentrations were not significantly affected by either settling or aeration. The conclusion of these pilot tests was that ponding and aeration would probably not be an effective treatment technique for reducing toxic metal concentrations, nor would they have a significant impact on acidity. The aeration and settling option therefore was not further investigated.

TABLE 9. EFFECTS OF SETTLING AND AERATION ON METAL CONCENTRATIONS

	Sampling Station				
	DF 1	DF 2	DF 4	DF 5	DF 7
Initial pH	4.8	3.6	5.5	2.92	7.75
Iron, dissolved (mg/l)					
Original sample	3.3	2.7	16.	210.	0.
1-week settling	0.	2.	0.	140.	0.
4-week settling	0.	2.2	0.	123.	0.
1-week aeration	0.	1.8	10.	120.	0.
Zinc, dissolved (mg/l)					
Original sample	20.	15.	15.	105.	.22
1-week settling	20.	11.	13.	105.	.16
4-week settling	13.	7.2	8.8	75.	*
1-week aeration	20.	11.	*	106.	.15
Manganese, dissolved (mg/l)					
Original sample	18.	7.	9.8	113.	.09
1-week settling	17.	6.7	9.8	113.	.08
4-week settling	17.	5.8	9.	113.	.1
1-week aeration	18.	6.7	*	89.	.1
Copper, dissolved (mg/l)					
Original sample	.32	.18	.15	3.2	<.01
1-week settling	.31	.18	.16	2.8	<.01
4-week settling	.25	.14	.14	3.	<.01
1-week aeration	.28	.18	*	1.6	<.01

*Rejected data. Reported values exceeded those in original sample by a factor of three or greater.

REFERENCES

Botz, M. K., and R. J. Pedersen. 1976. Summary of Water Quality Criteria. Unpublished report, Water Quality Bureau, Montana Department of Health and Environmental Sciences, Helena.

McKee, J. E., and H. W. Wolf. 1963. Water Quality Criteria. Publication 3-A. California State Water Resources Control Board, no place. 548 p.

Miller, J. F., R. H. Frederick, and R. J. Tracey. 1973. Precipitation-Frequency Atlas of the Western United States. Volume 1-Montana. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Silver Spring, Maryland.

Montana Water Quality Standards, adopted by the Montana Department of Health and Environmental Sciences. 1974. Montana Administrative Code 16-2.14(10)-S14480.

Revised Codes of Montana, 1947.

Small, Cooley, and Associates. 1969. Comprehensive Plan for Sewer and Water Systems, Cascade County, Montana. Billings, Montana. 107 pp.

State Engineer's Office. 1961 (June). Water Resources Survey, Cascade County, Montana. Department of Natural Resources and Conservation, Helena. 77 pp.

State Engineer's Office. 1963 (June). Water Resources Survey, Judith Basin County, Montana. Department of Natural Resources and Conservation, Helena. 86 pp.

U.S. Environmental Protection Agency. 1971. Methods for Chemical Analysis of Water and Wastes. EPA National Environmental Research Center; Analytical Quality Control Lab. Cincinnati, Ohio. 312 p.

U.S. Environmental Protection Agency. 1972. Water Quality Criteria. EPA-R3-73-033. U.S. Government Printing Office, Washington, D.C.

U.S. Environmental Protection Agency. 1973. Processes, Procedures, and Methods to Control Pollution from Mining Activities. EPA-430/9-73-011. U.S. Government Printing Office, Washington, D.C.

U.S. Environmental Protection Agency. 1975. Criteria for Developing Pollution Abatement Programs for Inactive and Abandoned Mine Sites. EPA-440/9-75-008.

U.S. Department of Commerce, Bureau of Census. 1970. Census of Population. U.S. Government Printing Office, Washington, D.C.

Weed, W. H. 1898. Geology of the Little Belt Mountains, Montana, with Notes on the Mineral Deposits of the Neihart, Barker, Yogo, and Other Districts. In 20th Annual Report, Part III--Precious Metal Mining Districts. U.S. Department of Interior, Geological Survey.

Wirth, T. J., and Associates; and Mueller Engineering. 1970 Comprehensive Area-Wide Water and Sewer Plan, 1970--Choteau, Judith Basin, and Fergus Counties. Billings, Montana. 108 pp. + 3 appendices.

APPENDIX A

CONVERSION FACTORS

Contents

APPENDIX A: CONVERSION FACTORS

Metric System

megameter	=	1,000,000	meters
myriameter	=	10,000	meters
kilometer*	=	1,000	meters
hectometer	=	100	meters
decameter	=	10	meters
meter*	=	1	meters
decimeter	=	.1	meters
centimeter*	=	.01	meters
millimeter*	=	.001	meters
micrometer	=	.000001	meters

* commonly used units

Length

Multiply...	By...	To obtain...
miles	1.609	kilometers
yards	.9144	meters
feet	.3048	meters
inches	2.54	centimeters
inches	25.4	millimeters
kilometers	.631	miles
meters	1.094	yards
meters	3.2809	feet
centimeters	.3937	inches
millimeters	.03937	inches

Area

Multiply...	By...	To obtain...
square miles	2.59	square kilometers
acres	.004047	square kilometers
acres	4,047	square meters
square feet	.0929	square meters
square inches	6.4516	square centimeters
square miles	640	acres
acres	43,560	square feet
square kilometers	.3861	square miles
square meters	.000247	acres
square meters	10.764	square feet
square centimeters	.155	square inches

Volume

Multiply...	By...	To obtain...
acre-feet	.001233	cubic hectometers
acre-feet	1,233	cubic meters
cubic feet	.02832	cubic meters
cubic feet	28.32	liters
U.S. gallons	3.785	liters
acre-feet	358,851	U.S. gallons
cubic feet	7.48	U.S. gallons
million gallons	3.07	acre-feet
cubic meters	.00081	acre-feet
cubic meters	35.3147	cubic feet
liters	.0353	cubic feet
liters	.2642	U.S. gallons

Mass

Multiply...	By...	To obtain...
pounds	.4536	kilograms
tons (short)	.9072	tons (metric)
kilograms	2.2046	pounds
tons (metric)	1.1023	tons (short)

Flow

Multiply...	By...	To obtain...
gallons per minute	.06309	liters per second
cubic feet per second	.02832	cubic meters per second
cubic feet per second	28.32	liters per second
gallons per minute	.00223	cubic feet per second
cubic feet per second	1.9835	acre-feet per day
cubic feet per second	40	Montana Miners inches
cubic feet per second	448.8	U.S. gallons per minute
cubic feet per second	724	acre-feet per year
liters per second	.03531	cubic feet per second
liters per second	15.85	gallons per minute
cubic meters per second	35.31	cubic feet per second

Velocity

Multiply...	By...	To obtain...
feet per second	.3048	meters per second
feet per second	1.097	kilometers per hour
feet per second	30.48	centimeters per second
feet per second	.68	miles per hour
miles per hour	1.4666	feet per second
meters per second	3.2808	feet per second

TEMPERATURE

The values in the body of the table give the equivalent, in degrees Fahrenheit, of the temperatures indicated in degrees Centigrade at the top and side.

°C	0	1	2	3	4	5	6	7	8	9
100	212.0	213.8	215.6	217.4	219.2	221.0	222.8	224.6	226.4	228.2
90	194.0	195.8	197.6	199.4	201.2	203.0	204.8	206.6	208.4	210.2
80	176.0	177.8	179.6	181.4	183.2	185.0	186.8	188.6	190.4	192.2
70	158.0	159.8	161.6	163.4	165.2	167.0	168.8	170.6	172.4	174.2
60	140.0	141.8	143.6	145.4	147.2	149.0	150.8	152.6	154.4	156.2
50	122.0	123.8	125.6	127.4	129.2	131.0	132.8	134.6	136.4	138.2
40	104.0	105.8	107.6	109.4	111.2	113.0	114.8	116.6	118.4	120.2
30	86.0	87.8	89.6	91.4	93.2	95.0	96.8	98.6	100.4	102.2
20	68.0	69.8	71.6	73.4	75.2	77.0	78.8	80.6	82.4	84.2
10	50.0	51.8	53.6	55.4	57.2	59.0	60.8	62.6	64.4	66.2
0	32.0	33.8	35.6	37.4	39.2	41.0	42.8	44.6	46.4	48.2
-0	32.0	30.2	28.4	26.6	24.8	23.0	21.2	19.4	17.6	15.8
-10	14.0	12.2	10.4	8.6	6.8	5.0	3.2	1.4	-0.4	-2.2
-20	-4.0	-5.8	-7.6	-9.4	-11.2	-13.0	-14.8	-16.6	-18.4	-20.2
-30	-22.0	-23.8	-25.6	-27.4	-29.2	-31.0	-32.8	-34.6	-36.4	-38.2
-40	-40.0	-41.8	-43.6	-45.5	-47.2	-49.0	-50.8	-52.6	-54.4	-56.2
-50	-58.0	-59.8	-61.6	-63.4	-65.2	-67.0	-68.8	-70.6	-72.4	-74.2
-60	-76.0	-77.8	-79.6	-81.4	-83.2	-85.0	-86.8	-88.6	-90.4	-92.2
-70	-94.0	-95.8	-97.6	-99.4	-101.2	-103.0	-104.8	-106.6	-108.4	-110.2
-80	-112.0	-113.8	-115.6	-117.4	-119.2	-121.0	-122.8	-124.6	-126.4	-128.2
-90	-130.0	-131.8	-133.6	-135.4	-137.2	-139.0	-140.8	-142.6	-144.4	-146.2
-100	-148.0	-149.9	-151.6	-153.4	-155.2	-157.0	-158.8	-160.6	-162.4	-164.2

APPENDIX B: WATER QUALITY SAMPLING SITES

Table B-1 lists water quality sampling sites established for this project along with their station number and location. Following the table is an explanation of the numbering system used to designate the geographical location of the stations. The system is illustrated in Figure B-1.

TABLE B-1. WATER QUALITY SAMPLING SITES

Station Number	Description	Location
DF 1	Galena Creek at lower weir	15N 09E 18BC
DF 2	Silver Creek at road above mouth	15N 09E 07BDB
DF 2A	Mine seep above Silver Creek (Bad Fork)	15N 09E 07BB
DF 3	Liberty Mine seep at Galena Creek	15N 09E 07BDA
DF 4	Galena Creek just below mine dump	15N 09E 07BAA
DF 5	Spring along Galena Creek in middle of mine cars	15N 09E 07BAA
DF 6	Bubbling spring at Block P Mine	15N 09E 06DCC
DF 7	Galena Creek at upper weir	15N 09E 06DCB
DF 8	Galena Creek at Harrison Mine, above Green Creek influx	15N 09E 06DB
DF 9	Caved tunnel outflow (Moulton Mine) on Galena Creek	15N 09E 06BD
DF 10	Galena Creek above caved tunnel	15N 09E 06DBA
DF 11	Green Creek above tributary	15N 09E 06BD
DF 12	Carter Mine tunnel drainage along Green Creek	15N 09E 06BD
DF 13	Tributary to Green Creek above mine drainage inflow	15N 09E 06BD
DF 14	Green Creek above mouth on Galena Creek	15N 09E 06DBC
DF 15	Daisy Creek above Galena Creek	15N 09E 06DCB
DF 16	Queen of the Hills Creek at mouth on Galena Creek	15N 09E 06DCC
DF 17	Silver Creek above mine seep (Good Fork)	15N 09E 07BB
DF 18	Bend Gulch Creek just above Galena Creek	15N 09E 07CAC
DF 20	Gold Run Creek at bridge at Cascade/ Judith Basin County line	15N 09E 18CBBC
DF 21	Galena Creek 150 m above mouth	15N 08E 13DCD
DF 22	Dry Fork Belt Creek above Galena Creek	15N 08E 13DCD

TABLE B-1 (continued)

Station Number	Description	Location
DF 23	Dry Fork by cabin 100 m east of site 16 km (9.75 mi) from Highway 89	15N 08E 23AAB
DF 24	Dry Fork above Finn Creek 13 km (8 mi) from Highway 89	15N 08E 16DBD
DF 25	Dry Fork at bridge-10 km (6 mi) from Highway 89 (bridge no. 9)	15N 08E 08DBB
DF 26	Dry Fork at bridge-3 km (2 mi) from Highway 89 (bridge no. 3)	15N 07E 02AAA
DF 27	Dry Fork at campground below Caste Rock-2 km (1 mi) from Highway 89	15N 07E 02BAC
DF 28	Dry Fork at bridge-1 km (0.7 mi) from Highway 89 (bridge no. 2)	15N 07E 03ABD
DF 29	Dry Fork 25 m (25 yards (yd)) above mouth	15N 07E 04AAA
DF 30	Belt Creek 20 m (20 yd) below Dry Fork	16N 07E 33DDD
DF 31	Belt Creek 10 m (10 yd) above Dry Fork	15N 07E 04AAA
DF 32	Belt Creek just above Neihart	13N 08E 05B

Features such as water sampling sites, wells, and springs are assigned a location number that is based on the system of land subdivision used by the U.S. Bureau of Land Management. The number consists of eleven characters and describes the location by township, range, section, and position within the section. Figure B-1 on the following page illustrates this numbering method. The first three characters of the number give the township, the next three the range. The next two numbers give the section number within the township, and the next three letters describe the location within the quarter section (160 acres), and quarter-quarter section (40 acres), and a quarter-quarter-quarter section (10 acres).

These subdivisions of the 640-acre section are designated as A, B, C, and D in a counterclockwise direction, beginning in the northeast quadrant. If there is more than one feature in a 10-acre tract, consecutive digits beginning with the number 02 are added to the number. For example, if a water quality sample was collected in Section 21, T6N, R7E, it would be numbered 06N07E21BDC. The letters BDC indicate that the well is in the southwest 1/4 of the southeast 1/4 of the northwest 1/4.

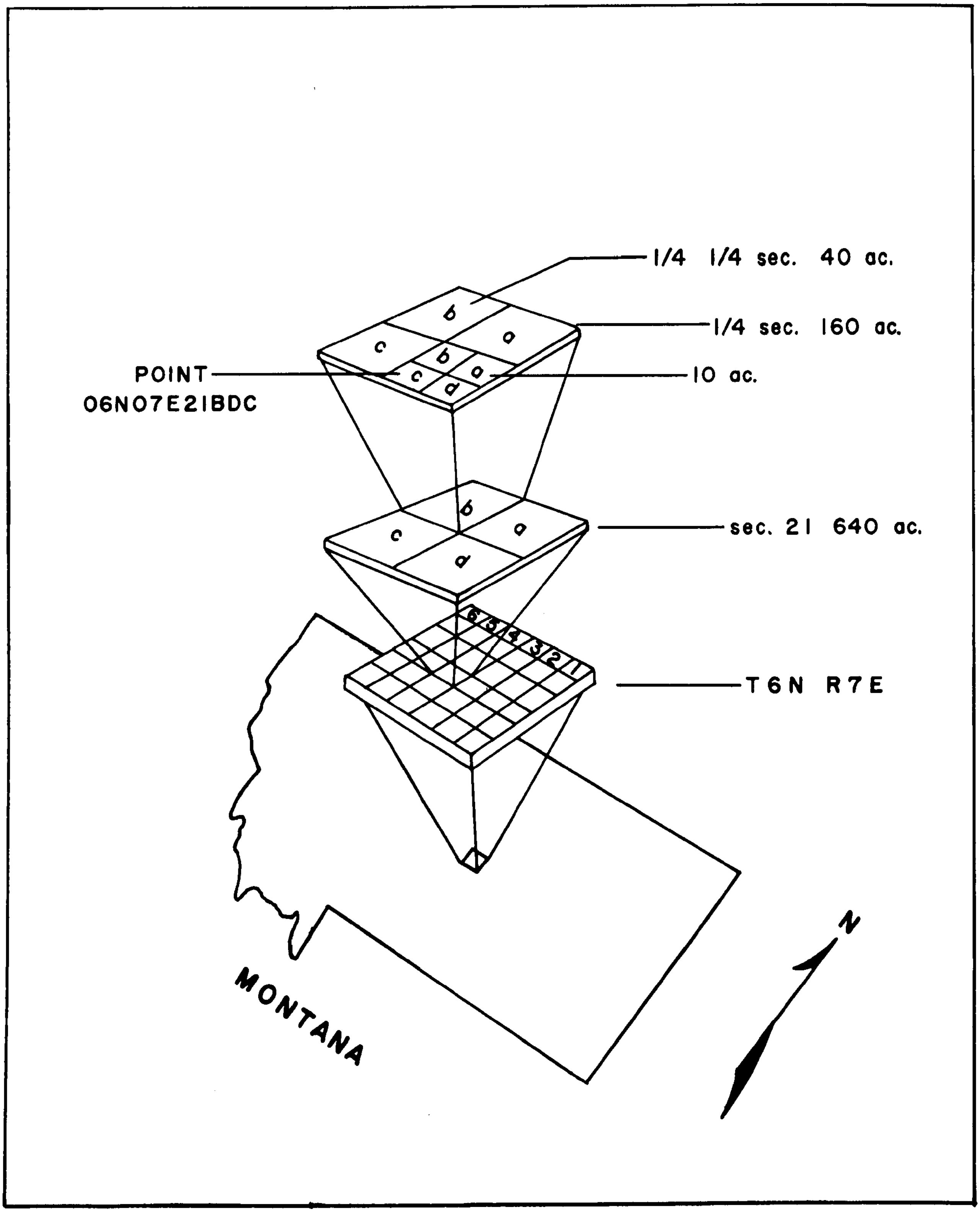

FIGURE B-1. Numbering System for Finding the Geographical Location of Sampling Stations.

