26

Hydrogeology of a Lead-Zinc Mine

by B. D. Trexler, Jr.,
Hydrogeologist, Metal Mines Division,
Kennecott Copper Corporation,
Salt Lake City, Utah, USA

INTRODUCTION

The Bunker Hill Mine consists of lead-zinc mining properties located along the Coeur d'Alene River near Kellogg, Idaho (Figure 1). Mining began in 1885 in the form of many shallow, small drifts and stopes around the original discovery site. The mine now includes more than 150 miles of workings to a depth of almost one mile below land surface. The volume of ground disturbed by mining is approximately five cubic miles. Development averages about four miles per year drifting and about 60,000 feet per year of diamond drill holes. (1)

Acid mine drainage from the Bunker Hill Mine is discharged into the Bunker Hill tailings pond and constitutes a major portion water treatment cost. The mine drainage averages about 2,000 to 2,500 gallons per minute with a pH of about 4 to 4.7. The pH occasionally drops to 3.3. The mine discharge is a major contributor of acid, heavy metals and suspended solids.

Acid production from the mine workings is controlled by: 1) oxygen, 2) availability of pyrite, 3) moisture in the mine atmosphere, 4) availability of other metal minerals, 5) availability of water to flush oxidized products throughout the

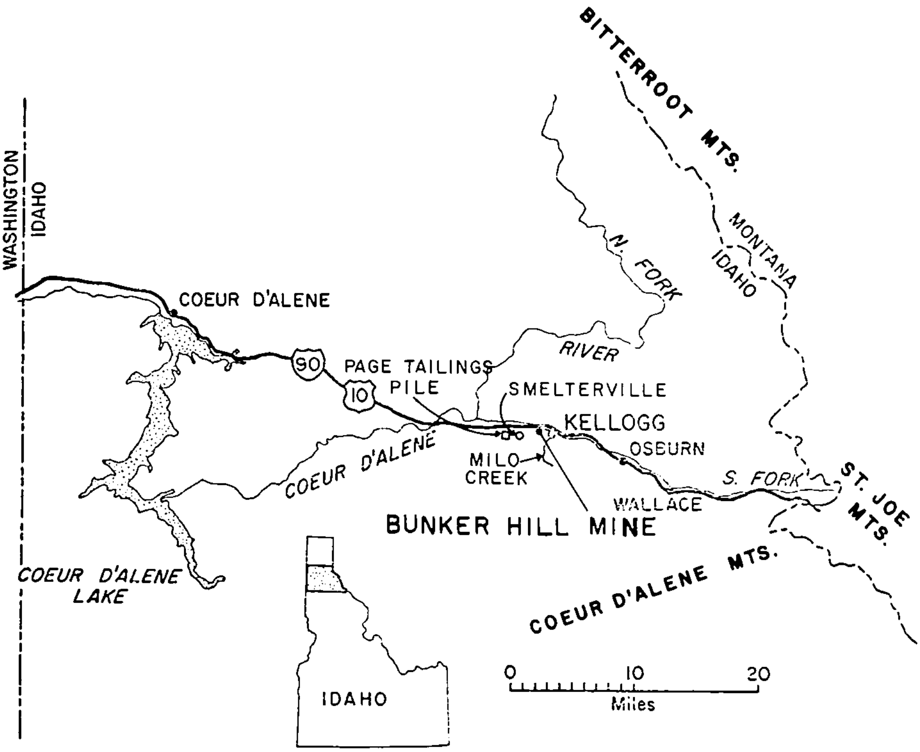

FIG. 1 MAP OF PART OF NORTHERN IDAHO AND ADJACENT AREAS SHOWING THE LOCATION OF THE BUNKER HILL MINE AND THE PAGE TAILINGS PILE

mine, and 6) mine characteristics (2). The availability of water in the mine to flush the oxidized minerals is the major factor in the production of the acid discharge.

