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Coping with Mine Drainage Regulations

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ABSTRACT

As of May 1, 1979, only one set of basic regulations govern the control of mine drainage. These regulations are at the federal level and they stem from the passage by Congress of the Water Pollution Control Act amendments of 1972 (Public Law 92-500). That Act was amended further in 1977 but the 1977 amendments did not change the basic intent of the 1972 Act. The regulations that govern the discharge of acid mine drainage as of July 1, 1977, are the result of what Public Law 92-500 refers to as "The Best Practicable Control Technology Currently Available". The regulations and the control technologies for several categories of industries, including ore mining and dressing, were derived from studies which produced so called "Development Documents" for the industries in each category. Public Law 92-500 provided for enforcement by either state or federal agencies depending on several variables. The enforcement agency theoretically applies the effluent guidelines limitation values to a company depending on the category it fits into. The up-to-date status of the regulations for any industry at any time can be obtained from a publication called "The Environment Reporter".

The Surface Mine Control and Reclamation Act of 1977 also provides for additional regulation of the mining industry. However, mine drainage from coal mines must meet the guidelines of Public Law 92-500 and the additional regulations are relatively insignificant with respect to mine drainage.

The Resource Conservation and Recovery Act of 1976 ultimately may result in some form of regulation for mine drainage, but we are of the opinion that it will be relatively insignificant compared to the effect of Public Law 92-500.

Two types of activities are involved in coping with regulations governing mine drainage. One set of activities requires a great deal of paper shuffling and filling out forms to comply with the National Pollutant Discharge Elimination System permits in order to comply with the appropriate effluent limitations guidelines under Public Law 92-500. Since the Best Practicable Control Technology Currently Available for most industrial categories consists of lime and settle, this procedure is fairly straight forward. It assumes that the company involved has elected to treat its mine drainage and meet the effluent limitation guidelines in that fashion.

The second category of activity is extremely technical in nature and considerably more challenging. It involves technological attempts to minimize the production of mine drainage, thereby eliminating or minimizing the mine drainage to be treated in order to achieve compliance with Public Law 92-500 by lime and settle. This paper deals primarily with the second category of activity. It discusses the technological approaches we use to minimize the production of mine drainage so that treatment via lime and settle can be avoided. The approach requires delineating and altering the ground water flow systems that produce the acid mine drainage.

INTRODUCTION

In October, 1972, the 92nd Congress of the United States passed the Federal Water Pollution Control Act Amendments of 1972. The purpose of the Act was to extend earlier legislation in the areas of protection and maintenance of the quality of the environment. Designated Public Law 92-500 (PL 92-500), the amendments apply to discharges from the mining, milling, and metallurgical industries by way of Sections 301, 302, and 304, under Title III - "Standards and Enforcement, Effluent Limitations". These sections state that by July 1, 1977, the best practicable control technology currently available must be applied to waste effluent, and that by July 1, 1983, the best available technology economically achievable must be applied to point source discharges.

The Effluent guidelines for Best Practicable Control Technology Currently Available for selected mining categories are as follows:

"The quantity of pollutants or pollutant properties discharged in mine drainage from mines operated to obtain copper bearing ores, lead bearing ores, zinc bearing ores, gold bearing ores, or silver bearing ores or any combination of these ores from open-pit or underground operations other than placer deposits shall not exceed the following limitations:

	Effluent Limitations	
Effluent characteristic	Maximum for any 1 day	Average of daily values for 30 consecutive days shall not exceed --
	Milligrams per liter	
TSS	30	20
Cu	.30	0.150
Zn	1.5	.75
Pb	.6	.3
Hg	0.002	0.001
pH	Within the range 6.0 to 9.0	- - - -

Permits issued to companies in these categories must comply with the guidelines except for unusual circumstances.

The mining industry historically has been a source of waste water with low pH and high concentrations of dissolved and suspended solids. In many instances this water was discharged directly into streams with no treatment to remove dissolved metals or suspended solids. With the implementation of PL 92-500, most operating mines have constructed settling ponds and installed water treatment facilities (mostly liming facilities) to meet effluent guidelines. However, some mines were abandoned or closed prior to adoption of effluent guidelines. These mines continue to discharge poor quality water to surrounding streams. In some cases they constitute field laboratories available to study the production of acid mine drainage with an eye to reducing or eliminating it at its source.

Numerous examples of this situation exist in metal mining areas of the northwestern United States. Sceva (1973) notes areas in Oregon, Idaho, and Washington where inactive mines contribute dissolved metals such as iron, manganese, copper, and zinc to nearby drainages. High concentrations of dissolved iron and aluminum pose a major water quality problem in the vicinity of Cooke City, Montana, where two inactive gold mines are located (Sonderegger and others, 1975). Poor quality water discharging from one of the mining areas drains into nearby Yellowstone National Park. Twenty-five areas in Colorado affected by acid mine drainage have discharges high in iron and sulphate as well as other trace elements (Wentz, 1974; Moran and Wentz, 1974). Abandoned mines constitute an important area of need with respect to eliminating or minimizing acid mine drainage.

ACID MINE DRAINAGE AT THE BLACKBIRD MINING DISTRICT

The Blackbird Mining District borders the Big Horn Crags Recreational Area on the south and lies east of the Central Idaho Primitive Area. The remainder of this paper discusses the production of acid water in the district as a means of illustrating a complex technological approach to coping with regulations governing the release of acid mine drainage.

Discharge high in dissolved metals and of low pH originates from the inactive Blackbird Mine, the principal mine in the district. Poor quality water discharging from the copper-cobalt mining area flows into Panther Creek, a tributary to the Salmon River which has been designated a Wild and Scenic River by the U.S. Congress. This study was conducted by University of Idaho personnel with funding from the Surface Environment and Mining program of the USDA, Forest Service. The Idaho Bureau of Mines and Geology (IBMG) provided field vehicles throughout the course of the field study. We present it here to illustrate the approach we believe necessary to minimize the production of acid mine drainage as an alternative to brute force treatment of point source discharges with lime.

Purpose and Objectives

The objective of any such study is to delineate alternatives for water quality control with respect to mine related features and to evaluate and recommend techniques to minimize water quality problems in future mining activities with minimal cost.

The specific objectives of this study were to:

i. Determine the relationship between ground-water recharge, movement, and discharge, and acid production in underground workings and surface waste features in the Blackbird mining area.

ii. Determine the relationship between surface and ground-water quality for surface waste features and stream drainages.

iii. Determine the relative contributions of poor quality water from the various sources in the mining area by a quantitative analysis of flow and metal loads.

iv. Recommend procedures for reducing acid production from present surface and underground mining features, and recommend solutions to potential problems of acid production from future mining operations.

This study is discussed in greater detail by Baldwin, Ralston and Trexler (1978).

Description of the Blackbird Mining District

The Blackbird Mining District is located approximately 25 miles west of Salmon, Idaho, and lies within the U.S. Geological Survey's Blackbird Mountain 1:62,500 quadrangle. The mining area is drained by Blackbird and Bucktail Creeks, both tributary to Panther Creek in the Salmon River drainage. The Panther Creek drainage basin includes Blackbird Creek which drains an area of about 23 square miles and Bucktail Creek which drains an area of about 1.7 square miles. Table I presents precipitation data for the area.

Geology of the Blackbird Mining District

The geology of the Blackbird Mining District is dominated by Pre-cambrian metamorphic rocks of the Belt series (Anderson, 1947). South of the district, these impure quartzites are overlain by Tertiary age Challis Volcanic rocks while they form discordant contacts with granitic intrusive rocks contemporary with the Idaho Batholith to the north. Border facies between the metamorphic and intrusive rocks are common to the area. These metamorphic rocks have a regional scale folding system striking east-west with moderate dips to the north and east (Anderson, 1947, p. 26).

Structure

Structure in the Blackbird Mining District is dominated by several open north plunging major folds with associated drag structures. Superimposed on the large folds are smaller scale folding features of generally the same orientation. Northwest trending joint and fault systems have provided avenues for the emplacement of the ore deposits with post ore shearing contributing to the complexity of the mining situation. Cobalt and copper are the ore minerals and pyrite is associated with them.