APPENDIX C

FLOW VERSUS CONCENTRATION TABLES FOR SELECTED STATIONS

Contents

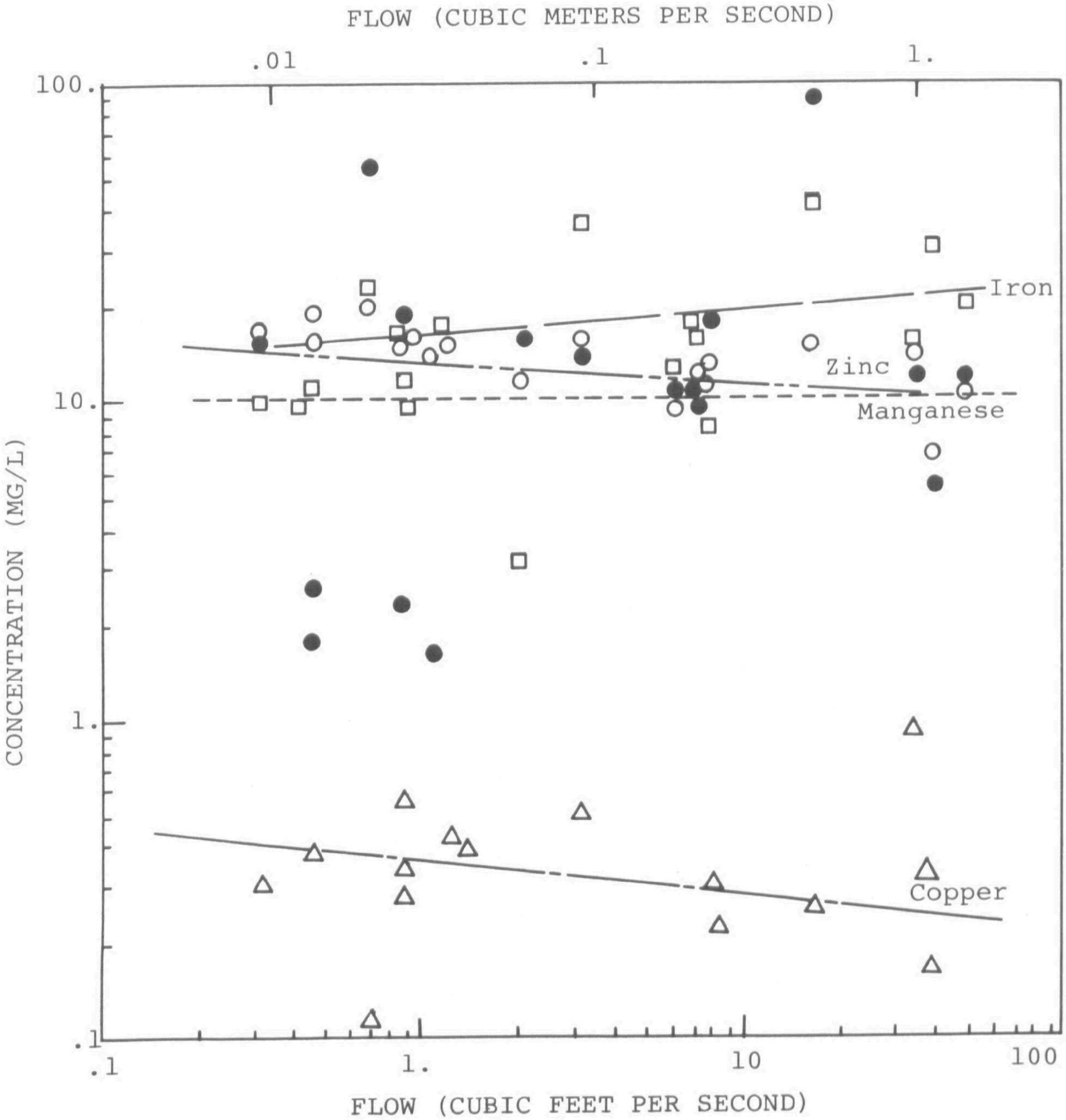

FIGURE C-1. Flow versus Concentration at Station DF 1. (Galena Creek at Lower Weir).

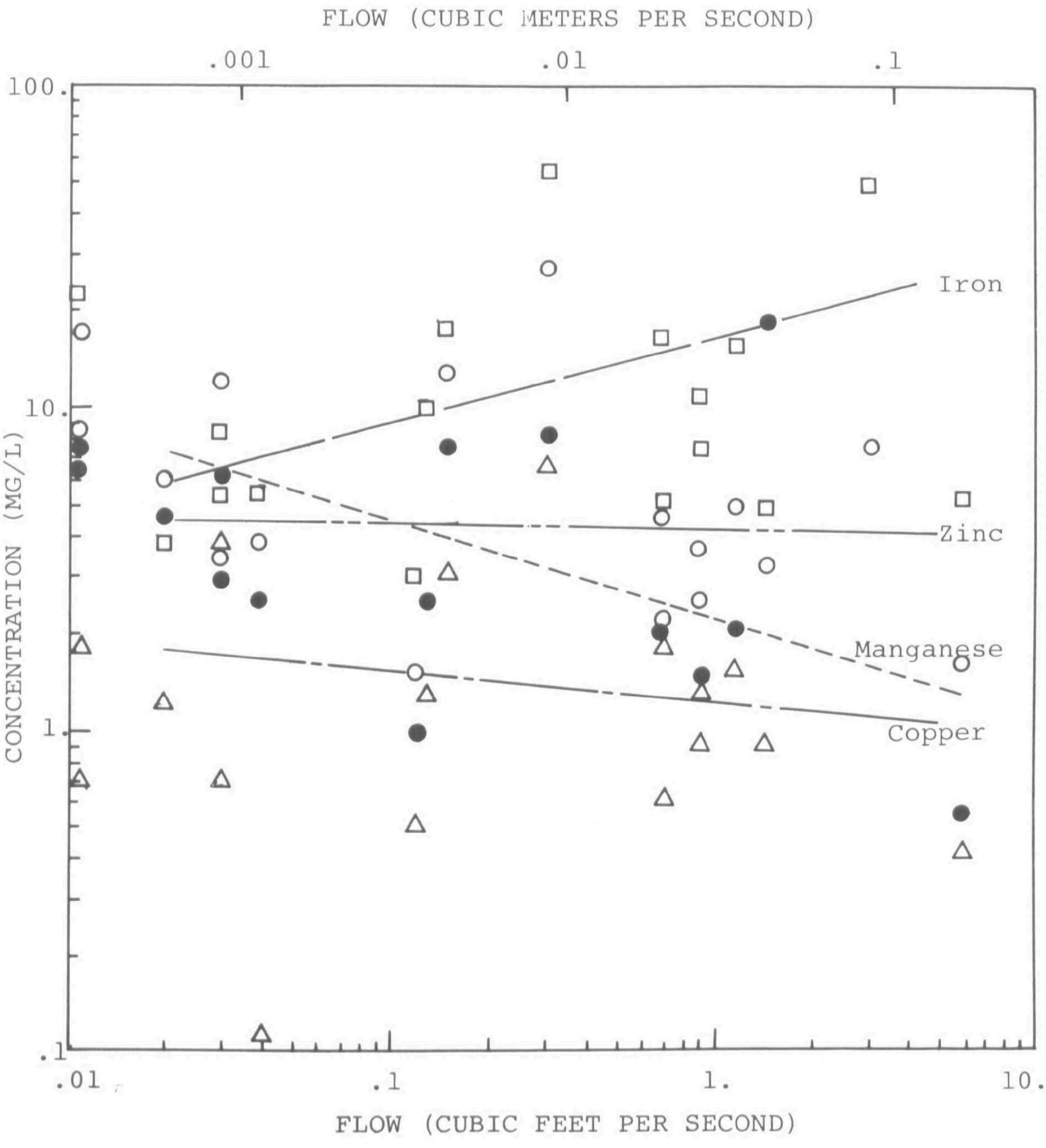

FIGURE C-2. Flow versus Concentration at Station DF 2. (Silver Creek).

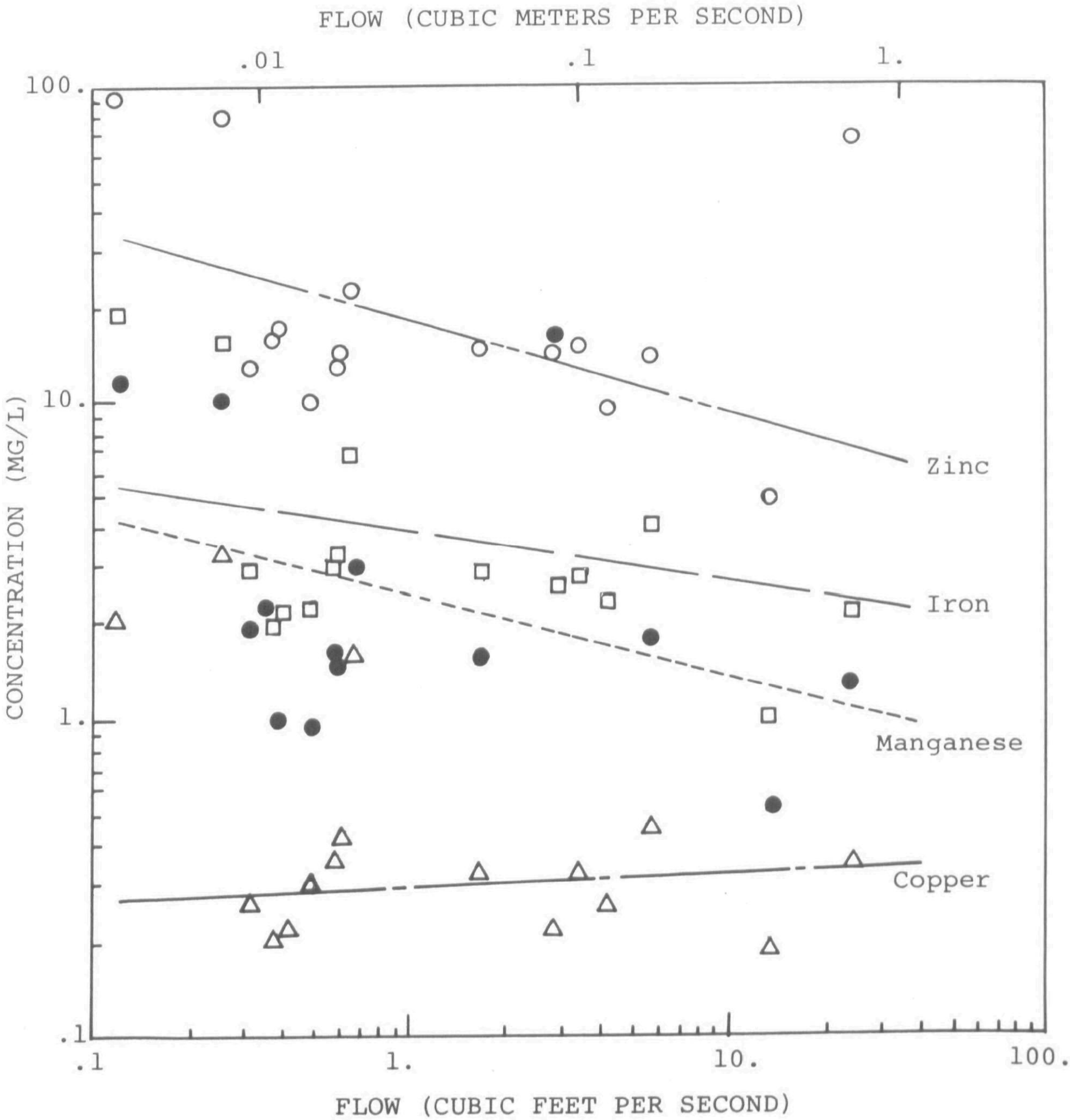

FIGURE C-3. Flow versus Concentration at Station DF 4. (Galena Creek Below Block P Mine Dump).

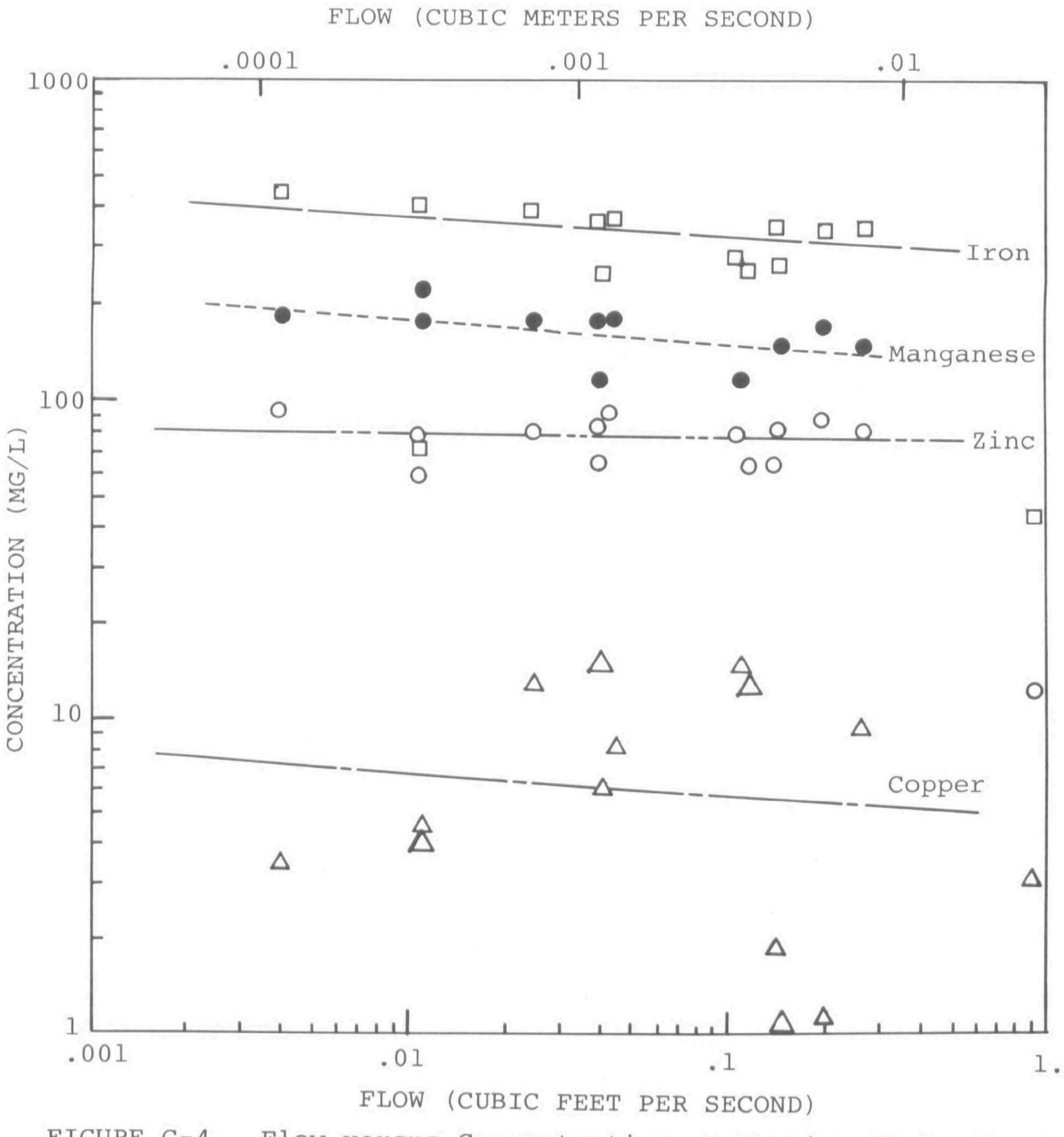

FIGURE C-4. Flow versus Concentration at Station DF 5. (Spring in Galena Creek near Abandoned Mine Cars).

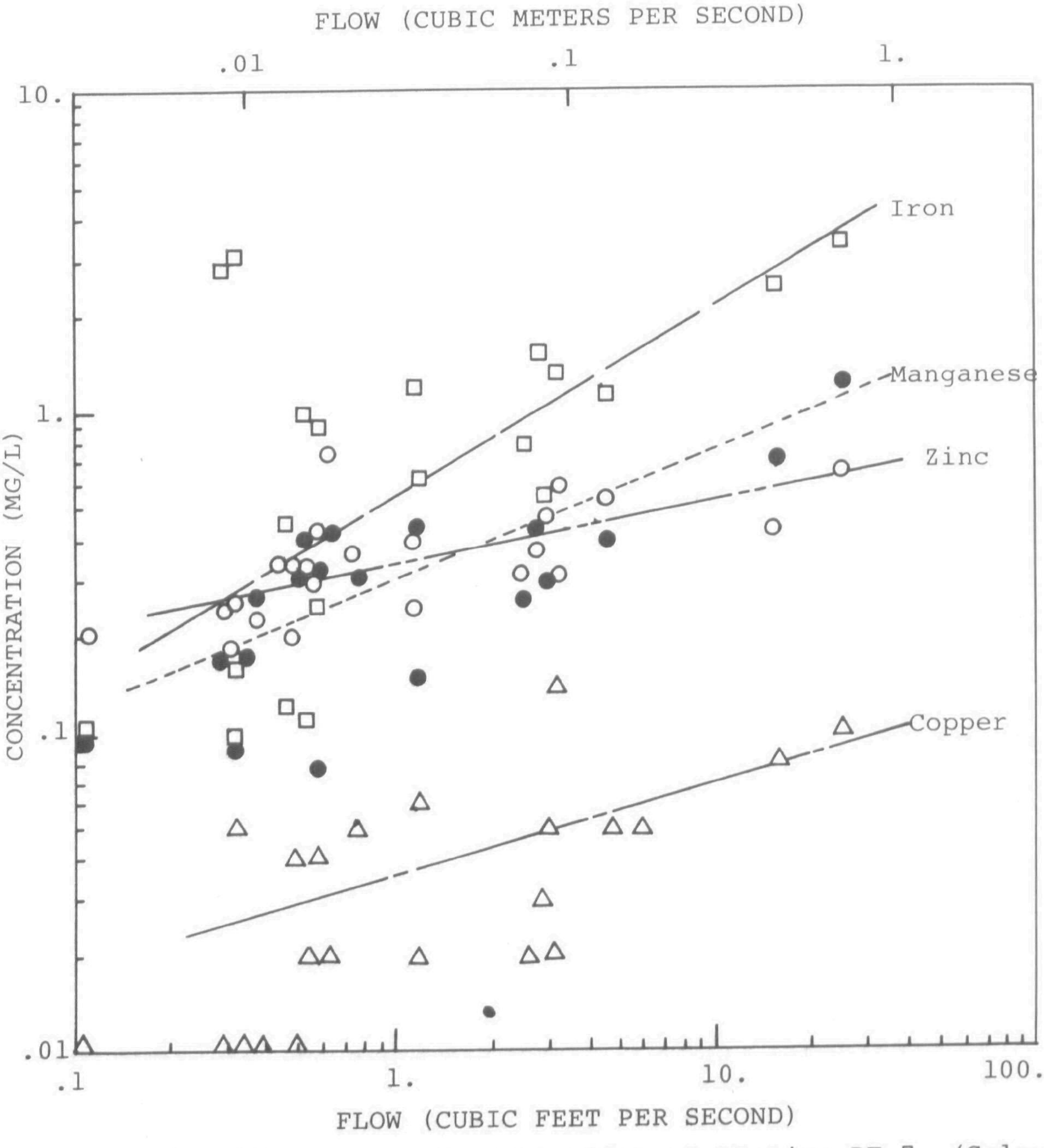

FIGURE C-5. Flow versus Concentration at Station DF 7. (Galena Creek at Upper Weir).

APPENDIX D

CONCENTRATION AND LOAD VERSUS TIME TABLES FOR SELECTED STATIONS

Contents

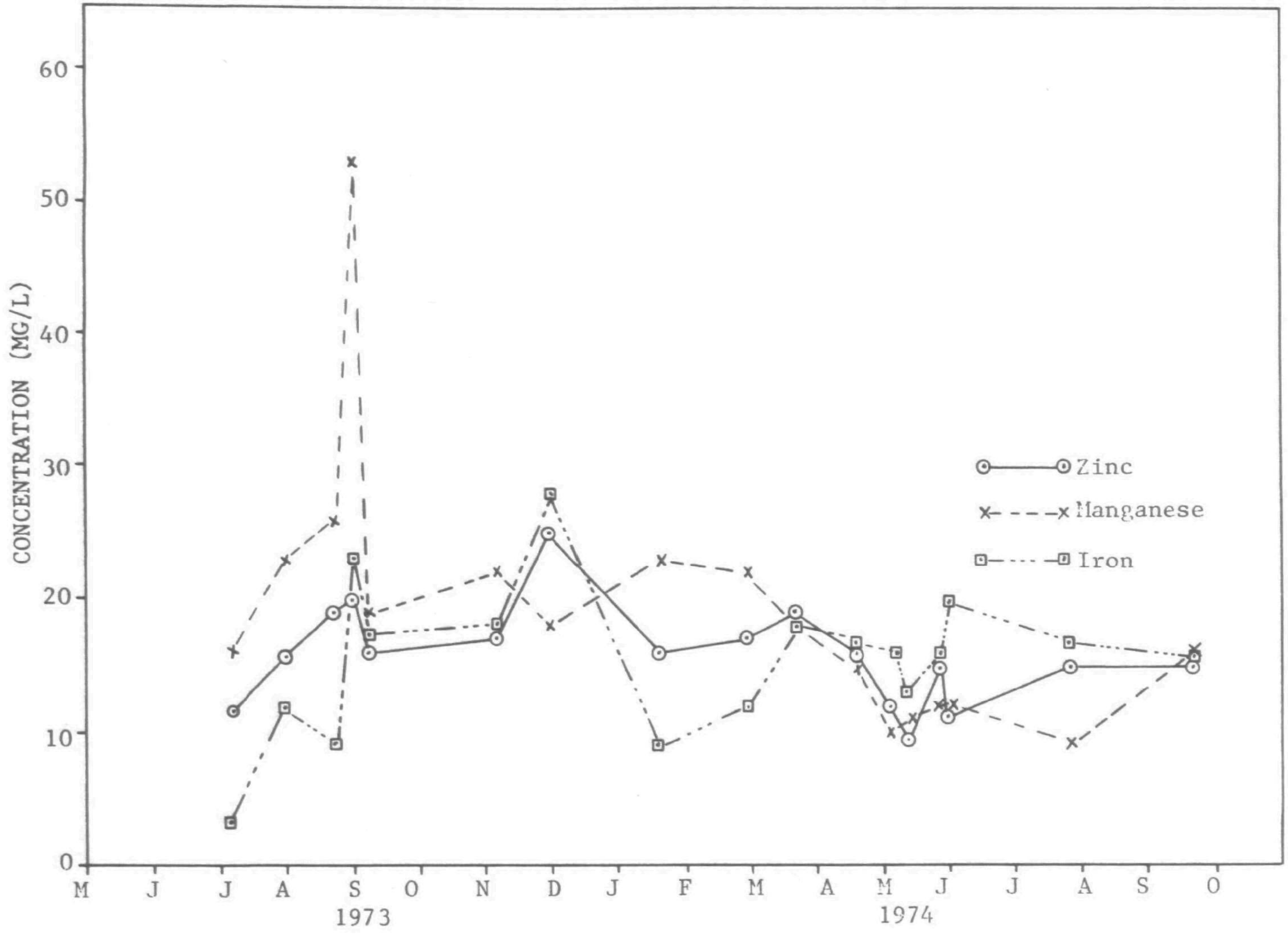

FIGURE D-1. Concentration versus Time at Station DF 1 (Galena Creek at Lower Weir).

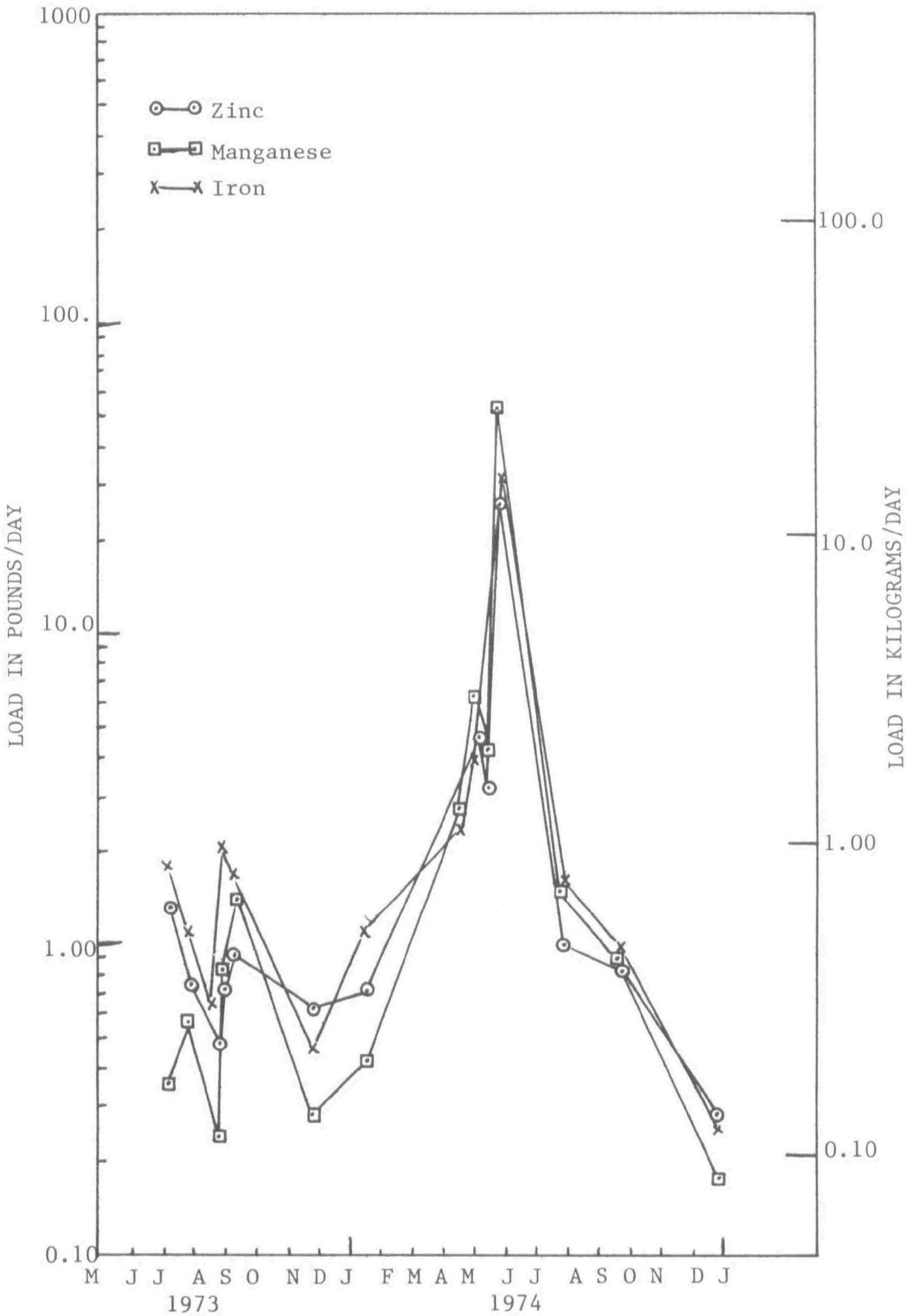

FIGURE D-2. Load versus Time at Station DF 1.

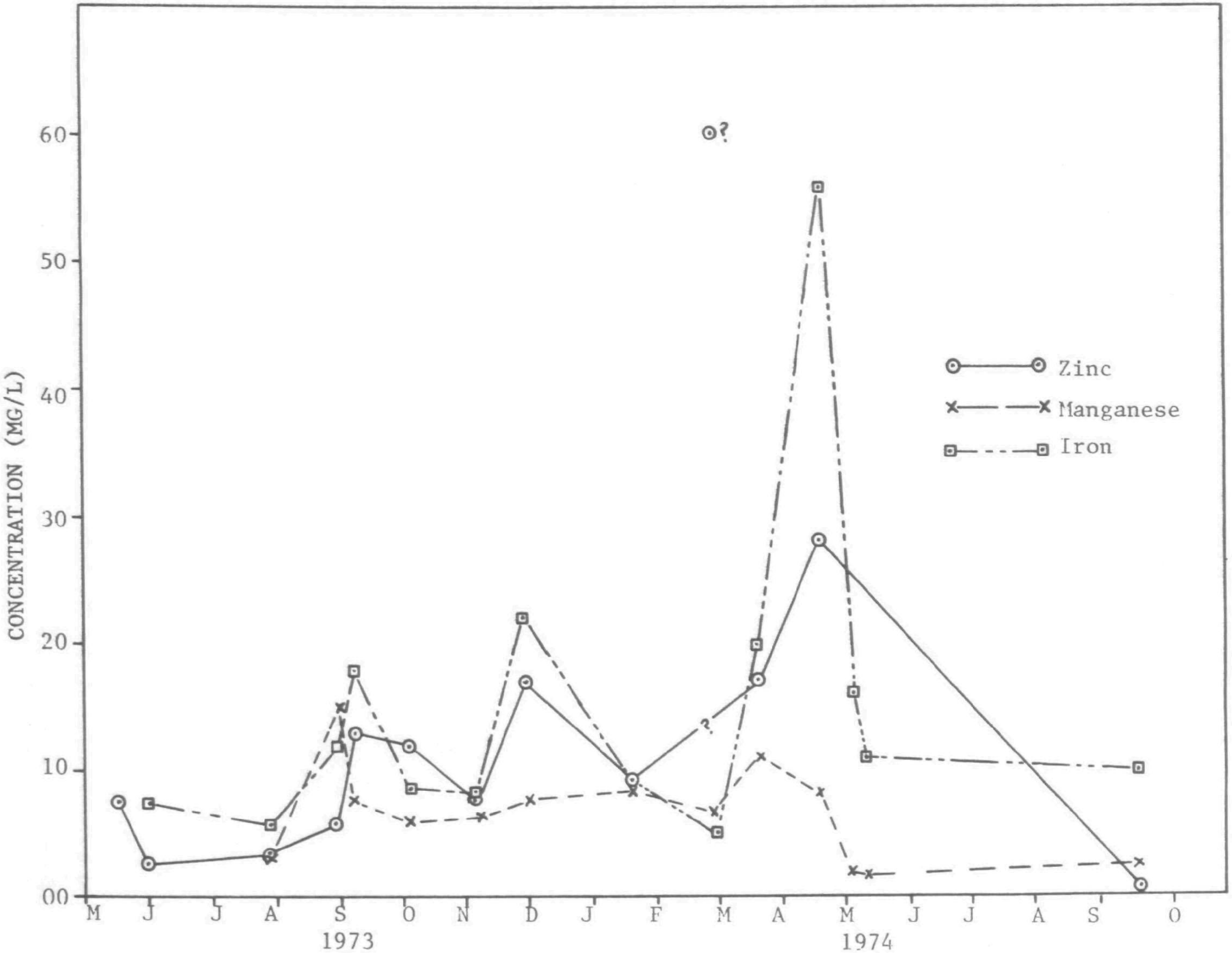

FIGURE D-3. Concentration versus Time at Station DF 2 (Silver Creek).