Location and Character of the Mine

The headquarters and mill for the Blackbird Mine are located on Blackbird Creek at its confluence with Meadow Creek (Figure 1). Levels of most recent mining are located above the main complex from a main mining level at an elevation of 6850 feet to the open pit operation located at 7800 feet. Mining extends below the open pit into the Bucktail Creek drainage.

Table I Total monthly precipitation in inches at Cobalt, Idaho, for the period January 1961 through December 1977.

	October	November	December	January	February	March	April	May	June	July	August	September	Annual
61-62				0.47	1.66E	0.49-	0.68	2.80	1.84-	1.33	0.91	0.07-	
62-63	1.42	2.04-	1.62	0.65-	2.59	0.79	3.17	1.36	5.21	0.62	0.35	1.11-	
63-64	2.61	1.69	0.73	2.54-	0.71	0.77	3.36				0.97	0.49	
64-65	0.29			2.56	0.29	0.10							
65-66	0.00-	1.03	1.01	1.44	1.39					0.00-	0.76	1.63	
66-67	0.78	0.88	0.99	1.69	0.61	1.89	3.36	0.93	2.91	1.65	0.24	1.48	17.41
67-68	2.98	0.47	0.99	0.72	1.69	0.86	1.07	1.42	2.29	1.99	3.34	2.48	20.30
68-69	0.76	3.24	1.27	2.58	0.39	0.63	1.09	0.99	2.52	1.76	0.13	0.68	16.04
69-70	0.99	0.64	1.52	2.75	0.40	1.85	1.08	1.65	3.42	1.35	0.49	2.68	18.82
70-71	1.76	2.06	1.50	3.33	1.10	1.70	3.25	2.54	1.56*	0.88	0.77	0.68	21.13
71-72	1.02	1.65	2.78	2.21	1.77	2.03	1.30	1.01	2.12	0.67	1.61	1.65	19.82
72-73	0.84	1.08	1.19	0.91	0.05	0.91	1.34	0.72	2.00	0.93	0.97	2.58	13.52
73-74	0.92	2.85	2.23	1.89E	0.83	2.89	0.59	1.63	0.43	0.74	1.45	0.18	16.63
74-75	0.75	0.87	1.17	3.26	1.02	1.18	2.65	1.88	1.65	3.30	1.80	0.32	19.85
75-76	3.20	1.32	2.80	2.20	1.61	1.24	1.83	1.56	1.77	1.07	2.00	1.90	22.50
76-77	0.33	0.34	0.29										
Mean	1.33	1.39	1.44	2.00	1.07	1.30	1.91	1.54	2.35	1.36	1.13	1.40	
No. of Months	14	13	14	13	15	13	13	12	11	12	14	12	
Percent Annual	7.3	7.6	7.9	11.0	5.9	7.1	10.5	8.5	12.9	7.5	6.2	7.7	

Mean Annual Precipation 18.22 inches.

- missing values during month
E estimated values during month
* accumulations during month

Mine Workings and Methods

The Blackbird Mine complex consists of 12 levels, 8 portals, an open pit, 3 major waste piles and a tailings pile (rich in pyrite), a mill and concentrator, and support facilities. The principal entrance to the mine is at 6850 feet of elevation, marked on various maps as the 6850' level (Figure I). This level opens to the main yard which contains the crusher bin, shops, offices, concentrator, etc. This level extends about 9600 feet into the mountain. About 2,200,000 tons of ore have been mined above this level including 758,000 tons from the open pit mine (Davis, 1972, p. 33). No ore has been mined below this level, although there is a winze to the 6600' level. Above the 6850' level on the south side of the mountain are the 7100', 7200', 7300', and 7400' levels. The St. Joe Shaft is between the 6850' and the 7100' portals. Two portals on the northern side of the mountain are situated below the existing open pit mine. These are the 7117' and the 7265' levels. The 6850' level passes beneath these two levels and continues to the northwest some 1200 feet.

Mining in the underground portion of the mine occurred from drifts following the lenticular and tabular ore bodies. As a result, much of the rock mined in drifting was of mill grade and waste rock was reduced to a minimum. Ore bodies were removed by room and pillar methods and block caving of overhead stopes. Sand fill recovered from the coarse fraction of the milling operation was returned to the mined areas to provide support for continued mining operations or to support abandoned areas. Backfill with tailings was not practiced between the years 1960 to 1967. The movement of equipment, personnel, ore, and waste rock between different levels in the mine was conducted through vertical openings, manways, and ore passes to the main work levels. Plates IA and IB (end of paper) show cross sectional and plan views of the Blackbird Mine workings. The mining operation in the open pit area removed a large volume of rock from an extensive ore zone and created a depression of 11 acres. Waste rock from this operation was dumped into two waste piles (Figure I).

Future plans are uncertain but the mine probably would be reopened if the acid mine drainage problem can be resolved and compliance with PL 92-500 achieved economically.

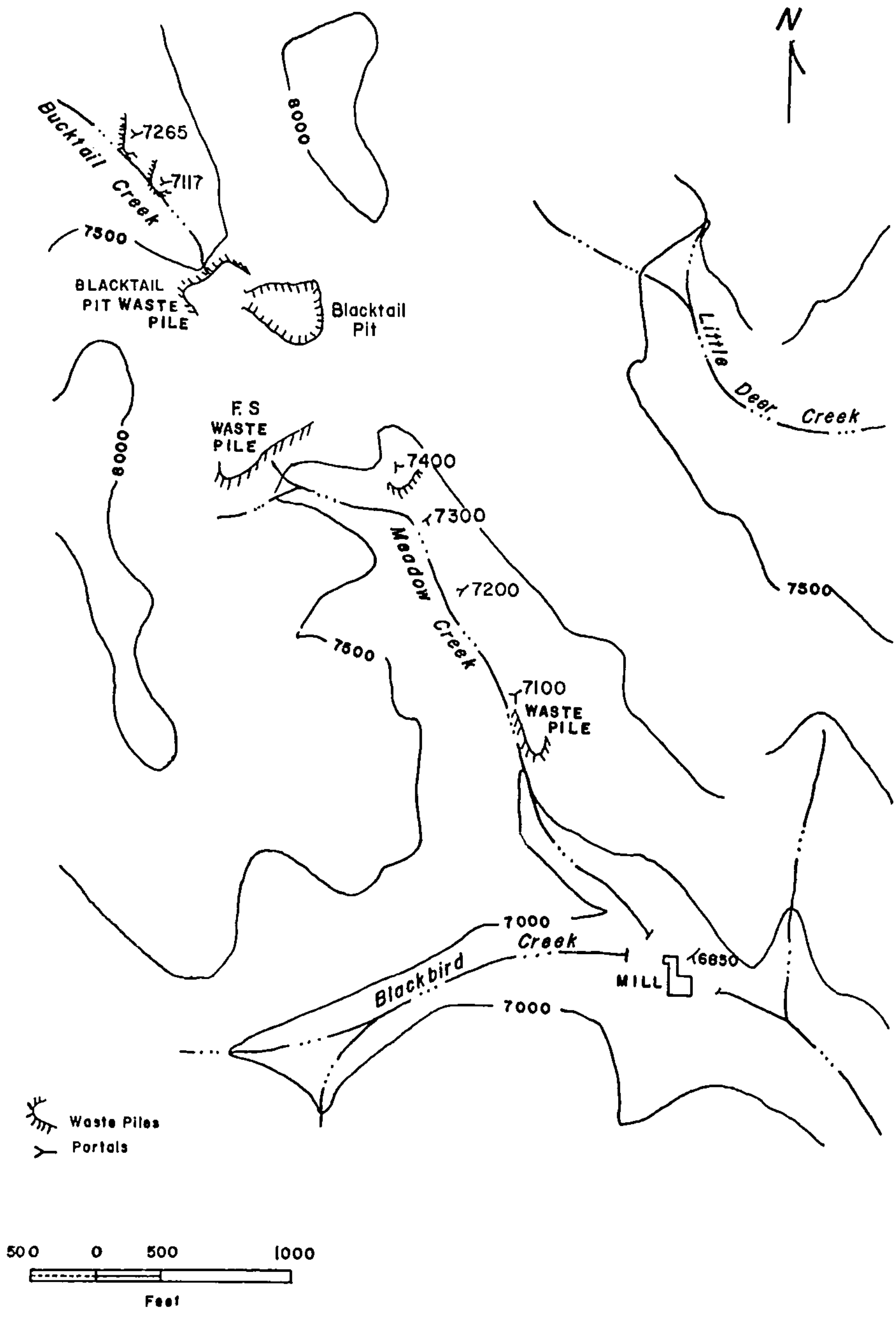

Figure I Blackbird Mine facilities.