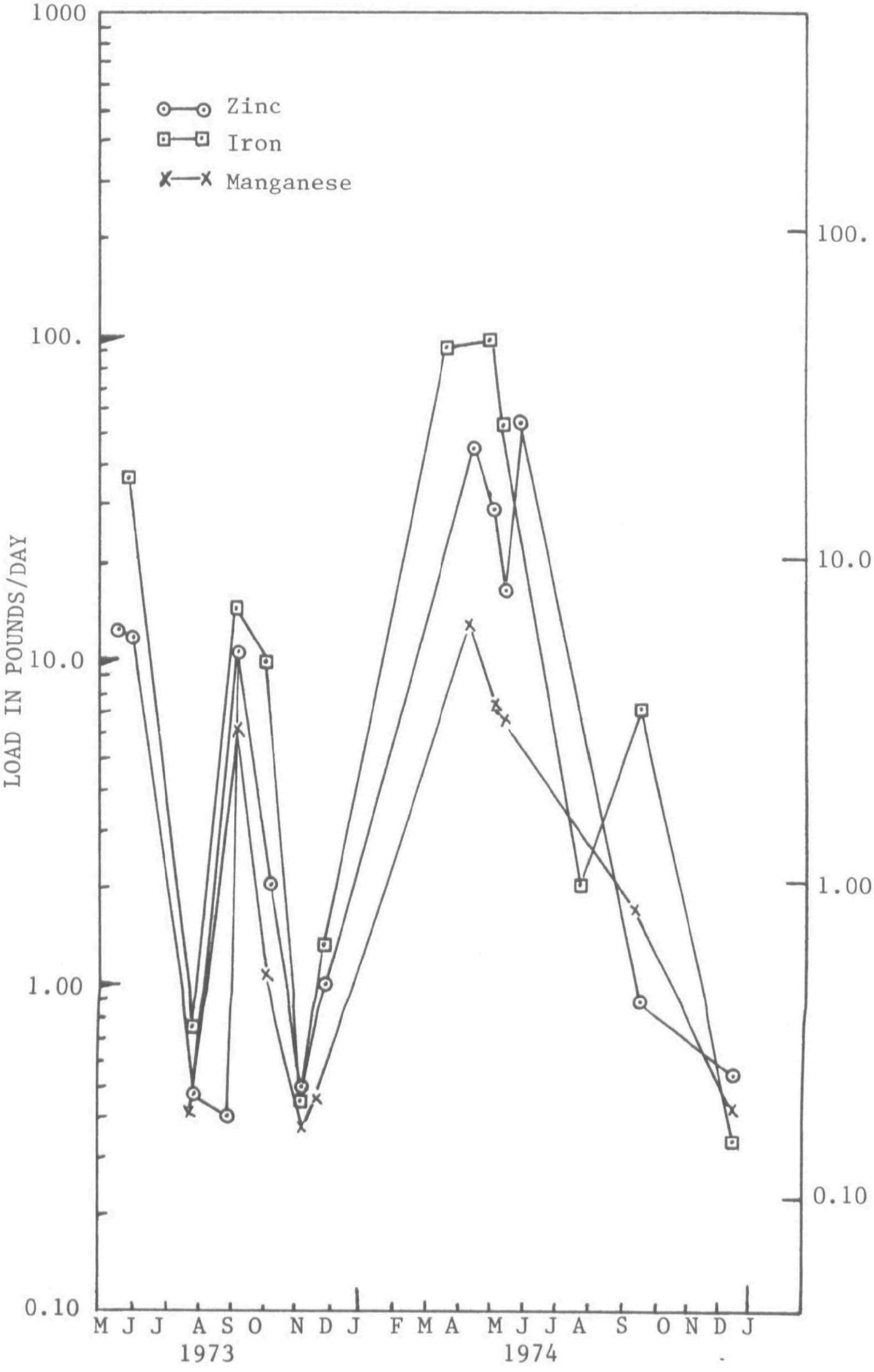

FIGURE D-4. Load versus Time at Station DF 2.

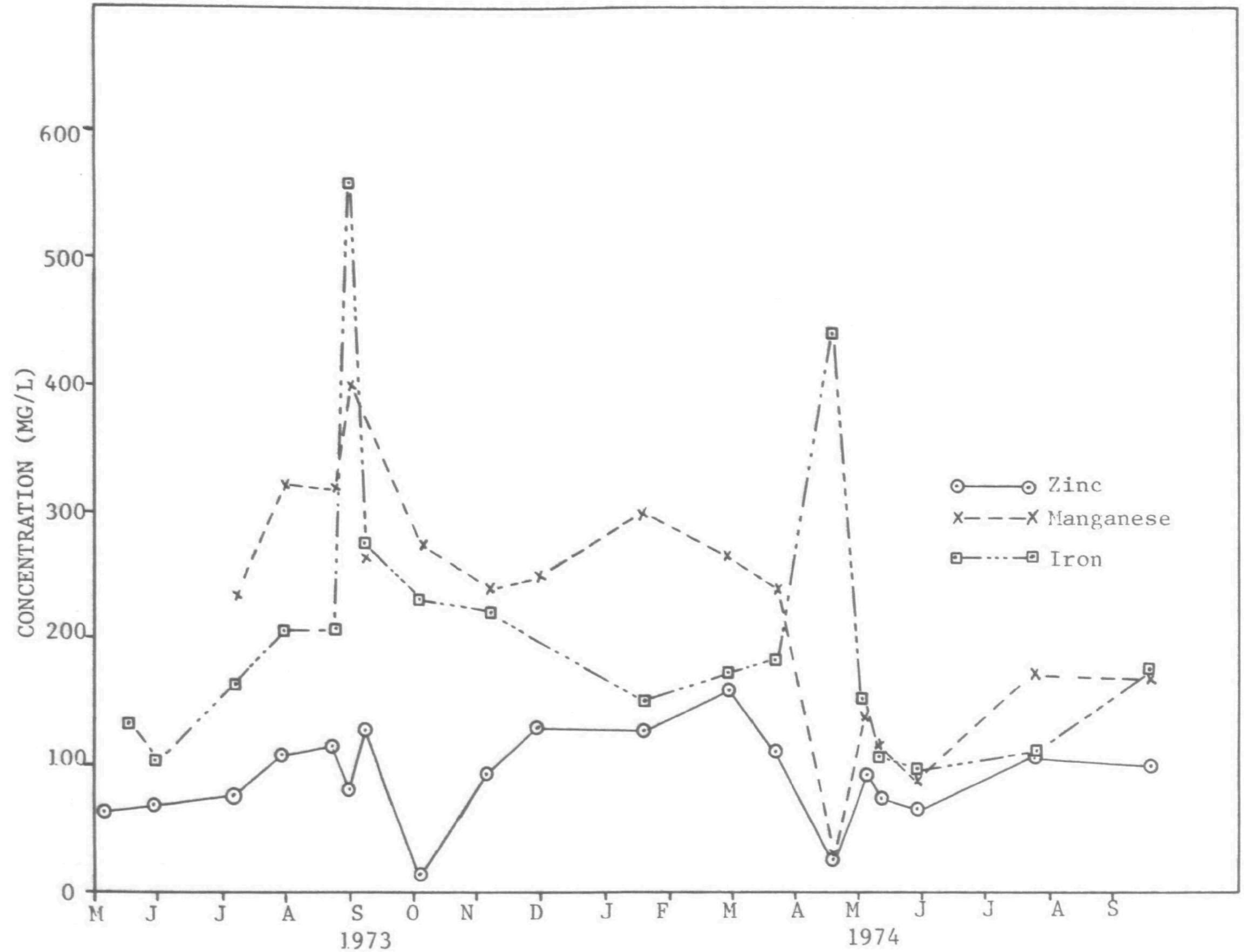

FIGURE D-5. Concentration versus Time at Station DF 3 (Liberty Mine Seep).

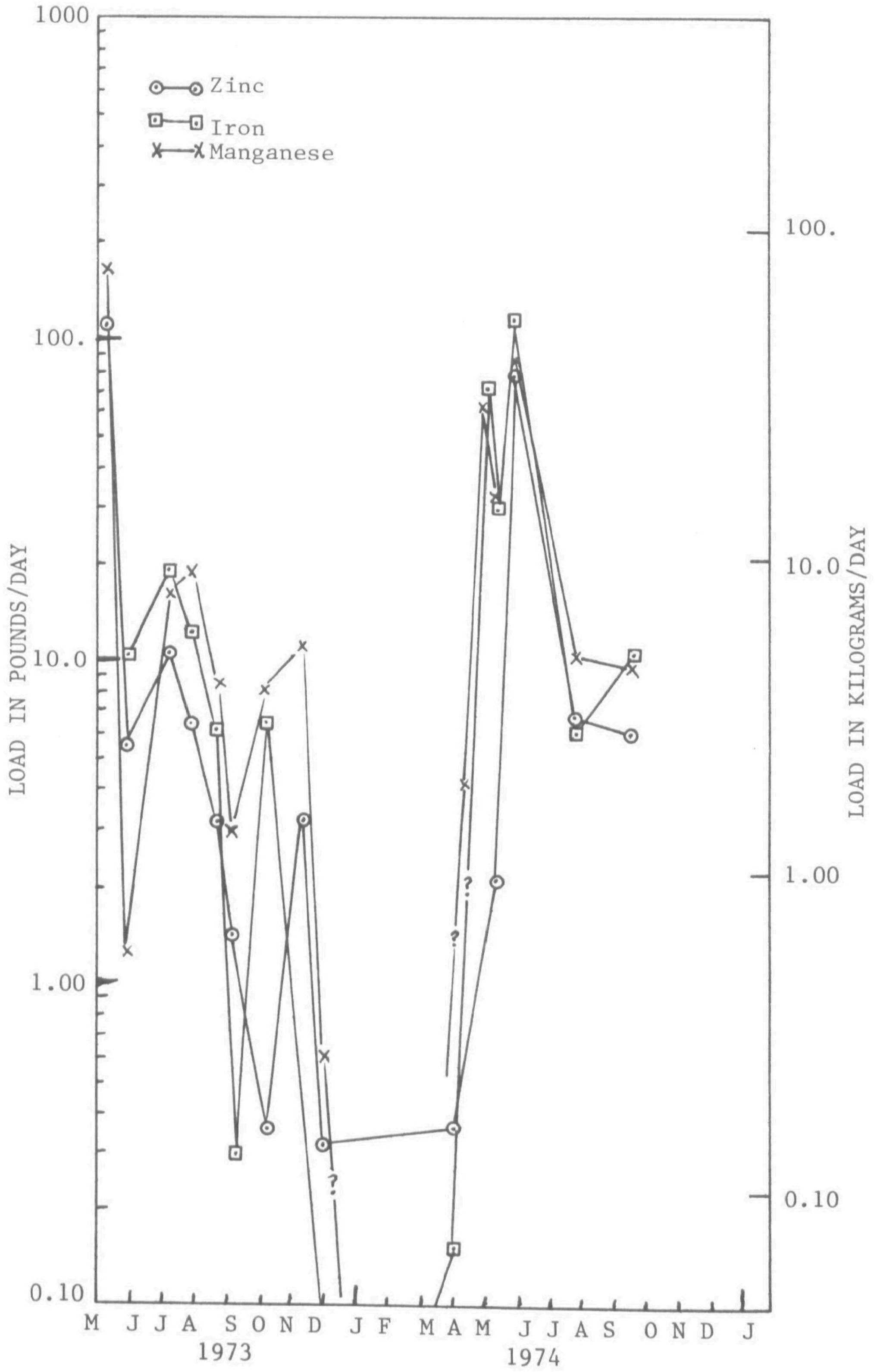

FIGURE D-6. Load versus Time at Station DF 3.

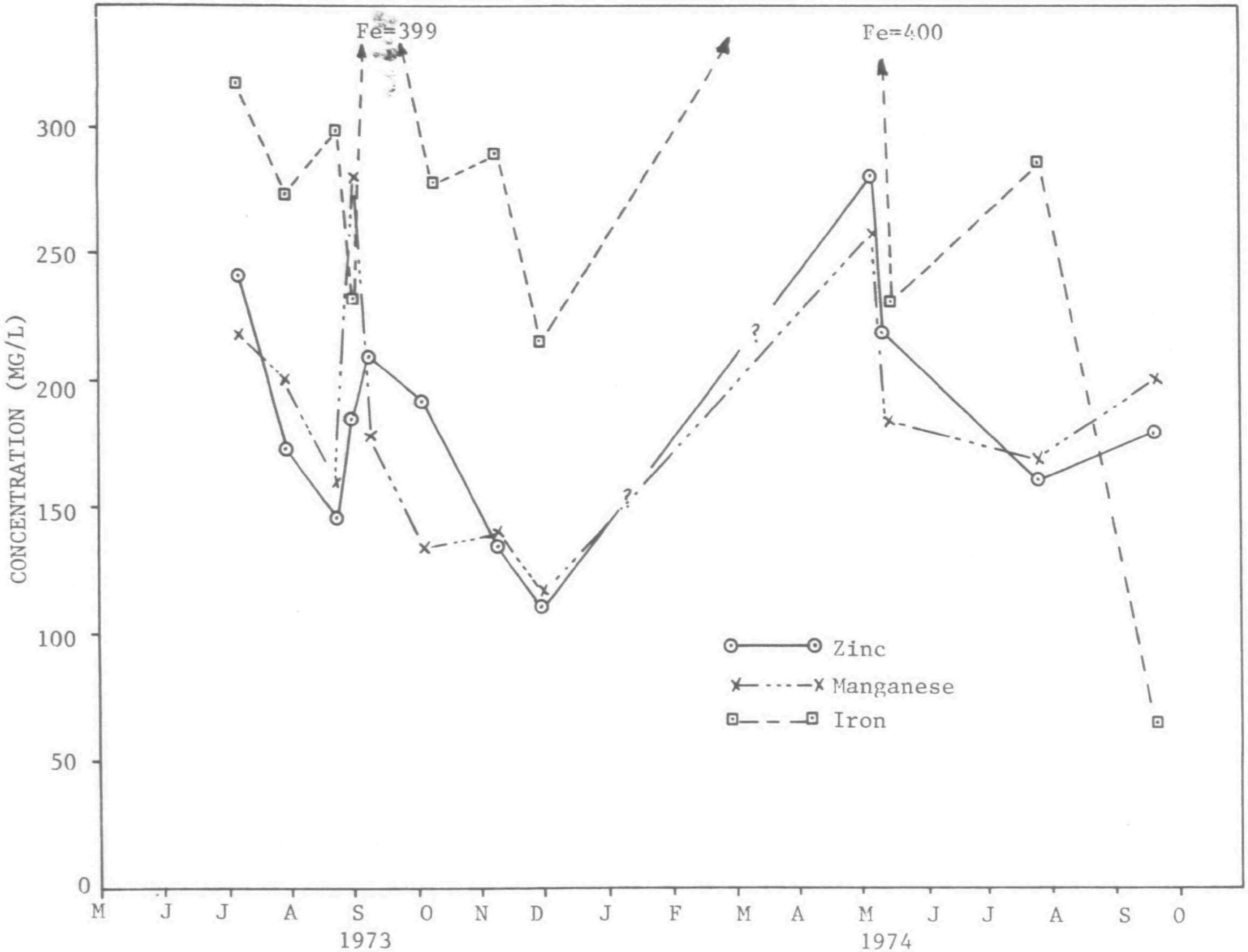

FIGURE D-7. Concentration versus Time at Station DF 5 (Spring at Abandoned Mine Cars in Galena Creek).

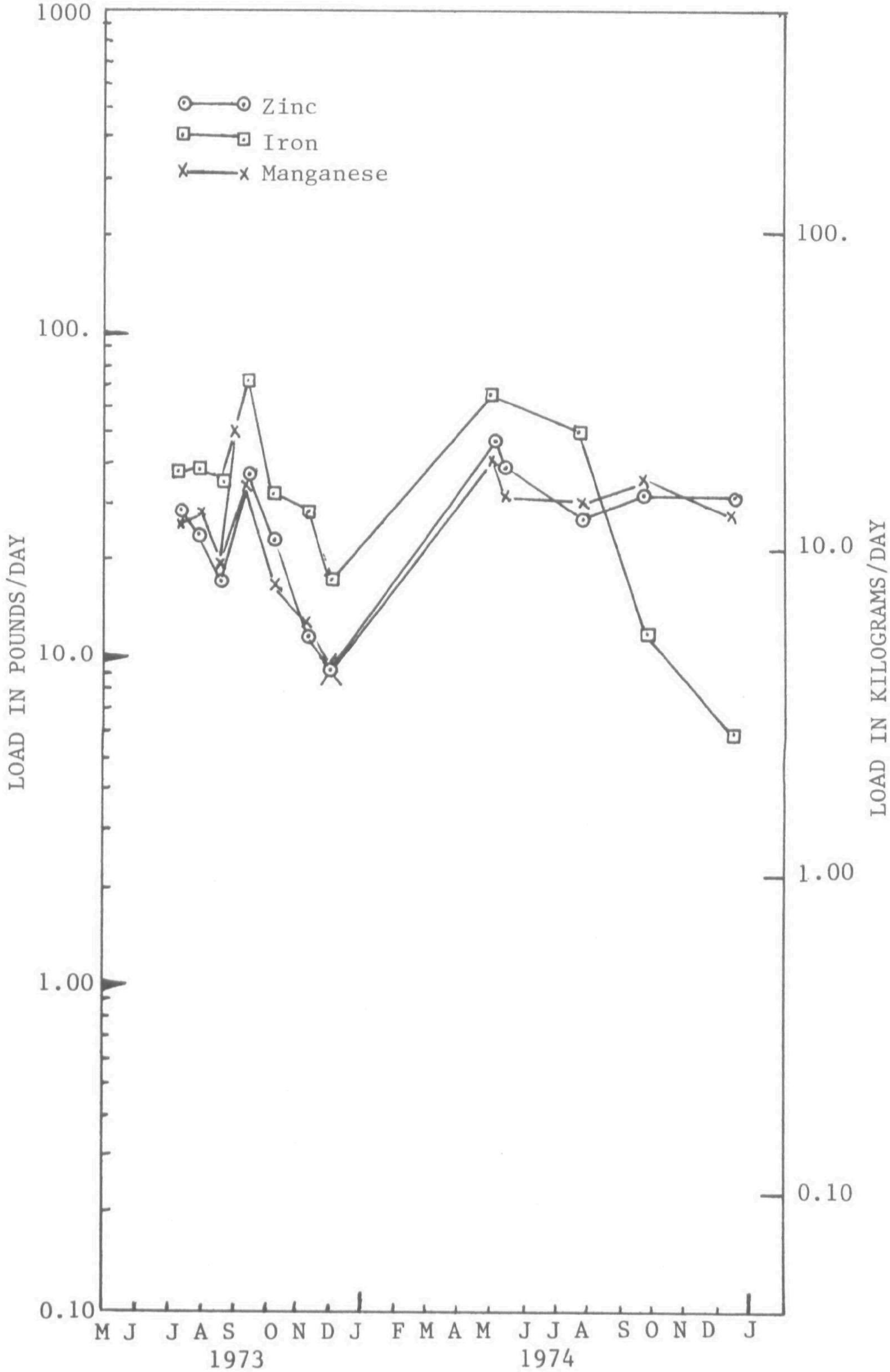

FIGURE D-8. Load versus Time at Station DF 5.

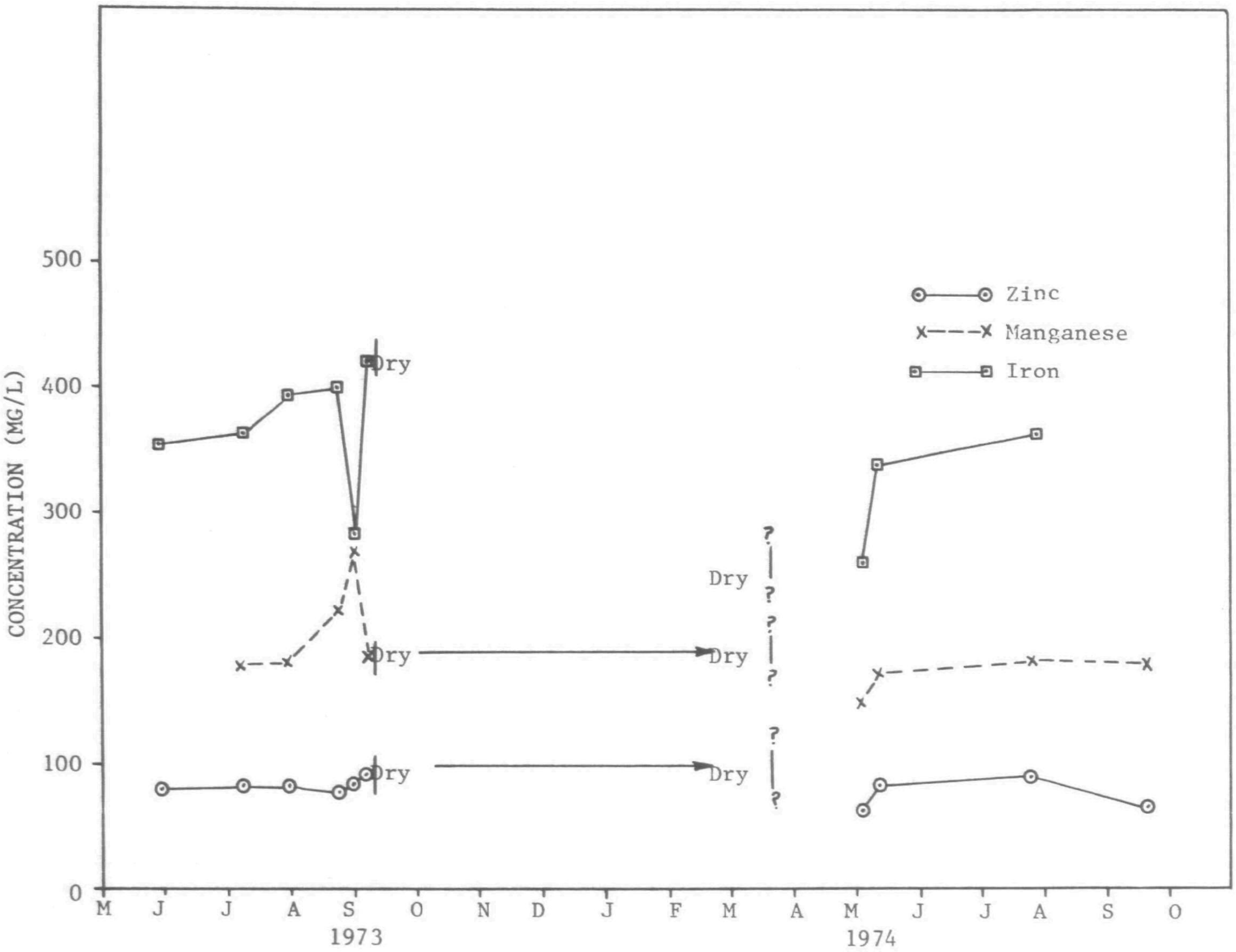

FIGURE D-9. Concentration versus Time at Station DF 6 (Spring at Block P Mine).

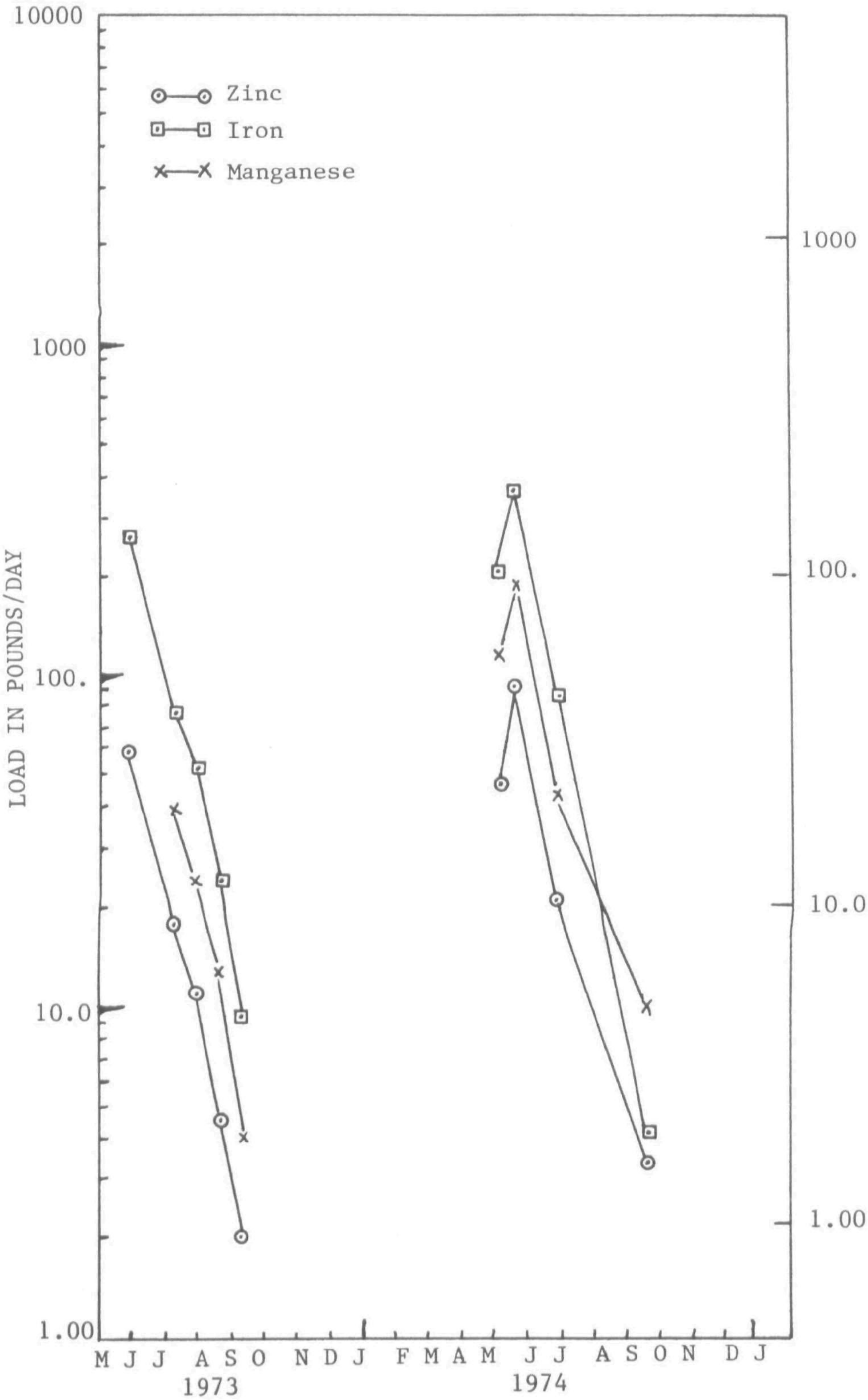

FIGURE D-10. Load versus Time at Station DF 6.

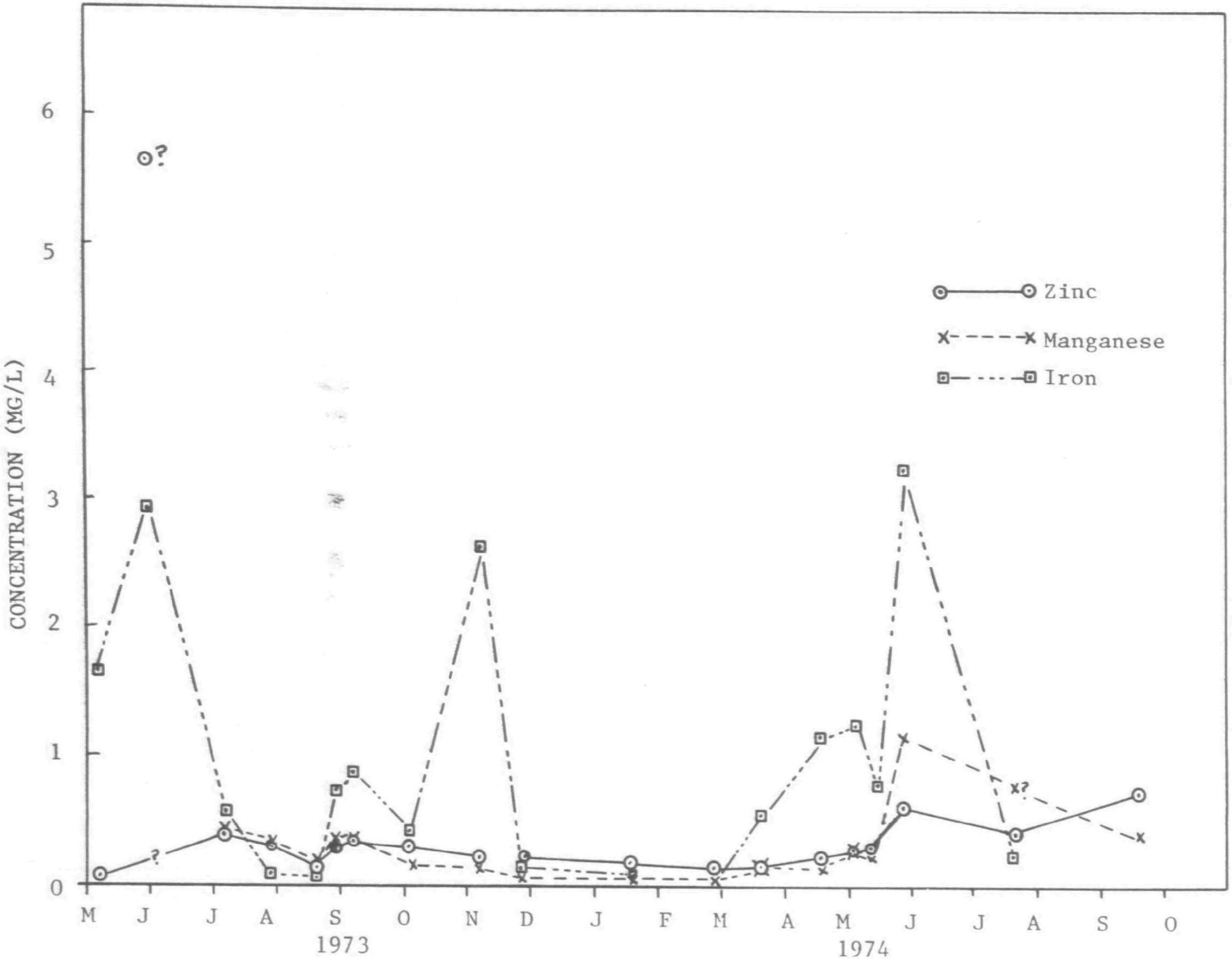

FIGURE D-11. Concentration versus Time at Station DF 7 (Galena Creek at Upper Weir).