The Acid Mine Drainage Problem at the Blackbird Mine

As early as 1628, references to acid mine drainage were made relative to the coal mining industry (Hawley, 1972). The following statement referred to a coal region in North America (Hawley, 1972, p. 5):

> "I have reason to believe (that) there are good coals (here) also for I have observ'd (that) the runs of water have the same color as that which proceeds from the coal mines in Wales."

Modern-day acid mine drainage has been noted and studied in coal mines in the eastern U.S. for many years (Ohio State University Foundation, 1971). However, articles on acid mine drainage problems in western hard rock mines are relatively uncommon in the literature. Mines of this type which contain pyrite often produce poor quality water with a low pH and a variety of metal ions. The chemistry of acid mine drainage and conditions favorable to the production of poor quality water are well established.

Production of acid water is common to mining situations where pyrite and other metal-sulphides become exposed to atmospheric conditions. Upon exposure to the atmosphere, sufficient oxygen and water are present to initiate the cycle. The oxidation of pyrite occurs according to the following process (Stumm and Morgan, 1970, p. 540-542):

$$FeS_{2(s)} + 7/2\ O_2 + H_2O \rightleftharpoons Fe^{++} + 2SO_4^{=} + 2H^+ \qquad (1)$$

Although the initial oxidation of pyrite may take place in a dry environment according to the equation

$$FeS_{2(s)} + 3\ O_2 \longrightarrow FeSO_4 + SO_2,$$

there is almost always sufficient moisture in mine waste piles and mine workings to favor reaction (1). The ferrous iron from reaction (1) is oxidized to ferric iron by:

$$Fe^{++} + 1/4\ O_2 + H^+ \rightleftharpoons Fe^{3+} + 1/2H_2O \qquad (2)$$

Hydrolysis of the ferric ion produces ferric hydroxide and releases additional acidity:

$$Fe^{3+} + 3H_2O \rightleftharpoons Fe(OH)_3\downarrow + 3H^+ \qquad (3)$$

The pale-yellow to orange ferric hydroxide is known as "yellow boy" among miners. This insoluble precipitate coats stream bottoms and forms thick sludges in adits.

The sum of reactions 1, 2, and 3,

$$FeS_{2(s)} + 15/4\ O_2 + 7/2H_2O \rightleftharpoons Fe(OH)_3 \downarrow + 2SO_4^{=} + 4H^+ \quad (4)$$

shows that 4 moles of H^+ are released for each mole of FeS_2 oxidized; few other natural weathering reactions produce this amount of acidity.

Various studies (Smith, 1971; Singer and Strumm 1970) on the importance of ferric iron in the oxidation of FeS_2 have shown that the following reaction accounts for the principle method of breakdown of the pyrite:

$$FeS_{2(s)} + 14Fe^{3+} + 8H_2O \rightleftharpoons 15\ Fe^{++} + 2SO_4^{=} + 16\ H^+ \quad (5)$$

When ferric iron is the oxidizing agent, reactions 2 and 4 determine the rate of oxidation of FeS_2. Reaction (2), the oxidation of ferrous to ferric iron appears to be the rate determining step. The rate of this reaction is a function of hydrogen ion concentration, decreasing with pH down to about 4.5. From pH 4.5 to 3.5 the relationship of Fe^{++} and O_2 concentration changes and below pH 3.5 reaction (2) is very slow and independent of pH.

At pH of 3.5 or less, bacteria such as _Ferrobacillus ferrooxidans_ _F_. _Sulfooxidans_, and _Thiobacillus ferrooxidans_ accelerate the rate of conversion of Fe^{++} to Fe^{3+}. Singer and Strumm (1970, p. 1122) note such bacteria may accelerate reaction (2) by a factor of 10^6 or more.

Wentz (1974, p. 20) describes the above reactions for a situation where oxygen laden water at a near neutral pH infiltrates mine waste containing pyritic material:

"The FeS_2 is oxidized, probably by molecular O_2 at first (reaction 1), thus releasing Fe^{++} and lowering the pH. In addition large amounts of SO_4 are produced. Some of the Fe^{++} is oxidized abiotically to Fe^{3+} (reaction 2) which in turn also oxidizes FeS_2 (reaction 4). As the pH and the amount of available O_2 decrease, reaction 1 becomes less important. Moreover, the abiotic rate of reaction 2 also decreases, thus limiting oxidation of FeS_2 by Fe^{3+}. However, at this point (about pH 4.5-5) the iron bacterium *Metallogenium* becomes important and catalyzes reaction 2 until a pH of about 3-3.5 is reached. Below this value, the *Ferrobacillus-Thiobacillus* group takes over the catalysis. It is these later organisms which are responsible for the pH's of less than 3 seen in nature. And, because of the inefficient nature of the Fe^{++} to Fe^{3+} oxidation, these organisms also contribute to the disposition of large amounts of $Fe(OH)_3$ (reaction 3)."

In addition to the formation of water with low pH and high iron, acid produced from the oxidation of pyrite may also dissolve other minerals which by themselves do not contribute to the formation of acid waters. The disolution of the sulphide copper mineral chalcopyrite is an example (Davis, 1972, p. 8):

$$CuFeS_2 + 2\ Fe_2(SO_4), + 2H_2O + 3\ O_2 \rightleftarrows CuSO_4 + 5FeSO_4 + 2H_2SO_4 \qquad (6)$$

Sources of Recharge to Mine Workings in the Blackbird Creek Drainage

A significant amount of the total discharge from the mine is due to recharge to mine workings which has been induced by the mine itself. Identification of recharge areas is prerequisite to reduction or elimination of recharge from surface waters. Mine-related surface features which allow surface water to recharge underground workings directly include raises intersecting ground surface, surface disturbed areas and abandoned open pits. Raises intersecting the ground surface should be covered to prevent direct surface water recharge. However, some raises at Blackbird were sealed inadequately or not sealed at all. Some raises connect only two levels but some connect several levels. An unrestricted flow path is created in the case where a raise extends from the ground surface to a working level with little offset between levels. Four such flow paths were identified based on observed discharge from raises on the 6850 level at the Blackbird. Plate I shows that these raises do extend from the 6850 level to the surface. Plate I also shows that the 706 vent raise (706VR) extends from the 7100 level to the ground surface. A circular opening about 20 feet in diameter marks the intersection of this raise with the ground surface. This opening lies near the bottom of a small draw which carries runoff water to acid forming minerals in the mine during spring months.

Surface water also may enter underground workings through mining-modified ground-water flow systems. At the Blackbird some 60 trenches and shallow pits were constructed during exploration and mapping of geologic structures in the mining area. Many of these features are located on surface expressions of fault and fracture zones. Water collects in these trenches from precipitation and runoff and infiltrates the fault zones. Many of these zones lead directly to underground workings. We estimate that recharge to underground workings from this source amounts to about 10 percent of the total discharge at station 7 (6850 portal Plate I).

Surface water also reaches underground workings through fractures created by mining at the Blackbird. Removal of ore from workings close to the ground surface causes stress on the overlying material. This stress has resulted in subsidence and produced surface fractures. Surface water from spring snowmelt enters these fractures and discharges to mine workings. This type of recharge to mine workings is estimated to constitute 10 percent of the total recharge at station 7 (6850 portal, Plate I)

An estimated 75,000 feet of surface diamond drilling has been completed in the mining area. This type of drilling is aimed at reaching ore bodies, which usually are more permeable than the surrounding rock. This type of exploration increases recharge to the ground-water flow systems by providing more interconnections between the surface and subsurface.