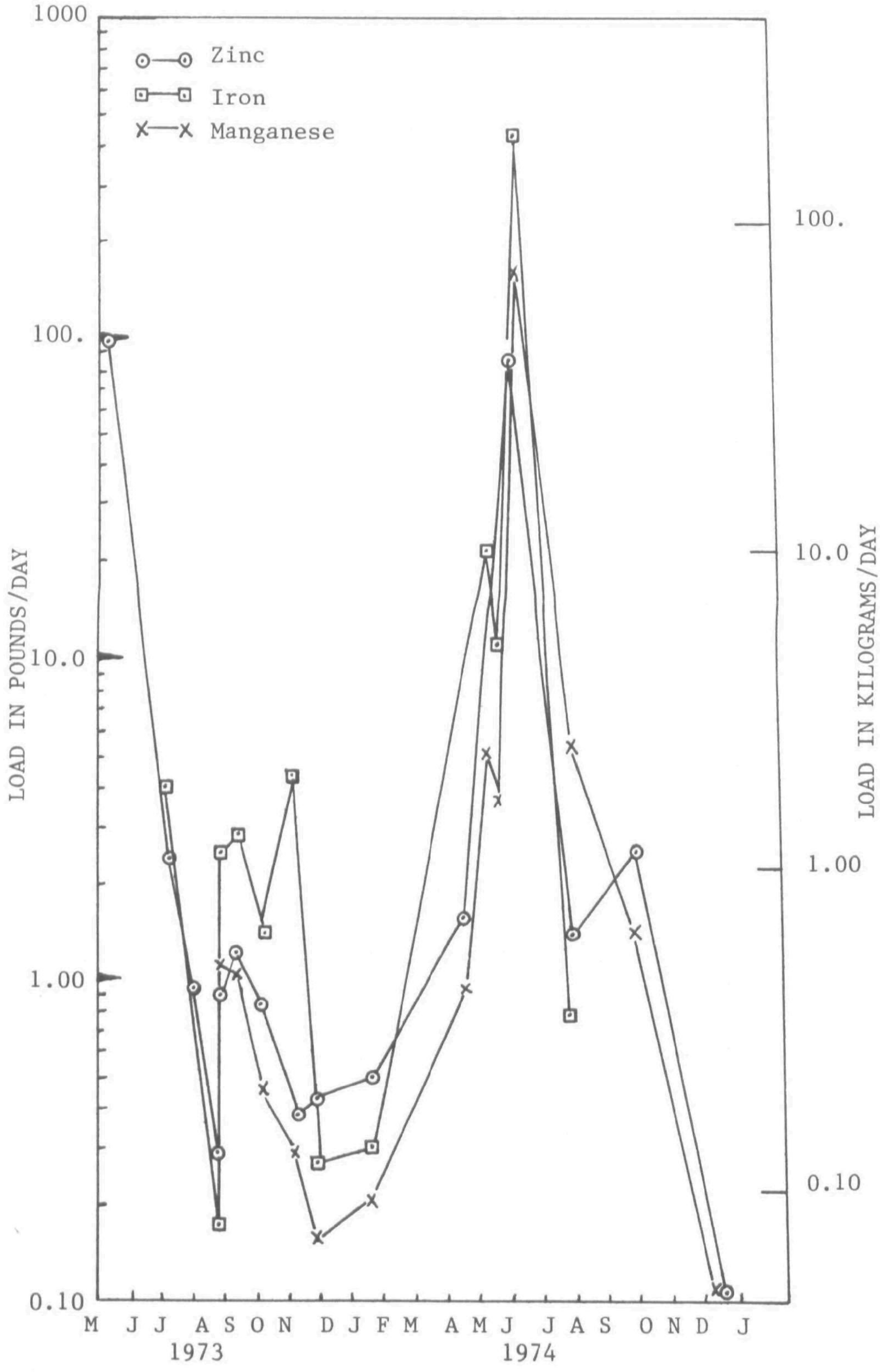

FIGURE D-12. Load versus Time at Station DF 7.

APPENDIX E

DAILY STREAMFLOW RECORDS FOR 1973 AND 1974

Contents

APPENDIX E: DAILY STREAMFLOW RECORDS

Identification of Gaging Stations

Station DF 1 Galena Creek near Barker, Montana

LOCATION: 15N 09E 18BC, Judith Basin County, 150 m (500 ft) upstream from Gold Run Creek, 16 km (10 mi) east of Monarch, Montana.

DRAINAGE AREA: 9.07 square km (3.5 square mi).

PERIOD OF RECORD: August, 1973 to November, 1974. Seasonal record published by the DNRC.

GAGE: Water-stage recorder on a 0.91 m (3 ft) Cipolleti weir. Altitude of gage is 1680 m (5515 ft), from topographic map.

Station DF 2 Silver Creek near Hughesville, Montana

LOCATION: 15N 09E 07BDB, Judith Basin County, on left bank 305 m (1000 ft) upstream from mouth, 914 m (3000 ft) south of Block P Mine at Hughesville, Montana, 16 km (10 mi) east of Monarch, Montana.

DRAINAGE AREA: 0.93 square km (0.36 square mi).

PERIOD OF RECORD: September, 1973 to November, 1974. Seasonal record published by the DNRC.

GAGE: Water-stage recorder on a 7.62 centimeter (cm) (3 in) Parshall flume. Altitude of gage is 1792 m (5880 ft), from topographic map.

Station DF 3 Liberty Mine Seep near Hughesville, Montana

LOCATION: 15N 09E 07BDA, Judith Basin County, 122 m (400 ft) upstream from mouth, 914 m (3000 ft) south of Block P Mine at Hughesville, Montana, 16 km (10 mi) east of Monarch, Montana.

DRAINAGE AREA: 0.05 square km (0.02 square mi).

PERIOD OF RECORD: September, 1973 to November, 1974. Seasonal record published by the DNRC.

GAGE: Water-stage recorder on a 7.62 cm (3 in) Parshall flume. Altitude of gage is 1829 m (6000 ft), from topographic map.

Station DF 6 Block P Seep at Hughesville, Montana

LOCATION: 15N 09E 06DCC, Judith Basin County, behind the Block P Mine building at Hughesville, Montana, and 16 km (10 mi) east of Monarch, Montana.

DRAINAGE AREA: 92.90 square m (1000 square ft).

PERIOD OF RECORD: September, 1973 to November, 1974. Seasonal record published by the DNRC.

GAGE: Water-stage recorder on a 7.62 cm (3 in) Parshall flume. Altitude of gage is 1814 m (5950 ft), from topographic map.

Station DF 7 Galena Creek at Hughesville, Montana

LOCATION: 15N 09E 06DCB, Judith Basin County on right bank 305 m (1000 ft) downstream from confluence with Green Creek, 150 m (500 ft) north of Block P Mine at Hughesville 16 km (10 mi) east of Monarch, Montana.

DRAINAGE AREA: 3.63 square km (1.4 square mi).

PERIOD OF RECORD: August, 1973 to November, 1974. Seasonal record published by the DNRC.

GAGE: Water-stage recorder on a 0.91 m (3 ft) Cipolleti weir. Altitude of gage is 1817 m (5960 ft), from topographic map.

TABLE E-1

Discharge in Liters per Second at Station DF 1 (1973)

Date	April	May	June	July	Aug.	Sept.	Oct.
1						101.	25.5
2						72.5	25.5
3						47.0	25.5
4						35.7	25.5
5						35.7	25.5
6						25.5	25.5
7						25.5	25.5
8					16.7	25.5	25.5
9					16.7	25.5	25.5
10					16.7	16.7	25.5
11					16.7	16.7	25.5
12					16.7	16.7	25.5
13					16.7	16.7	25.5
14					16.7	16.7	25.5
15					16.7	16.7	25.5
16					16.7	16.7	25.5
17					16.7	16.7	25.5
18					16.7	25.5	25.5
19					16.7	25.5	25.5
20					16.7	25.5	25.5
21					16.7	25.5	25.5
22					16.7	25.5	25.5
23					16.7	25.5	25.5
24					16.7	25.5	25.5
25					16.7	25.5	25.5
26					16.7	25.5	25.5
27					16.7	25.5	25.5
28					16.7	25.5	25.5
29					16.7	25.5	25.5
30					9.06	25.5	25.5
31					16.7		35.7

TABLE E-2

Discharge in Liters per Second at Station DF 1 (1974)

Date	April	May	June	July	Aug.	Sept.	Oct.
1	25.5				35.7	59.2	35.7
2	25.5	205.			35.7	47.0	25.5
3	25.5	205.			35.7	47.0	25.5
4	25.5	205.			35.7	47.0	25.5
5	25.5	205.			25.5	47.0	25.5
6	25.5	224.			35.7	47.0	25.5
7	25.5	205.			35.7	35.7	25.5
8	25.5	205.			86.4	47.0	25.5
9	35.7	186.			72.5	35.7	25.5
10	47.0	168.			47.0	59.2	25.5
11	47.0	168.		72.5	59.2	59.2	25.5
12	47.0	150.		59.2	59.2	47.0	25.5
13	47.0	150.		59.2	72.5	47.0	25.5
14	47.0	150.		59.2	117.	47.0	25.5
15	47.0	133.		59.2	101.	35.7	16.7
16	59.2	117.		59.2	86.4	35.7	16.7
17	72.5	101.		47.0	72.5	35.7	16.7
18		101.		59.2	59.2	35.7	16.7
19		101.		59.2	86.4	35.7	16.7
20		101.		47.0	117.	35.7	16.7
21		47.0		47.0	101.	35.7	25.5
22		117.		47.0	101.	35.7	25.5
23		150.		47.0	86.4	35.7	25.5
24		186.		47.0	72.5	35.7	25.5
25		312.		35.7	72.5	35.7	25.5
26		688.		35.7	72.5	35.7	25.5
27				35.7	59.2	35.7	25.5
28				35.7	59.2	35.7	25.5
29				35.7	59.2	35.7	16.7
30				35.7	59.2	35.7	16.7
31				35.7	59.2		16.7

TABLE E-3

Discharge in Liters per Second at Station DF 2 (1973)

Date	April	May	June	July	Aug.	Sept.	Oct.
1							.793
2							1.19
3							1.05
4							.935
5							.793
6						1.50	.793
7						1.81	.793
8						1.64	.793
9						1.33	.793
10						1.19	.680
11						1.05	.793
12						.935	.793
13						1.05	.793
14						1.19	.793
15						1.19	.793
16						1.33	.793
17						1.33	.680
18						1.19	.680
19						1.05	.680
20						1.05	.680
21						.935	.680
22						.935	.680
23						.935	.680
24						.935	1.19
25						1.05	1.05
26						1.05	.793
27						.935	.935
28						.793	1.33
29						.793	1.33
30						.793	1.19
31							1.19

TABLE E-4

Discharge in Liters per Second at Station DF 2 (1974)

Date	April	May	June	July	Aug.	Sept.	Oct.
1	.935	18.4		6.54	4.36	4.36	1.05
2	1.05	21.1		6.54	4.36	4.36	.935
3	1.05			6.54	4.36	4.36	.935
4	1.05			6.54	4.36	4.36	.935
5	1.33			6.54	4.36	4.36	2.89
6	1.33			6.83	4.59	4.36	3.91
7	1.33			5.55	4.59	4.36	.935
8	1.64	28.1		4.81	8.18	4.36	.793
9	2.52	32.1		3.09	5.07	4.36	.793
10	3.71	28.1		4.36	4.81	4.59	.793
11	3.91	23.5		4.36	5.30	4.36	.935
12	3.71	19.9		3.31		4.14	.793
13	3.31	14.4		3.31		3.71	.935
14	3.09	12.7		3.31		3.51	.793
15	3.51	9.60		3.09		3.09	.793
16	5.07	8.18		3.09		2.69	.793
17	6.29	6.83		3.09		2.52	.793
18	10.5	6.03		3.91		2.32	.793
19	14.1	5.07	12.1	4.59		2.15	.793
20	12.7	3.51	13.4	4.59		2.32	.680
21	9.60	5.55	11.1	4.59		1.81	.935
22	11.1	8.18	8.75	4.59		1.81	1.05
23	17.3	11.1	8.18	4.59		1.64	1.33
24	21.1	16.2	7.62	4.59		1.50	1.19
25	22.7	23.5	7.36	4.59		1.50	1.05
26	27.2	23.9	7.08	4.59	4.36	1.33	.935
27	27.7	23.9	6.83	4.36	4.36	1.19	.935
28	22.7	23.9	6.83	4.36	4.36	1.19	.793
29	19.5	23.1	6.83	4.36	4.36	1.05	.793
30	17.3	22.7	6.83	4.36	4.36	1.05	.793
31		21.5		4.36	4.36		1.19

TABLE E-5

Discharge in Liters per Second at Station DF 3 (1973)

Date	April	May	June	July	Aug.	Sept.	Oct.
1							.113
2							.113
3							.113
4							.453
5							.057
6							.057
7							.057
8						.057	.113
9						.057	.113
10						.057	.680
11						.057	.113
12						.057	.028
13						.057	.028
14						.368	.057
15						.113	.057
16						.198	.057
17						.113	.057
18						.113	.057
19						.113	.057
20						.057	.057
21						.057	.057
22						.057	.057
23						.057	.113
24						.057	.057
25						.057	.057
26						.057	.028
27						.057	.057
28						.057	.057
29						.057	.057
30						.057	.057
31							.057

TABLE E-6

Discharge in Liters per Second at Station DF 3 (1974)

Date	April	May	June	July	Aug.	Sept.	Oct.
1		2.32		.283	.113	.793	.113
2		2.35		.283	.113	.680	.113
3		2.52		.283	.198	.680	.113
4		2.52		.283	.113	.680	.113
5		2.32		.368	.113	.680	.566
6		2.15		1.50	.198	.680	.283
7		2.15		1.50	.198	.680	.113
8		1.81		.283	.453	.680	.057
9		1.64		.198	.453	.793	.057
10		1.50		.113	.283	1.05	.057
11		1.19		.057	.283	.680	.057
12		1.05		.198		.453	.057
13		1.05		.198		.453	.057
14		.935		.198		.453	.057
15		.935		.283		.453	.057
16		.793		.198		.368	.057
17		.793		.198		.368	.057
18	.935	.793		.283		.368	.057
19	1.64	.793	.566	.113		.368	.057
20	2.52		.793	.113		.283	.057
21	3.09		.453	.283		.283	.028
22	2.89		.368	.198		.283	.057
23	3.31		.368	.113		.283	.057
24	4.59		.368	.198		.283	.028
25	6.83		.368	.198		.198	.057
26	7.61		.283	.198	.793	.198	.057
27	6.82		.283	.198	.793	.198	.057
28	5.30		.283	.198	.793	.198	.028
29	3.91		.283	.198	.793	.198	.028
30	3.09		.283	.198	.793	.113	.057
31				.113	.680		.057

TABLE E-7

Discharge in Liters per Second at Station DF 6 (1973)

Date	April	May	June	July	Aug.	Sept.	Oct.
1							0.
2							0.
3							0.
4							0.
5							0.
6						.113	
7						.028	
8						0.	
9						0.	
10						0.	
11						0.	
12						0.	
13						0.	
14						0.	
15						0.	
16						0.	
17						0.	
18						0.	
19						0.	
20						0.	
21						0.	
22						0.	
23						0.	
24						0.	
25						0.	
26						0.	
27						0.	
28						0.	
29						0.	
30						0.	
31							

TABLE E-8

Discharge in Liters per Second at Station DF 6 (1974)

Date	April	May	June	July	Aug.	Sept.	Oct.
1		2.52			1.19	1.33	.566
2		2.69			1.05	1.33	.453
3		3.31			1.05	1.19	.453
4		3.31			1.05	1.19	.453
5		3.51			1.05	1.19	.368
6		4.14			1.05	1.19	.368
7		4.59			1.05	1.05	.368
8		4.81			1.33	1.05	.368
9		5.07			1.19	1.05	.368
10		5.07			1.05	1.05	.368
11		4.59			.935	1.05	.283
12		4.36			1.05	1.05	.368
13		4.14			1.50	.936	.283
14		3.51			1.33	.936	.283
15		2.89			1.19	.936	.283
16		2.69			1.19	.936	.283
17		2.32			1.05	.793	.198
18		2.15			1.05	.793	.198
19		2.15	5.07		1.19	.793	.198
20		1.98	4.59		1.19	.793	.198
21		2.32	4.14		1.33	.680	.198
22		2.89	3.91		1.50	.680	.198
23			3.71		1.50	.680	.198
24			3.51		1.50	.680	.198
25			3.31	1.33	1.50	.680	.198
26			3.31	1.33	1.50	.566	.198
27				1.33	1.33	.566	.198
28				1.33	1.33	.566	.113
29				1.19	1.33	.566	.057
30				1.19	1.33	.566	.057
31				1.19	1.33		.113