Recharge from Meadow Creek to mine workings is another potential source of water in the mine. During the course of our underground investigations, it was noted that faults, fractures and raises on the 7100 level northwest of the 7100 portals consistently discharged water to the level while similar structures east of the portal were essentially dry. Figure 2 shows the cross-sectional relationship between Meadow Creek and mine workings in the vicinity of the 7200 and 7100 portals. The workings on the 7100 level northwest of the portal are below creek level. A similar situation exists on the 7200 level, where workings north-

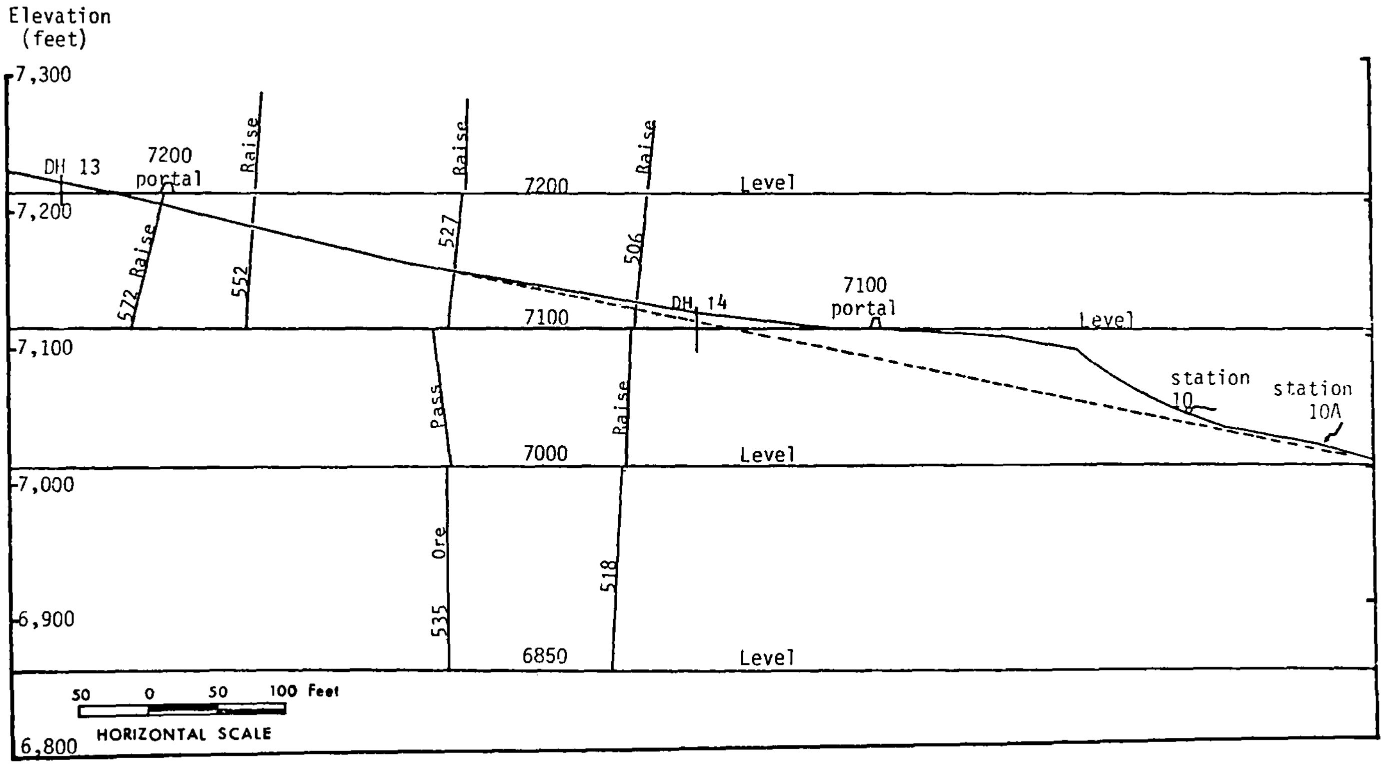

Figure 2. Cross sectional relationship between Meadow Creek and mine workings in the vicinity of the 7100 and 7200 portals.

west of the 7200 portal are below creek level. Faults and fractures connecting mine workings and Meadow Creek provide an avenue for recharge. Vertical distances of up to 275 feet between the 7100 level and Meadow Creek provide ample head to drive ground water down along permeable zones. Northwest of the 7200 portal, raises extend upward and intersect the ground surface. These raises undoubtedly dewater colluvium and fault zones saturated from snowmelt runoff. Rock units in this area dip 30^{o} to 60^{o} NE from Meadow Creek to the mine workings. The amount of water moving in this manner from Meadow Creek to mine workings is difficult to measure. Discharge data show that during the spring runoff period Meadow Creek is a gaining stream; therefore, stream recharge to mine workings could not be detected by this technique. Water level data from piezometers show that this area of the valley floor is a recharge zone. Therefore, the gain in Meadow Creek must result from surface runoff and shallow ground-water flow from spring snowmelt. It is believed that recharge to mine workings from Meadow Creek represents about 5 percent of the total discharge at station 7 (6850 portal, Plate I).

Water reaching the 7200 level (Plate I) normally flows out the 7200 portal but the portal was blocked by a small cave-in until mid-1976. Water ponded up behind the cave-in until it reached a sufficient depth to flow down raises to the 7100 level. One such raise was the 572R, which connects the 7200 and 7100 levels in the vicinity of the 7200 portals (Plate I). This raise is filled partially with ore and water flowing down the raise leaches out metal ions. Underground investigations on the 7100 level showed that this raise normally discharged about one gpm. But when peak spring runoff occurs, this raise discharges about 20 gpm. Analysis of a sample of this discharge showed that the metal load was 8 pounds per day of cobalt, 11 pounds per day of copper, and 5 pounds per day of iron. Later, the cave-in was removed from the 7200 portal and mine drainage flowed out the portal and into Meadow Creek. This maintenance work resulted in a reduction in cobalt, copper, and iron loads at station 7 by 15, 10 and 5 percent, respectively.

Water Quality in Mine Workings in the Blackbird Creek Drainage

Distinct water types within the Blackbird mine workings can be identified on the basis of water quality differences.

These water quality differences exist because of differences in mineralogy, flow path length and travel time for the various sources of recharge to the mine workings. Mine-created flow, water discharging from raises, ground water (water from flooded levels below 6850), and diamond drill hole water all have differing water-quality characteristics.

Water discharging from diamond drill holes can be further subdivided based on whether or not the drill hole encountered an ore body. Table 2 is a summary of water-quality data for various discharge sources in the underground workings. Table 3 presents additional water quality data from various sources.

Surface runoff water was sampled at one point in the mine, the 706 vent raise (706VR) on the 7300 level. The water at this station does not come into contact with sulfide minerals. The water derives from a ground-water flow system in the shallow sediments where the 706VR intersects the ground surface; therefore the water is of good quality.

Water flowing from flooded levels below the 6850 was sampled at station 6827 (Plate I). The source of this water is ground-water from faults and fractures. The high iron concentrations indicate that this water comes into contact with sulfide mineralization; however, average pH of this water is 6.4. The flooded nature of this portion of the mine limits acid production by limiting oxygen availability. Solubility relationships show that at these high pH values, most of the iron exists as Fe(II) or $Fe(OH)_2$.

Water quality data for five diamond drill holes which did not encounter ore are shown in Table 2. The quality of this water is high; very little cobalt, copper, and iron is present. Water discharging from these drill holes follows faults and fractures that do not contain ore or pyrite.

Water discharging from diamond drill holes which penetrate ore bodies is lower in pH and higher in dissolved metals than water from diamond drill holes which do not penetrate ore bodies. The pyrite is associated with ore. Water percolating through the ore bodies dissolves pyrite oxidation products and removes metal ions from the oxidation sites. In addition, active mining of the ore bodies exposes pyrite minerals to atmospheric conditions which enhances the oxidation process. Water from drill holes pene-

Table II. Water quality data for different sources in mine workings in Blackbird Creek drainage. See Plate I for locations. (Metal ion concentrations given in parts per million)

Water Source	pH	E.C.	Co	Cu	Fe	Mn	Mg	Ca	Na	Number of Samples
73707 (706 vent raise-surface water)	6.7		-0.1	-0.1	-0.1	-0.1	0.8	3.6		1
6827 (Pierce Winze-ground water)	6.4	770	2.1	-0.1	162.0	3.8	23.4	10.3	7.8	14
Diamond Drill Holes (Ore bodies[a])	4.5		17.7	1.2	242.0	11.1	45.1	21.4	9.9	5
Diamond Drill holes (No ore bodies encountered)	5.0		1.2	0.2	0.4	2.4	2.3	1.5	2.8	5
5 Raises	2.6	2500	23.3	46.9	518.0	25.0	118.0	15.4	4.7	37
6835 (Drainage from back part of 6850)			3.2	1.3	4.2	1.3	6.9	2.0	2.7	1

[a] Ore body has been actively mined

-0.1 less than 0.1

Table III. Ground-water quality in the Blackbird Creek drainage during the 1976 field season. (Concentrations are dissolved metal ions in parts per million, except as noted.)

Sample Station Number	pH	E.C.	Co	Cu	Fe	Mn	Mg	Ca	Na	Number of Samples
DH4	5.6	430	7.1	1.2	10.7	2.3	23.1	60.7	16.0	6
13	3.0	500	27.4	26.6	4.9	2.9	31.1	21.8	4.1	1
DH3S	3.9	940	50.5	64.0	5.4	50.0	35.7	3.1	10.2	7
DH3D	6.2	255	3.9	3.1	4.3	2.9	8.3	33.4	8.4	7
10B	3.7	720	7.7	39.9	7.1	2.0	33.0	20.3	4.3	11
DH2	4.0	1110	1.2	1.4	92.3	1.4	11.4	132.0	23.9	7
DH1	3.1	950	14.6	1.6	243.0	4.4	25.4	77.8	19.7	7
100[a]	4.7	760	6.7	1.3	31.6	4.7	82.0	235.0		3
101[a]	3.1	960	7.3	2.3	34.8	3.5	84.8	190.0		3

[a] Concentrations are total metal ions in parts per million.

trating ore bodies which have been mined is higher in dissolved metals and has lower pH than other drill holes. Five samples were taken from diamond drill holes where an ore body was encountered but had not been mined. The quality of this water was intermediate between the previous two water types.

A total of 37 water samples were collected from raises discharging water to the 6850 level (Table 2) during the 1976 field season. This water displayed the lowest pH and highest metal concentrations of any of the water types identified in underground discharge points. This water type results from the most favorable conditions for production of acid water. Large amounts of ore-rich materials in raises, stopes, and drifts are exposed to atmospheric conditions and oxidation products are removed by water. Increased flow through mine workings during spring runoff flushes oxidation products from areas not normally in contact with water. Numerous pools of acid water also collect in the mine during low flow periods. The influx of water during spring runoff flushes out these pools, adding additional poor quality water to the system.

The chemical processes of acid production are identical for both underground and surface situations. One variable which favors increased acid production in underground workings is greater exposure of sulfide minerals to atmospheric conditions. Stopes, drifts, cross-cuts, ore chutes, and raises all expose ore material to oxygen. The major limiting factor on acid and heavy metal production from underground workings at the Blackbird mine is the lack of water to carry away oxidation products; the Blackbird is a relatively "dry" mine by most standards.

Variations in metal ion concentrations for underground workings are very similar to variations observed at surface waste features. Figures 3 and 4 show metal ion and discharge variations for the 6850 and 7400 portals for 1976. Discharging raises on the 6850 level show similar metal ion variations with flow. As with surface waste features, runoff water entering mine workings flushes away accumulated oxidation products resulting in increased metal loads from underground discharge points during high runoff. Oxidation products begin to accumulate as soon as the spring runoff water recedes. This accumulation process continues until a surge of water again passes through the mine, transporting the acid salts away. Runoff from late summer thunder-

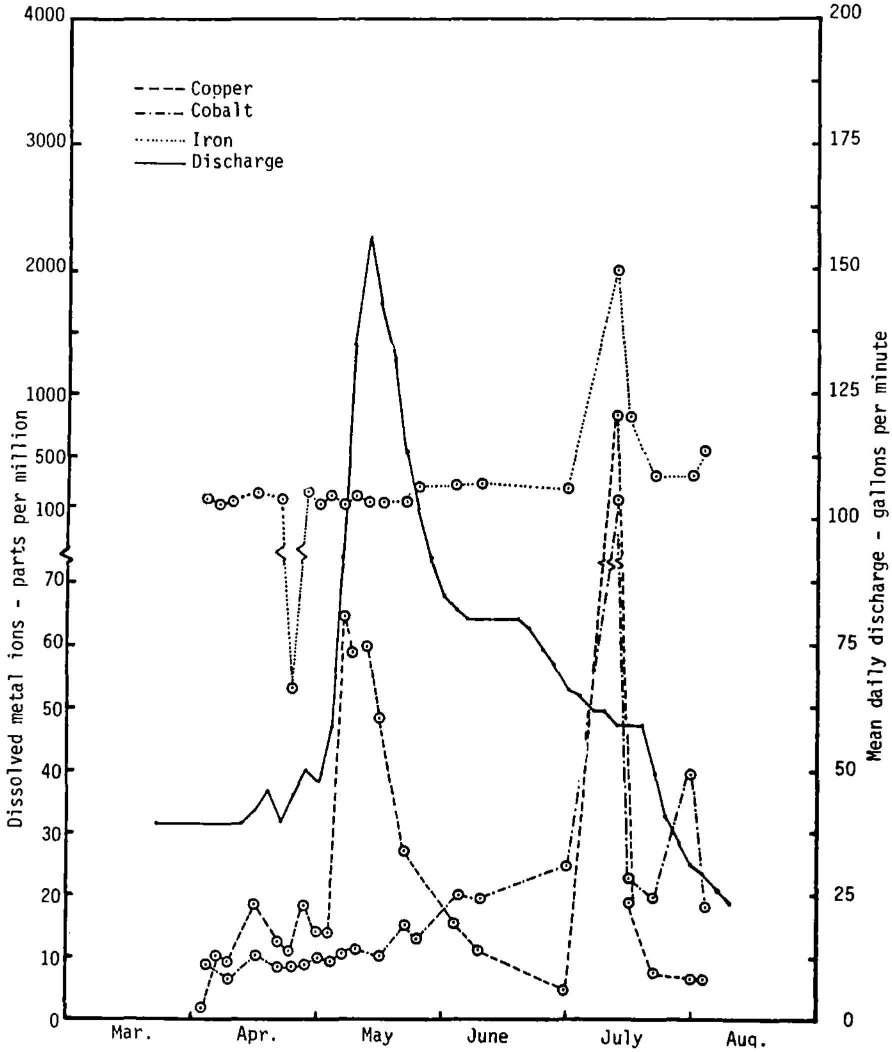

Figure 3. Dissolved cobalt, copper, and iron concentrations at station 7 (6850 portal) for 1976.