TABLE E-9

Discharge in Liters per Second at Station DF 7 (1973)

Date	April	May	June	July	Aug.	Sept.	Oct.
1						35.7	16.7
2						35.7	16.7
3						25.5	16.7
4						16.7	16.7
5						16.7	16.7
6						16.7	16.7
7						16.7	9.06
8					9.06	16.7	9.06
9					16.7	16.7	9.06
10					9.06	16.7	9.06
11					9.06	16.7	9.06
12					9.06	16.7	9.06
13					9.06	16.7	9.06
14					9.06	16.7	9.06
15					9.06	16.7	9.06
16					9.06	16.7	9.06
17					9.06	16.7	9.06
18					9.06	16.7	9.06
19					9.06	16.7	9.06
20					9.06	16.7	9.06
21					9.06	16.7	9.06
22					9.06	9.06	9.06
23					9.06	9.06	9.06
24					9.06	9.06	9.06
25					9.06	9.06	9.06
26					9.06	9.06	9.06
27					9.06	9.06	9.06
28					9.06	9.06	9.06
29					9.06	9.06	9.06
30					9.06	9.06	9.06
31					9.06		9.06

TABLE E-10

Discharge in Liters per Second at Station DF 7 (1974)

Date	April	May	June	July	Aug.	Sept.	Oct.
1	9.06	86.4		35.7	16.7	25.5	16.7
2	9.06	86.4		35.7	16.7	25.5	16.7
3	9.06	86.4		35.7	16.7	25.5	16.7
4	9.06	86.4		25.5	16.7	25.5	16.7
5	9.06	86.4		25.5	9.06	25.5	16.7
6	9.06	101.		25.5	16.7	16.7	16.7
7	9.06	101.		47.0	16.7	16.7	16.7
8	9.06	101.		35.7	59.2	16.7	16.7
9	9.06	86.4		25.5	47.0	16.7	9.06
10	9.06	86.4		35.7	47.0	25.5	9.06
11	16.7	72.4		35.7	35.7	25.5	9.06
12	16.7	72.4		25.5	35.7	25.5	9.06
13	16.7	101.		25.5	47.0	25.5	9.06
14	16.7	72.4		25.5	72.5	25.5	9.06
15	16.7	59.2		25.5	59.2	25.5	9.06
16	16.7	59.2		25.5	59.2	25.5	9.06
17	25.5	47.0		16.7	47.0	25.5	9.06
18	35.7	47.0		25.5	35.7	16.7	9.06
19	59.2	47.0		25.5	59.2	16.7	9.06
20	72.5	47.0	72.5	25.5	72.5	16.7	9.06
21	59.2	101.	72.5	16.7	72.5	16.7	9.06
22	59.2	86.4	72.5	16.7	72.5	16.7	9.06
23	86.4	59.2	59.2	16.7	59.2	16.7	9.06
24	150.	86.4	59.2	16.7	47.0	16.7	9.06
25	205.	168.	59.2	16.7	47.0	16.7	9.06
26	224.		47.0	16.7	35.7	16.7	9.06
27	186.		47.0	16.7	25.5	16.7	9.06
28	132.		47.0	16.7	25.5	16.7	9.06
29	86.4		35.7	16.7	25.5	16.7	9.06
30	86.4		35.7	16.7	25.5	16.7	9.06
31				16.7	25.5		

APPENDIX F

CLIMATOLOGICAL DATA FOR 1973 AND 1974

Contents

TABLE F-1.
1973 MAXIMUM AND MINIMUM AIR TEMPERATURE -- C*

DAY	JAN	FEB	MAR	APR	MAY	JUN		JUL		AUG		SEP		OCT		NOV		DEC	
1								20	2	29	7	9	3						
2								15	-1	31	8	5	2	23	0				
3								22	4	29	9	13	0	1	-6			9	-5
4								26	7	24	11			8	-6	3	-22	0	-5
5								28	7	23	8							0	-14
6								25	5	26	4	24	4	17	-3			2	-7
7						23	12	24	0	18	1	24	5	14	1				
8						20	9	23	2	19	3	19	7						
9						25	3	27	6	23	6								
10						15	1	28	8	28	7	21	6	11	-8	12	-19		
11						16	-2	32	9	24	7	21	5			13	1		
12						17	1	26	2	20	6	23	6						
13						26	5	23	3	24	6	20	0	16	-4				
14						25	6	20	2	31	6			16	6			6	-13
15						17	2	24	3	27	7							0	-9
16						9	0	27	6	29	8	5	-6			12	-3		
17						13	1	26	5	31	6					6	-3		
18						5	0	18	4	29	6			19	0				
19						4	0	24	6	23	2	20	-5	19	2				
20						16	0	26	9	28	4	14	-4	20	5				
21						19	2	24	8	31	10	14	0						
22						24	2	14	4	28	10	11	-1					8	-14
23						28	8	15	7	23	3	17	0			2	-13		
24						26	9	21	3	26	5					-1	-7		
25						20	11	22	5	17	2			19	0				
26						21	8	26	6	17	2	12	0	4	-6				
27						23	7	25	7	24	3	13	0	11	-3				
28						23	7	27	4	23	3	23	0	13	0				
29						27	8	23	4	21	3	22	0			7	-13		
30						23	5	24	4	24	4	23	2	16	2	9	-3		
31								26	6	26	5								

* AT BARKER, MONTANA, ELEVATION 1737 METERS, LATITUDE 47-04, LONGITUDE 110-38.
SOURCE: MONTANA DEPARTMENT OF NATRUAL RESOURCES AND CONSERVATION

TABLE F-2.

1974 MAXIMUM AND MINIMUM AIR TEMPERATURE -- C*

DAY	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC	
1											14	-2	27	7	23	6	10	0	14	-2	13	-2		
2			3	-22	8	-9	8	-6	17	-1	20	1	23	7	15	2	9	-4	16	3				
3			0	-6							21	6	16	1	21	2	17	-2			3	-10	9	-8
4									14	-4	14	4	21	2	23	6	20	2	21	-2	5	-8	8	-1
5							6	-7			11	3	26	6	26	7	23	2	8	-5	8	-7		
6							11	0			13	-2	21	7	29	9	16	2						
7							6	-6			9	-1	19	4	20	5	20	3	11	-10	9	-4		
8							11	-3	20	-3	13	1	19	4	17	3	19	2						
9			4	-15	4	-15	12	0			14	-1			17	3			20	-6				
10			5	-5									26	4	14	1			21	2				
11							11	0	12	-3	24	0	23	5	19	3	21	-3	15	2	12	-10	8	-11
12											24	4	15	2			-1	-6	15	-2				
13	5	-36					6	-4			25	4	22	4					15	-1	8	-7	3	-12
14									12	-4	25	7	24	7	22	1	17	-4					-2	-12
15							11	-5			28	6	28	11	12	1	22	0						
16			7	-7							27	8	28	8			23	1	18	-7	5	-11		
17			6	-6	12	-13					28	8	26	6	21	0			22	2				
18			0	-6							28	9	28	7	22	4	26	1	22	2				
19	10	-9					18	-6	10	-7	31	8	27	8	25	6	21	0	22	2				
20	3	-6											28	11					24	3			5	-12
21											24	7	27	6			13	-3						
22											17	6	26	7			17	-3	22	-6	12	-7		
23			5	-16	9	-24			16	-4	23	6	28	6	22	1								
24			0	-16			20	-3			27	7	24	4	21	6	23	1						
25	3	-11							18	0	31	8	26	6	23	6	22	6	15	-3				
26							23	0	16	2	27	9	26	3	23	3	25	5	18	0	6	-9	7	-21
27									17	2	22	2	26	5	20	6			15	-2			3	-6
28	3	-9									24	6	25	6	22	4	16	-2						
29	3	-2			13	-13					24	5	26	9	13	0	13	-1	16	-1	3	-11		
30							12	-6	14	0	21	3	28	11	20	3								
31									14	-2			22	7	13	0								

* AT BARKER, MONTANA, ELEVATION 1737 METERS, LATITUDE 47-04, LONGITUDE 110-38.
SOURCE: MONTANA DEPARTMENT OF NATRUAL RESOURCES AND CONSERVATION

TABLE F-3.
1973 MAXIMUM AND MINIMUM PAN WATER TEMPERATURE -- C*

DAY	JAN	FEB	MAR	APR	MAY	JUN		JUL		AUG		SEP		OCT	NOV	DEC
1								20	8	23	9	11	6			
2								8	4	27	11	7	5			
3								27	5	27	11	14	3			
4								27	9	19	12					
5								26	12	21	10					
6								27	11	23	9					
7						12	9	24	7	21	7	23	12			
8						15	11	24	7	17	7	23	11			
9						24	8	27	9	24	6					
10						14	5	27	11	25	9	22	3			
11						19	4	29	11	22	11	22	5			
12						21	4	26	8	21	9	21	5			
13						25	7	26	7	23	9					
14						23	11	24	7	23	9					
15						15	6	26	7	26	11					
16						12	3	27	9	26	11					
17						14	3	26	11	24	9					
18						7	3	22	9	25	7					
19						4	2	26	9	22	6					
20						6	3	26	11	23	9					
21						23	5	26	11	24	9					
22						27	8	14	8	21	9					
23						24	9	16	11	17	8					
24						19	9	25	9	17	11					
25						23	8	26	9	19	8					
26						21	10	26	9	17	7					
27						26	11	24	9	22	7					
28						27	11	26	9	18	6					
29						26	11	26	10	21	6					
30						21	9	24	10	23	7					
31								18	9	19	8					

* AT BARKER, MONTANA, ELEVATION 1737 METERS, LATITUDE 47-04, LONGITUDE 110-38.
SOURCE: MONTANA DEPARTMENT OF NATRUAL RESOURCES AND CONSERVATION

TABLE F-4.
1974 MAXIMUM AND MINIMUM PAN WATER TEMPERATURE -- C*

DAY	JAN	FEB	MAR	APR	MAY	JUN max	JUN min	JUL max	JUL min	AUG max	AUG min	SEP max	SEP min	OCT	NOV	DEC
1								26	9	27	11	9	3			
2								27	11	17	7	11	2			
3								16	7	24	7	17	8			
4						17	7	22	7	24	7	19	2			
5						14	5	27	8	28	9	22	3			
6						13	3	26	8	27	11	21	6			
7						12	3	22	8	21	10	17	7			
8						16	5	18	9	17	9	17	7			
9						15	4			11	7					
10								23	9	14	4					
11						24	6	24	10	17	4	17	2			
12						26	8	21	7							
13						27	9	24	7							
14						28	10	28	9	25	5					
15						29	11	31	12	13	5					
16						29	12	26	12							
17						30	11	28	12	5	7					
18						30	12	30	12	23	8					
19						29	14	23	14	22	7					
20								28	11							
21						27	11	27	11							
22						18	9	28	11							
23						25	9	28	11	19	4					
24						27	10	28	9	20	9					
25						28	11	27	9	23	9					
26						31	11	26	9	23	9					
27						27	7	27	8	23	10					
28						27	7	25	9	24	10					
29						25	8	31	9	14	4					
30						24	9	28	9	21	5					
31								24	11	16	5					

* AT BARKER, MONTANA, ELEVATION 1737 METERS, LATITUDE 47-04, LONGITUDE 110-38.
SOURCE: MONTANA DEPARTMENT OF NATRUAL RESOURCES AND CONSERVATION

TABLE F-5.
1973 PRECIPITATION -- MILLIMETERS*

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	.	.	.	.	.	.	21.58	0	37.08	.	.	.
2	.	.	.	.	.	.	0	0	39.62	10.92	.	.
3	.	.	.	.	.	.	0	0	0	0	.	0
4	.	.	.	.	.	.	0	1.01	.	0	0	0
5	.	.	.	.	.	.	0	0	.	.	.	0
6	.	.	.	.	.	.	0	0	0	0	.	0
7	.	.	.	.	.	0	0	0	2.53	0	.	.
8	.	.	.	.	.	0	0	2.53	5.58	.	.	.
9	.	.	.	.	.	0	0	0	.	.	.	.
10	.	.	.	.	.	0	0	0	.50	2.79	11.68	.
11	.	.	.	.	.	0	0	2.28	0	.	0	.
12	.	.	.	.	.	0	0	0	0	.	.	.
13	.	.	.	.	.	0	0	0	0	0	.	.
14	.	.	.	.	.	0	0	0	.	1.77	.	9.65
15	.	.	.	.	.	36.82	0	0	.	.	.	0
16	.	.	.	.	.	4.31	0	0	10.66	.	4.82	.
17	.	.	.	.	.	2.53	0	0	.	.	.50	.
18	.	.	.	.	.	5.58	0	0	.	1.77	.	.
19	.	.	.	.	.	29.20	0	0	0	0	.	.
20	.	.	.	.	.	0	0	0	3.55	0	.	.
21	.	.	.	.	.	0	0	0	0	.	.	.
22	.	.	.	.	.	0	4.06	0	0	.	.	15.74
23	.	.	.	.	.	0	5.84	2.03	0	.	3.04	.
24	.	.	.	.	.	0	0	16.50	.	.	1.01	.
25	.	.	.	.	.	0	0	0	.	23.62	.	.
26	.	.	.	.	.	0	0	0	8.38	0	.	.
27	.	.	.	.	.	0	0	0	0	0	.	.
28	.	.	.	.	.	0	0	0	0	0	.	.
29	.	.	.	.	.	.76	0	0	0	.	1.01	.
30	.	.	.	.	.	0	0	0	0	.25	.50	.
31	.	.	.	.	.	.	0	0	.	.	.	.
TOTAL						79.20	31.50	24.35	107.90	41.12	22.56	25.39

* AT BARKER, MONTANA, ELEVATION 1737 METERS, LATITUDE 47-04, LONGITUDE 110-38.
SOURCE: MONTANA DEPARTMENT OF NATRUAL RESOURCES AND CONSERVATION

TABLE F-6.
1974 PRECIPITATION -- MILLIMETERS*

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	.	.	.	.	.	. 0	. 0	. 0	6.35	. 0	. 0	.
2	.	. 0	2.03	9.65	. 0	. 0	. 0	. 0	. 0	. 0	.	.
3	.	. 0	.	.	.	. 0	2.28	. 0	. 0	.	2.79	. 0
4	.	.	.	.	. 0	1.01	. 0	. 0	. 0	. 0	. 0	. 0
5	.	.	.	12.19	.	5.33	. 0	. 0	1.77	2.53	. 0	.
6	.	.	.	1.26	.	. 0	9.65	. 0	. 0	.	.	.
7	.	.	.	2.03	.	.76	24.38	10.15	. 0	. 0	. 0	.
8	.	.	.	. 0	. 0	20.57	21.58	11.68	. 0	.	.	.
9	.	17.77	8.12	. 0	.	. 0	.	29.46	.	. 0	.	.
10	.	. 0	.	.	.	.	. 0	2.28	.	. 0	.	.
11	.	.	.	5.33	.50	. 0	17.52	8.63	29.71	. 0	4.82	. 0
12	.	.	.	.	.	. 0	1.77	.	. 0	. 0	.	.
13	53.33	.	.	8.38	74.68	. 0	. 0	.	.	. 0	23.11	18.03
14	.	.	.	.	27.94	. 0	. 0	38.10	. 0	.	.	. 0
15	.	.	.	.50	.	. 0	. 0	2.53	. 0	.	.	.
16	.	. 0	.	.	.	. 0	3.30	.	. 0	. 0	. 0	.
17	.	. 0	7.36	.	.	. 0	. 0	. 0	.	. 0	.	.
18	.	. 0	.	.	.	. 0	. 0	. 0	. 0	. 0	.	.
19	. 0	.	.	. 0	7.11	. 0	11.17	. 0	. 0	. 0	.	.
20	. 0	.	.	.	.	.	. 0	.	.	. 0	.	12.70
21	.	.	.	.	.	22.85	. 0	.	. 0	.	.	.
22	.	.	.	.	.	. 0	. 0	.	. 0	16.50	. 0	.
23	.	11.42	21.58	.	94.23	. 0	. 0	36.57	.	.	.	.
24	.	. 0	.	. 0	.	. 0	. 0	. 0	. 0	.	.	.
25	9.14	.	.	.	. 0	. 0	. 0	. 0	. 0	. 0	.	.
26	.	.	.	. 0	. 0	. 0	. 0	. 0	. 0	. 0	. 0	18.28
27	.	.	.	.	. 0	. 0	. 0	. 0	.	. 0	.	. 0
28	1.26	5.07	.	.	.	. 0	. 0	. 0	7.11	.	.	.
29	. 0	.	1.26	.	.	. 0	. 0	. 0	.76	. 0	. 0	.
30	5.58	.	.	18.03	19.81	. 0	. 0	3.04	.	.	.	.
31	.	.	.	.	2.03	.	.76	. 0	.	11.42	.	.
TOTAL	69.31	34.26	40.35	57.37	225.80	50.52	92.41	142.44	45.70	30.45	30.72	49.01