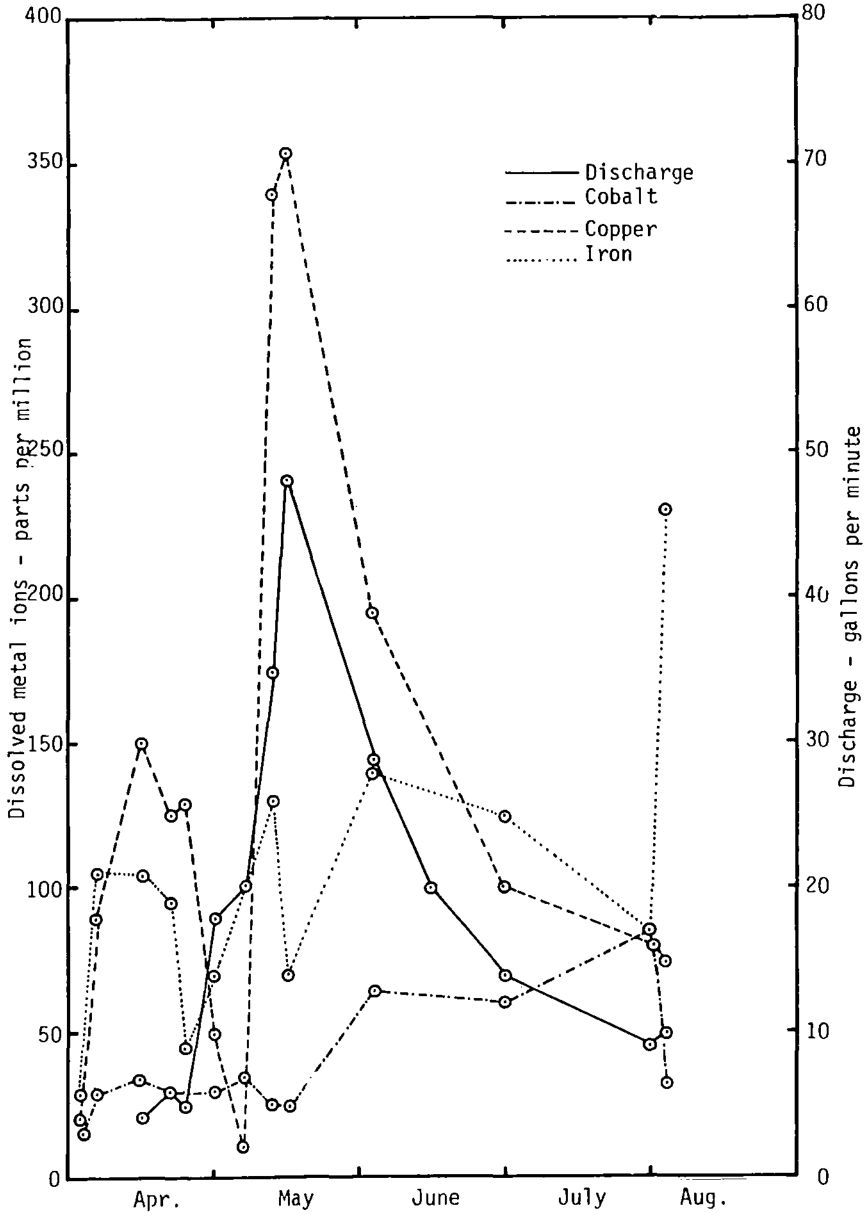

Figure 4. Dissolved cobalt, copper, and iron concentrations at the 7400 portal for April to August, 1976.

storm activity may transport metals from the mine during the low-flow period. This process caused the peak in metal-ion concentration in mid-July on Figure 3. Figure 4 shows that a peak in metal-ion concentrations occurred at the 7400 portal during mid-April of 1976. This peak resulted from the first introduction of snowmelt into the mine workings during the 1976 runoff period. The discharge hydrograph for the 7400 portal (Figure 4) shows that only a very small volume of water was necessary to bring about high metal ion concentrations during mid-April. Total metal-ion concentrations increase with downstream position as each source contributes its share of acid and metal ions. Farther downstream, dissolved metal-ion concentrations begin to decrease, indicating that dissolved metals begin to form precipitates but remain in suspension and are transported out of the mine. The precipitation of dissolved metals results from the addition of relatively good quality water from diamond drill holes downstream of station 6824 (Plate I).

Water discharging from the 6850 and the 7400 portals represents the majority of all point source acid discharge from underground workings in the Blackbird Creek drainage. Table 4 gives metal loads for various periods from 1969 through 1976. Sample collection was not conducted during winter months but projected water quality and quantity parameters show that approximately 3,000 pounds of copper and cobalt would have been produced at the 6850 portal for 1976. The data show that the St. Joe portal contributes about 1 percent of the metal load from the three portals for the period April 3 to August 3, 1976. The data for the 6850 portal and the 7400 portal are not comparable directly for the various years of record because of differences in analytical techniques, but variations in metal loads are evident for different years. The amount of water available to transport metals from the mine is probably the major factor which determines total metal loads from year to year. Water produced by mine waste dumps containing pyrite are also a source of acid drainage at the Blackbird mine. Water in drill holes monitored during the 1976 field season show a decreasing head potential with depth at key location. Ground water is therefore moving downward in those areas. Figure 5 shows the interpreted ground-water flow system in the vicinity of the waste pile at the 7100 portal. The figure shows that the water table intersects land surface at the lower portion of the waste pile, resulting in the spring discharge which was monitored at station 10 shown

Table IV. Metal load production from underground workings in the Blackbird Creek drainage. (Metal load is total metals except as indicated.) (See Plate I for portal locations)

		Metal Load (lbs)		
Station	Period	Co	Cu	Fe
7 (6850 portal)	2/25 - 9/30/69	3,600	3,400	7,200
7	6/21 - 11/01/71	1,300	1,000	22,600
7	8/04 - 12/31/74	900	300	4,500
7	5/19 - 7/31/75	2,200	5,300	11,700
7	4/03 - 8/03/76[a]	1,600	2,100	21,000
7	1976 Water year[a]	3,100	3,300	
9(St.Joe portal)	4/03 - 8/03/76[a]	60	160	180
15(7400 portal)	2/15 - 9/30/69	2,300	3,200	2,500
15	7/21 - 11/02/74	300	400	200
15	4/13 - 8/03/76[a]	1,000	6,000	1,500

a Metals are calculated as dissolved metal ions

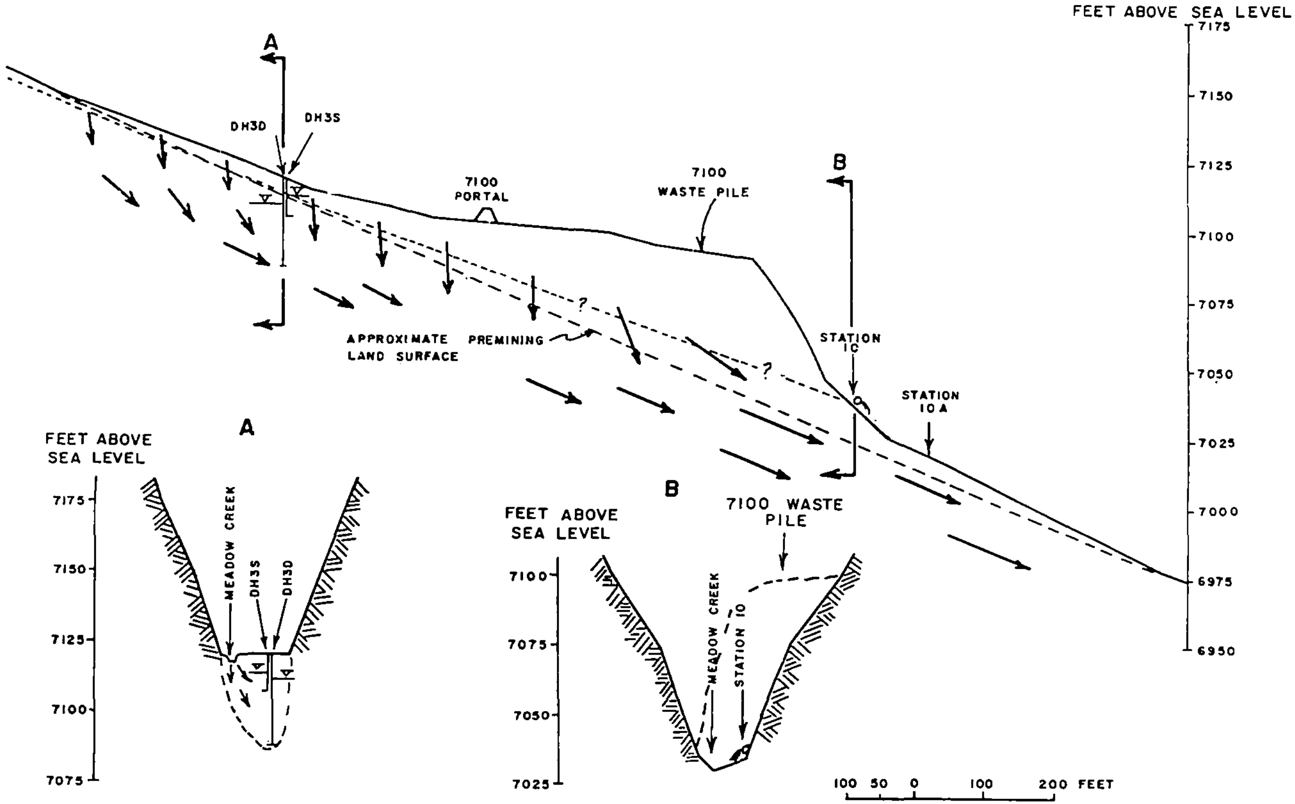

Figure 5. Meadow Creek stream profile in the vicinity of the 7100 waste pile.

in the Figure. This discharge probably represents only a small portion of the total quantity of ground water moving through the mine waste and valley fill material. Additional ground water probably moves down gradient at depth. This ground-water underflow discharges to Meadow Creek in the form of poor quality water.

CONCLUSIONS AND CORRECTIVE MEASURES FOR ACID MINE DRAINAGE AT THE BLACKBIRD MINE

Total Discharge

Total discharge from the Blackbird Mining area for the 1976 water year was about 5,900 acre-feet, with about 5,800 acre-feet of this discharge deriving from Blackbird Creek and about 100 acre-feet from Bucktail Creek. In Blackbird Creek, acid drainage totaled about 420 acre-feet from Meadow Creek and 63 acre-feet from the 6,850 portal for the 1976 water year; the remaining 5,320 acre-feet was good-quality water from Blackbird Creek above the Blackbird mill and small tributaries. Only about 50 acre-feet of the 420 acre-feet measured at Meadow Creek is actual acid mine drainage from point discharge sources; the remaining 370 acre-feet is good-quality water from snow-melt runoff and Meadow Creek above the uppermost Waste Pile. The entire 100 acre-feet of discharge measured in the Bucktail Creek drainage is acid mine discharge. This gives a total of 213 acre-feet of acid mine drainage from point discharge sources in the Blackbird Mining Area for the 1976 water year. These point source discharges will require NPDES permits and unending legal obligation by any company that reopens the mine which is the only known domestic source of cobalt.

Discharge-Metal-Ion Relationships

Stream discharges and water quality are closely inter-related in the Blackbird Mining Area. Discharge-metal-ion relationships show that heavy metal concentrations occur: (1) low during winter months, (2) increase sharply during the initial spring runoff period, (3) are very low during the latter part of the spring runoff, and (4) rise gradually during later summer months. As much as 75 percent of the total annual metal production occurs during April and May.

Acid Production: Underground Workings

Acid production from underground workings is controlled by: (1) oxygen, (2) distribution of pyrite, (3) moisture in the mine atmosphere, (4) availability of water to transport oxidation products, and (5) mine characteristics (Trexler and others, 1974) (Williams, 1975). An additional variable may be the presence of iron bacteria which facilitate the oxidation of Fe^{2+} to Fe^{3+}. Variables 4 and 5 can be managed to reduce or eliminate acid mine drainage from the underground workings.

Several raises in the Blackbird Creek drainage intersect the ground surface and receive direct recharge from surface runoff and ground-water discharge from shallow ground-water flow systems recharged by snowmelt. Recharge to mine workings also occurs in areas where Meadow Creek flows above workings on the 7100 and 7200 levels. Oxidation of sulfide ore minerals takes place continuously. Flood events flush the oxidation products out of the mine. In the Bucktail Creek drainage, the 7265 and 7400 levels are hydrologically connected with flow systems associated with the Blacktail Pit. Workings at the 7117 level are isolated from these flow systems. Mine workings at higher elevations produce greater quantities of discharge than do workings at lower elevations in the mountain.

Acid Production: Surface Waste Features

Acid production from surface waste features is governed by the following variables: (1) oxygen, (2) availability of pyrite and other heavy metals, (3) moisture in the waste material, (4) availability of water to transport oxidation products, (5) physical location of the waste feature, and (6) presence of iron bacteria. Variables 4 and 5 may be managed to reduce acid drainage from surface waste features.

Certain piles near the Blackbird mine produce water with significantly lower iron concentrations and lower total iron loads than waste piles located at lower elevations in the Meadow and Bucktail Creek drainages. Waste features located at lower elevations are recharged by acid water with high metal-ion concentrations and low pH values. Acid production from tailings and waste rock deposited in and near stream channels is a significant source of acid water and heavy metals in the Meadow Creek drainage.

Corrective Measures

Reduction of acid production from surface and underground mine and waste structures can be accomplished by initiating various maintenance procedures. Future mining activities should incorporate hydrological variables in mine planning and surface waste site selection procedures. Prevention of acid mine drainage is much less difficult than curing acid mine drainage.

Underground Workings

Field investigations have shown that mine characteristics and availability of water to transport oxidation products out of the mine are factors which can be controlled to reduce acid mine drainage.

Mine Characteristics

All raises intersecting the ground surface should be carefully inspected for signs of recharge from both surface and ground water. This inspection should include in particular raises: 506R, 527R, 598R, 607R, 619R, 622R, 663R, 669R, and the 706VR. Any additional raises intersecting ground surface which are not shown on mine diagrams should also be inspected for signs of recharge. Many raises have been sealed against direct surface water recharge in the past three years. Water seeping into the raises from saturated soils and colluvium may be prevented by grouting around the outside of the raise to a depth of 8 to 10 feet. This recommendation applies in particular to raises located in areas where ponding or direct surface-water flow exists. Raise 706VR has not been sealed and the raise is forming an increasingly large pit as sloughing occurs along its sides.

Mine characteristics contributing to recharge to mine workings in the Bucktail Creek drainage are difficult to correct. One solution is to seal the bottom of the Blacktail Pit to eliminate direct recharge to the 7400 and 7265 levels. However, water would then collect in the pit and seepage through the pit walls would occur unless the walls also were sealed. Seepage through the pit walls would probably leach heavy metals from the ore zones. Metal production might even be increased if this procedure was used. The above problems could be avoided if the Blacktail Pit were filled to an elevation of about 7,520 feet (an expensive alternative), whereupon surface water would drain out of the pit area and down the Blacktail Pit waste pile (Figure I).

Availability of Water to Mine Workings

Reducing or redirecting water flow in a mine reduces metal loads discharging from the mine. A first priority should be to grout or cap all flowing drill holes on all levels, especially the 6850 level. This would result in an immediate reduction of 16 acre-feet of water at the 6850 portal.

Maintenance work should be continued on all levels to prevent ponding of water and flooding of ore filled raises, such as on the 7200 level. During spring runoff ponding occurs on levels which are blocked by cave-ins or excessive accumulations of iron hydroxide precipitates. Water ponds until it flows down raises that normally are dry. Oxidation products are then flushed out of the raises as acid mine drainage. Water discharging from raises to the 7100 and 7200 levels should be traced back to its origin and appropriate steps taken to reduce this flow. Water should be prevented from flowing through stopes or raises containing oxidized ore where production of acid salts is inevitable. In many cases this would involve erecting and sealing a bulkhead at the entrance to the stope or raise, while in other cases merely cleaning out the drainage ditch on the level to allow water to flow freely along the level would suffice.

Diversion of discharge to central flow points within the mine workings would help to eliminate flushing of accumulated oxidation products or contamination of good-quality discharge sources. Discharge from the 7400 portal could be diverted down the Brown Bear shaft (Plate I) and down raises to the 6850 level. Diversion of this flow down the Brown Bear shaft would not result in any additional metal leaching since the shaft is fully timbered. Such a diversion would be a temporary solution since the timbering in the shaft will deteriorate with time. This discharge and water flowing to the shaft from other levels could be directed to the 6850 level down raises which do not contain oxidized ore. The drainage system on the 6850 level could handle this increased discharge if flowing drill holes on the 6850 level were capped. There should be no net increase in discharge at the 6850 portal since the annual discharge from the drill holes is about equal to flow on the 7400 level. As an additional advantage in this diversion, discharge from the 7400 portal would no longer be available to leach metals from waste piles and mine debris in the Meadow Creek drainage, resulting in decreased metal production from this source. Decreased metal production should be especially apparent during low flow periods when the 7400 portal is the major source of poor quality in the upper Meadow Creek drainage.

A second major diversion would direct water from the upper Bucktail Creek drainage down through a bore hole to the 6850 level and out of the mine. If this diversion could also include discharge from upper Bucktail Creek, the majority of all water quality problems in the Bucktail Creek drainage could be eliminated. Such a diversion would necessitate enlarging the drainage system on the 6850 level as a maximum flow of about 2 cfs should be expected at the 6850 portal during peak runoff periods. The diversion site on Bucktail Creek should be selected carefully so that all poor-quality water discharging to Bucktail Creek is included. The original plan called for completing a borehole from the 7117 to the 6850 level, but this would not allow for diversion of poor-quality water from the creek. Analysis of the data show that poor-quality ground water enters Bucktail Creek below the 7117 waste pile, from 7000 to 6975 feet elevation. This poor-quality ground water might be diverted at higher elevations in the drainage. However, drill logs show that the water table is about 35 feet below land surface in the 7265 waste pile. A similar depth to water probably exists at station 21 (7117 waste pile). It appears that completing a bore hole from an elevation of about 6975 feet in the Bucktail Creek streambed to the 6850 level would intercept all poor-quality water produced by upstream mining features, including portals and waste piles. This plan would have the drawback of diverting much good quality water during the spring runoff.