* AT BARKER, MONTANA, ELEVATION 1737 METERS, LATITUDE 47-04, LONGITUDE 110-38.
SOURCE: MONTANA DEPARTMENT OF NATRUAL RESOURCES AND CONSERVATION

TABLE F-7.
1973 WIND TOTAL -- KILOMETERS*

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	.	.	.	.	.	.	28.3	240.3	345.9	.	.	.
2	.	.	.	.	.	.	59.5	242.6	348.5	437.6	.	.
3	.	.	.	.	.	.	64.3	249.2	348.5	437.6	.	1475.1
4	.	.	.	.	.	.	74.8	249.8	.	450.5	766.2	1504.4
5	.	.	.	.	.	.	81.5	250.1	.	.	.	1512.4
6	.	.	.	.	.	.	116.0	273.5	349.1	476.2	.	1552.3
7	.	.	.	.	.	1145.2	135.9	278.0	349.1	483.9	.	.
8	.	.	.	.	.	1184.2	142.7	290.4	353.9	.	.	.
9	.	.	.	.	.	1245.3	147.0	295.2	.	.	.	.
10	.	.	.	.	.	929.6	149.9	296.3	353.9	496.3	837.0	.
11	.	.	.	.	.	1283.4	153.6	297.6	353.9	.	877.7	.
12	.	.	.	.	.	1298.7	159.4	298.4	353.9	.	.	.
13	.	.	.	.	.	1299.1	161.5	299.2	366.8	561.5	.	.
14	.	.	.	.	.	1331.7	174.5	302.8	.	563.1	.	134.6
15	.	.	.	.	.	1333.8	179.4	307.3	.	.	.	146.7
16	.	.	.	.	.	1362.8	190.9	312.1	370.0	.	1078.5	.
17	.	.	.	.	.	1386.1	194.3	315.3	.	.	1105.3	.
18	.	.	.	.	.	1401.1	200.4	320.1	.	611.9	.	.
19	.	.	.	.	.	1441.5	203.3	321.7	378.1	621.5	.	.
20	.	.	.	.	.	1448.0	203.6	323.0	382.9	624.2	.	.
21	.	.	.	.	.	1454.5	207.5	325.6	390.1	.	.	.
22	.	.	.	.	.	1464.5	209.0	326.1	390.5	.	.	271.9
23	.	.	.	.	.	1484.1	209.6	326.7	394.2	.	1157.1	.
24	.	.	.	.	.	1505.2	211.5	328.2	.	.	1176.9	.
25	.	.	.	.	.	1553.8	215.6	329.8	.	668.8	.	.
26	.	.	.	.	.	1596.1	223.6	330.6	410.2	674.9	.	.
27	.	.	.	.	.	3.0	230.0	333.0	418.3	688.6	.	.
28	.	.	.	.	.	10.4	230.2	334.9	431.2	695.5	.	.
29	.	.	.	.	.	16.2	234.9	341.1	432.8	.	1351.5	.
30	.	.	.	.	.	18.6	237.4	343.5	437.6	759.4	1359.6	.
31	.	.	.	.	.	.	239.2	346.7	.	.	.	.

* AT BARKER, MONTANA, ELEVATION 1737 METERS, LATITUDE 47-04, LONGITUDE 110-38.
SOURCE: MONTANA DEPARTMENT OF NATRUAL RESOURCES AND CONSERVATION

TABLE F-8.
1974 WIND TOTAL -- KILOMETERS*

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	.	.	.	.	.	1265.3	1603.2	108.2	164.7	247.3	360.4	.
2	.	979.0	1583.2	587.2	1008.8	1289.2	8.6	109.0	165.7	249.7	.	.
3	.	994.3	.	.	.	1331.6	9.1	110.3	.0	.	360.7	815.9
4	.	.	.	.	1040.5	1353.1	17.0	113.5	167.6	.0	361.2	822.1
5	.	.	.	602.0	.	1364.7	27.0	116.6	.0	.0	363.3	.
6	.	.	.	616.8	.	1377.6	27.9	119.3	172.1	.	.	.
7	.	.	.	635.7	.	1387.9	29.6	122.2	176.9	253.7	385.1	.
8	.	.	.	643.5	1135.4	1394.0	31.5	122.6	177.7	.	.	.
9	.	1051.9	147.2	659.6	.	1400.1	.	124.2	.	.0	.	.
10	.	1064.0	.	.	.	.	37.8	124.3	.	.0	.	.
11	.	.	.	682.8	1168.7	1421.5	41.0	125.9	184.0	.0	454.3	851.1
12	.	.	.	.	.	1434.1	52.7	.	.0	299.2	.	.
13	289.6	.	.	722.6	.	1448.4	62.7	.	.	308.9	482.6	946.4
14	.	.	.	.	1180.3	1456.6	64.3	.0	.0	.	.	954.6
15	.	.	.	740.1	.	1458.7	65.1	.0	.0	.	.	.
16	.	1186.6	.	.	.	1462.5	65.9	.	187.7	324.3	492.6	.
17	.	1213.3	275.9	.	.	1467.7	67.2	.0	.	.0	.	.
18	.	1246.8	.	.	.	1471.9	68.7	.0	.0	.0	.	.
19	594.3	.	.	769.7	1197.2	1477.7	69.3	.0	.0	336.6	.	.
20	615.6	.	.	.	.	.	71.6	.	.	337.8	.	1037.1
21	.	.	.	.	.	1489.4	74.3	.	197.4	.	.	.
22	.	.	.	.	.	1489.9	78.0	.	198.2	343.8	643.5	.
23	.	1343.3	367.6	.	1198.7	1491.5	83.6	.0	.	.	.	.
24	.	1351.5	.	832.6	.	1492.8	84.1	134.1	.0	.	.	.
25	645.6	.	.	.	1202.2	1494.1	86.4	151.5	202.2	346.5	.	.
26	.	.	.	867.2	1223.1	1499.4	94.9	155.5	204.9	352.0	797.5	1181.4
27	.	.	.	.	1241.3	1515.0	97.3	155.5	.	353.3	.	1258.3
28	785.9	.	.	.	.	1525.3	99.1	157.0	223.0	.	.	.
29	859.0	.	516.9	.	.	1556.8	102.6	157.1	227.6	357.3	800.9	.
30	.	.	.	943.3	1247.7	1591.3	103.2	164.4	.	.	.	.
31	.	.	.	.	.0	.	104.5	164.9	.	.	.	.

* AT BARKER, MONTANA, ELEVATION 1737 METERS, LATITUDE 47-04, LONGITUDE 110-38.
SOURCE: MONTANA DEPARTMENT OF NATRUAL RESOURCES AND CONSERVATION

TABLE F-9.
1973 NET EVAPORATION -- MILLIMETERS*

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1						0.0	4.82	3.04	0.76			
2						0.0	3.47	4.59	0.0			
3						0.0	3.93	4.69	0.50			
4						0.0	4.19	0.48	0.0			
5						0.0	4.74	1.54	0.0			
6						0.0	5.48	1.21	0.0			
7						5.51	5.38	2.64	1.52			
8						3.68	3.80	0.50	-3.55			
9						4.06	4.41	2.74	0.0			
10						0.12	3.85	3.50	2.28			
11						4.87	5.68	-0.20	4.31			
12						2.71	4.82	2.13	1.26			
13						3.83	3.35	2.76	0.0			
14						3.47	4.82	4.03	0.0			
15						-35.48	3.20	4.24	0.0			
16						-2.64	5.20	4.54	0.0			
17						1.29	4.31	4.62	0.0			
18						-5.25	2.87	5.13	0.0			
19						-30.37	3.04	2.69	0.0			
20						1.82	1.52	3.40	0.0			
21						4.08	5.07	3.55	0.0			
22						4.95	-4.06	2.53	0.0			
23						2.87	-4.06	-1.67	0.0			
24						4.97	2.53	-13.05	0.0			
25						5.25	4.06	2.15	0.0			
26						2.84	1.52	1.85	0.0			
27						4.52	5.07	3.07	0.0			
28						4.41	4.06	2.15	0.0			
29						2.76	2.03	3.14	0.0			
30						2.23	3.25	3.09	0.0			
31						0.0	2.08	2.28	0.0			
TOTAL						-3.50	104.44	67.36	7.08			

* AT BARKER, MONTANA, ELEVATION 1737 METERS, LATITUDE 47-04, LONGITUDE 110-38.
SOURCE: MONTANA DEPARTMENT OF NATRUAL RESOURCES AND CONSERVATION

TABLE F-10.

1974 NET EVAPORATION -- MILLIMETERS*

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1						0.0	4.47	3.63	-6.29			
2						0.0	4.62	1.37	0.53			
3						0.0	-0.71	2.61	1.39			
4						0.96	3.32	2.97	2.87			
5						-5.07	5.15	4.19	-0.88			
6						1.37	-7.69	3.07	2.08			
7						-0.05	-20.31	-8.30	3.12			
8						-18.84	-19.73	-11.25	1.32			
9						1.44	0.0	0.0	0.0			
10						0.0	6.45	-0.91	0.0			
11						7.89	-12.62	-18.38	0.0			
12						5.48	2.59	0.0	0.0			
13						5.35	3.58	0.0	0.0			
14						5.15	3.78	0.0	0.0			
15						3.60	3.86	0.0	0.0			
16						4.72	-1.16	0.0	0.0			
17						4.64	3.30	1.82	0.0			
18						3.78	4.59	6.60	0.0			
19						5.28	-8.55	1.98	0.0			
20						0.0	1.14	0.0	0.0			
21						-16.86	5.76	0.0	0.0			
22						0.50	5.02	0.0	0.0			
23						2.53	3.65	-25.40	0.0			
24						2.64	2.59	1.32	0.0			
25						6.09	3.25	2.08	0.0			
26						4.54	1.90	3.80	0.0			
27						6.19	6.27	1.42	0.0			
28						2.10	4.06	3.04	0.0			
29						5.99	3.55	1.29	0.0			
30						4.31	4.01	-1.09	0.0			
31						0.0	0.93	1.42	0.0			
TOTAL						44.09	17.07	-22.72	4.14			

* AT BARKER, MONTANA, ELEVATION 1737 METERS, LATITUDE 47-04, LONGITUDE 110-38.
SOURCE: MONTANA DEPARTMENT OF NATURAL RESOURCES AND CONSERVATION.

APPENDIX G: THE CHEMISTRY OF ACID MINE DRAINAGE

Iron disulfides (FeS_2) usually occur naturally in crystalline form as pyrite or marcasite, found in varying amounts in many metal ore and coal deposits. In spoil piles and mine shafts, such as those in the study area, the disulfides are exposed to oxygen and water, causing them to decompose as illustrated in equation 1:

$$2FeS_2 + 2H_2O + 7O_2 \rightarrow 2FeSO_4 + 2H_2SO_4 \qquad (1)$$

(Pyrite + Water + Oxygen → Ferrous Sulfate + Sulfuric Acid)

The ferrous sulfate product of this reaction can be oxidized to ferric sulfate by chemical or biological reactions as in equations 2 and 3:

$$4FeSO_4 + O_2 + 2H_2SO4 \rightarrow 2Fe_2(SO_4)_3 + 2H_2O \qquad (2)$$

$$2FeSO_4 + O + H_2SO4 \xrightarrow{\text{bacteria}} Fe_2(SO_4)_3 + H_2O \qquad (3)$$

The bacteria referred to in equation 3, *Thiobacillus ferrooxidans*, accelerate oxidation of the ferrous ion.

The ferric sulfate produced by biological or chemical means in equations 2 and 3 can then contribute further to acid formation in two ways. First, it can serve as an oxidizing agent, oxidizing additional sulfides as in equation 4:

$$Fe_2(SO_4)_3 + FeS_2 \rightarrow 3FeSO_4 + 2S \qquad (4)$$

The elemental sulfur released in this process can be utilized by the bacteria *Thiobacillus thiooxidans* as an energy source, producing more acid by the reaction illustrated in equation 5:

$$S + 3O + H_2O \xrightarrow{\text{bacteria}} 2H^+ + SO_4^= \qquad (5)$$

Second, the ferric sulfate produced in equations 2 and 3, can be hydrolyzed to form sparingly soluble ferric hydroxide and release additional sulfuric acid, as shown in equation 6:

$$Fe_2(SO_4)_3 + 6H_2O \rightarrow 2Fe(OH)_3 + 3H_2SO_4 \qquad (6)$$

Separately or in combination, chemical or bacterial oxidation indicated by these reactions produces acidic water, which usually flows through geological materials, dissolving minerals to varying degrees and thereby adding constituents to the stream load.

THE EFFECT OF ACID WATERS ON STREAMS

Although the specific effects of acid mine wastes on any stream are dependent on the concentration of those wastes, some generalizations can be made. Usually, as in Galena Creek, the acid waste produces a characteristic yellow-orange precipitate (iron hydroxides), some of which settles. The alkalinity of the receiving stream decreases, while the iron and sulfate concentration increases. If the stream contains sufficient alkalinity to maintain a pH above 4.5, most of the iron is precipitated. If sufficient alkalinity is not present in the receiving to maintain this pH, hydrolysis of ferric sulfate can occur, increasing the acidity.

The native aquatic plants and animals normally found in unpolluted streams cannot exist in a stream severely polluted by acid mine drainage. The heavy metal loading and acidity of Galena Creek make the water impotable to the wildlife in the area.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/2-77-225		

4. TITLE AND SUBTITLE
FEASIBILITY OF SILVER-LEAD MINE WASTE MANIPULATION FOR MINE DRAINAGE CONTROL

5. REPORT DATE
November 1977 issuing date

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Montana Department of Natural Resources and Conservation
Engineering Bureau
32 South Ewing
Helena, Montana 59601

10. PROGRAM ELEMENT NO.
1BB610

11. CONTRACT/GRANT NO.
S802122

12. SPONSORING AGENCY NAME AND ADDRESS
Industrial Environmental Research Laboratory - Cin., OH
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Final 3/73 - 3/75

14. SPONSORING AGENCY CODE
EPA/600/12

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The purpose of the Feasibility Study Dry Fork of Belt Creek, Montana is to examine solutions and methods of abatement of acid mine drainage problems and recommend a solution. The Galena Creek area in the Dry Fork of Belt Creek drainage contains several old mine tailings piles from which acidic waters emerge. The acidic water has destroyed the aquatic life in Galena Creek and the Dry Fork of Belt Creek as well as ruined the overall aesthetic value of both creeks.

Mine dump surface regrading and sealing are recommended as the method of reducing the acidic wastes entering Galena Creek. The top of Block P Mine dump should be sloped so as to allow proper drainage. The top should also be sealed with a bentonite seal, and top soil added to allow revegation. The bypass pipeline around the Block P dump should be extended to prevent water in Galena Creek from creating seeps in the toe of the dump.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Drainage	Acid Mine Drainage	13B
Mine Waters	Little Belt Mountains	
Water Pollution	Cascade County	
Water Quality	Judith Basin County	
Water Chemistry	Mine Waste	
	Silver Mines	

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	106
	20. SECURITY CLASS (This page)	22. PRICE
	UNCLASSIFIED	

EPA Form 2220-1 (9-73)

☆U.S. GOVERNMENT PRINTING OFFICE: 1977— 757-140/6609