Surface Waste Features

Reclamation alternatives for surface waste features in the Blackbird Mining area are more expensive and difficult to initiate than underground reclamation alternatives. Surface waste features are vulnerable to flushing of oxidation products from both the pile surface and within the waste material. Erosion of the waste material by surface water is a problem also. Revegetation research is continuing on the F. S. and upper Blacktail Pit waste piles with encouraging results. This approach deals effectively with erosion and also helps to prevent leaching of acid salts from the waste pile. The development of a mature soil profile and establishment of vegetation eliminates direct action of weathering processes on the waste material. Evapotranspiration losses from vegetation established on the waste pile will reduce the amount of water infiltrating into waste piles. Therefore poor quality seeps and springs originating from waste piles should show a decrease in discharge. Additional reclamation procedures which may be applied to other surface waste features in the area are discussed in the following section.

Considerations for Future Mining Development

The Blackbird Mining area contains the largest known cobalt deposit in the United States. Mining of the deposit will resume when economic conditions become favorable. These economic conditions include assuming legal responsibility for the production of acid mine drainage for the duration, including after abandonment. Water quality problems associated with mining activities can be minimized by applying procedures discussed in previous sections and by considering the following points.

Hydrologic site selection factors should be considered for the location of tailings disposal areas, waste rock storage areas, and low grade ore storage areas planned for future mining activities. Disposal areas for tailings and waste rock are limited by the physical characteristics of the Meadow Creek and Blackbird Creek valleys. These valleys would normally be considered marginal for the disposal of the solid wastes since both have perennial streams and associated ground water flow systems, but there are no alternative sites in the Blackbird Mining Area.

Plans are being considered for two new open pits, two overburden disposal areas, a low-grade ore disposal area, and a tailings disposal area. The potential tailings disposal is located on Blackbird Creek about 500 feet upstream of its confluence with Meadow Creek (Figure 1). About 2 million cubic yards of tailings can be deposited behind a dam built from about 800,000 cubic yards of overburden from the proposed open pit. Water from Blackbird Creek is to be diverted around the tailings pile.

Discharge from underground workings can be expected to increase following the resumption of mining activities. Water for diamond drilling, sand-fill water, and recharge from the Idaho-Dandy open pit will constitute the majority of this increase. Recharge to mine workings from Meadow Creek should decrease with the development of the Brown Bear open pit. Discharge from Meadow Creek will enter the Brown Bear pit and continuous pumping of the pit will be required. Plans call for backfilling deep mine areas with sand fill from the mill. It is suggested by the writers that those workings nearest the surface, both existing and proposed, be sand filled to discourage the entrance of recharge to mine workings. Sand filling will reduce subsidence problems and prevent the development of fracture systems associated with subsidence. Numerous bulkheads have collapsed in the existing workings allowing sand fill to escape from mined-out areas. Bulkheads installed for future sand fill operations should be constructed so as to prevent collapse.

The total volume of acid water presently discharging is small in relation to total discharge from the mining area. Some poor-quality water from the proposed mining area is unavoidable. But treatment costs will be considerably less if this discharge is isolated from good-quality water. Ground water discharge from all surface waste features should be intercepted by the use of cutoff walls and this discharge should be diverted to a water treatment plant.

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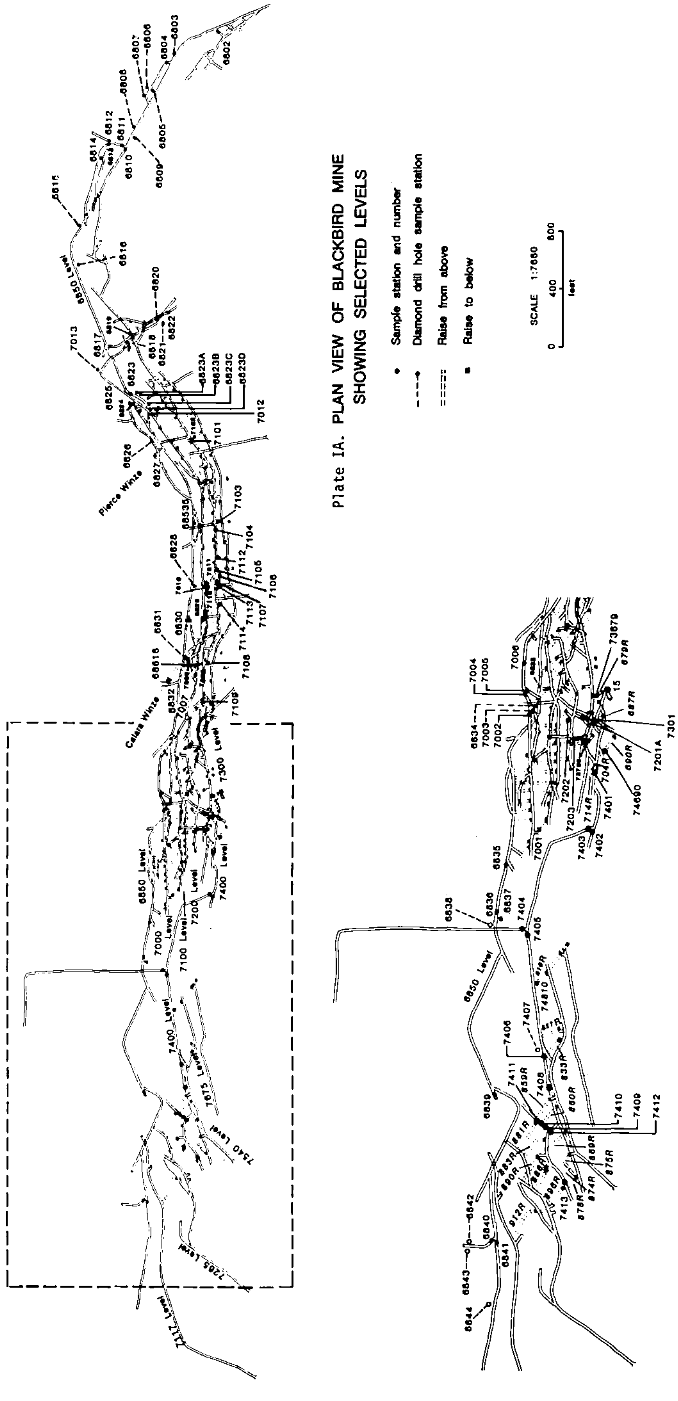

Plate IA. PLAN VIEW OF BLACKBIRD MINE
SHOWING SELECTED LEVELS

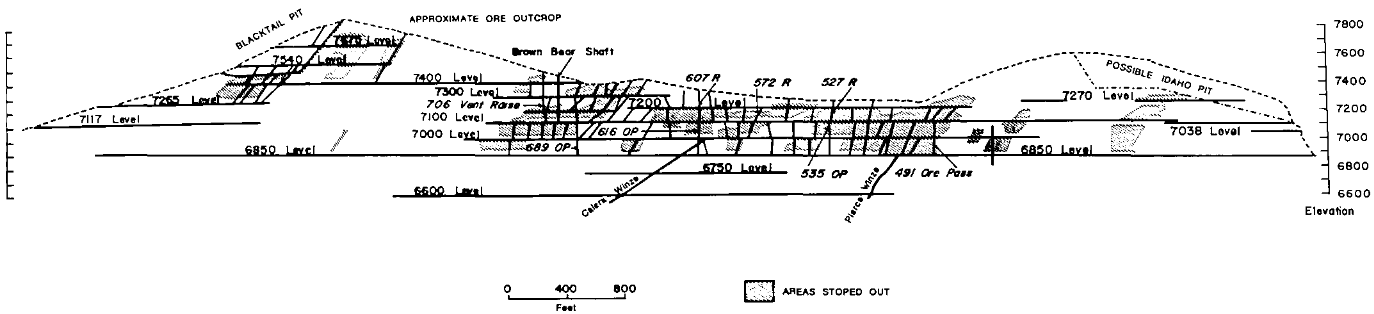

Plate IB. Cross sectional view of Blackbird Mine workings.