PREMINING HYDROGEOLOGY

Milo Creek and Deadwood Creek are perennial streams which drain the majority of the surface area over the mine. All of the initial workings are located in the two drainages. Land use in the two drainages is limited primarily to mining activities. The Silverhorn Ski Area is located in the upper part of the Milo Creek drainage basin. The tall peaks (+6,100 feet) and surrounding slopes receive most of their precipitation in the form of snowfall. The average snow-water equivalent on April 1 is 33.5 inches as measured by the U. S. Department of Agriculture, Snow Survey Section (1958-1977 period of records).

The vegetation in the drainage is mostly conifers with strands of fir, pine, and larch in the higher elevations. Some deciduous trees are present in the lower elevations along the creeks. Much of the forest in the lower elevations was cut for mine timbers, lost in forest fires, or the new growth retarded by smelter fumes. The lack of vegetation and the steep slopes create quick runoff responses to rainfall and snowmelt.

The basins are underlain by crystalline rock of the Belt Series which have extremely low primary hydraulic conductivity. Ground water is limited to alluvium in the stream channels, the thin soil and rock cover of the slopes, and the fractures in the basement material. The stream channels are narrow, and alluvium is generally less than ten feet thick.

MINE HYDROGEOLOGY

Available Water in the Mine

The occurrence and movement of water in the Bunker Hill mine are controlled by five mechanisms. These mechanisms are: 1) natural ground-water flow and seepage, 2) faults and shear zones, 3) diamond drill holes, 4) mam-made openings (drifts, stopes, shafts, raises), and 5) water injected into the mine as potable water and sand-fill water. The average yearly total flow discharged from these mechanisms is 3,600 acre-feet.

Natural Ground-Water Flow

One source of available water is from ground-water seepage through country rocks and from natural fracture systems. The county rock is relatively impermeable quartzites and siltite-argillites having extremely low primary hydraulic conductivity except where faulted or fractured.

The primary source of ground water is from the natural fracture systems intersected by drill holes and workings. A survey of approximately 2,340 drill holes and accessible drifts showed 115 drill holes and two drifts flowing 400-500 gallons per minute. Many other drill holes were capped and valved for use in drilling. A crude estimate of the volume of ground water from these valved holes actually used in drilling was calculated. Approximately seven diamond drill rigs using 15 gallons per minute and 55 production drills using 2 gallons per minute are in use during any given year (actual drilling time approximately five hours per day for 220 days per year).

Combining both the free flowing drill holes and the drill water used gives a volume of about 690 acre-feet per year. These values should be considered minimum potential ground-water flow values.

Sand-Fill Water

The sand fill is another mine activity that furnishes water to the mine. Approximately 6.9 acre-feet of water per week is used to transport the sand fill from the mill to the sand tanks. Approximately 1.3 acre-feet of water per week is used in transporting the sand from the sand tanks to the stopes. Estimates of actual sand fill placed and transport water used from 1961 to 1977 are presented in Table I. It can be seen that sand fill is increasing yearly with a resulting increase in transport water.

TABLE I

Sand and Transport Water Used in the Bunker Hill Mine Sand Backfilling

Year	Sand (tons/year)	Transport Water (acre-feet/year)
1961-1962	100,000	160
1969	188,000	300
1970	179,000	290
1971	188,000	300
1972	214,000	340
1973	223,000	360
1974	272,000	390
1977	296,000	430

Other Mechanisms of Water

The sand-fill water volume (430 acre-feet) and the drill water volume (690 acre-feet) add to approximately 1120 acre-feet and account for approximately 30 percent of the total mine drainage discharged through the Kellogg tunnel. This volume of water represents water needed in the mining (sand fill and drilling water) and ground-water flow. Said volume of water is not available for reduction until active mining ceases. The other 70 percent of the Kellogg tunnel discharge can be reduced or eliminated during active mining by eliminating surface recharge.

MINING FEATURES RELATED TO WATER MOVEMENT

Proximity of Mining to the Surface

After the mining began in 1885, the equilibrium of the ground-water system in the mine area was disturbed. Often the stopes were worked to the surface, some even into creek beds. This caused increased recharge through stopes and increased discharge from the portals. The Milo Creek area and the Deadwood Creek area are examples of such a disturbance (Figure 2).

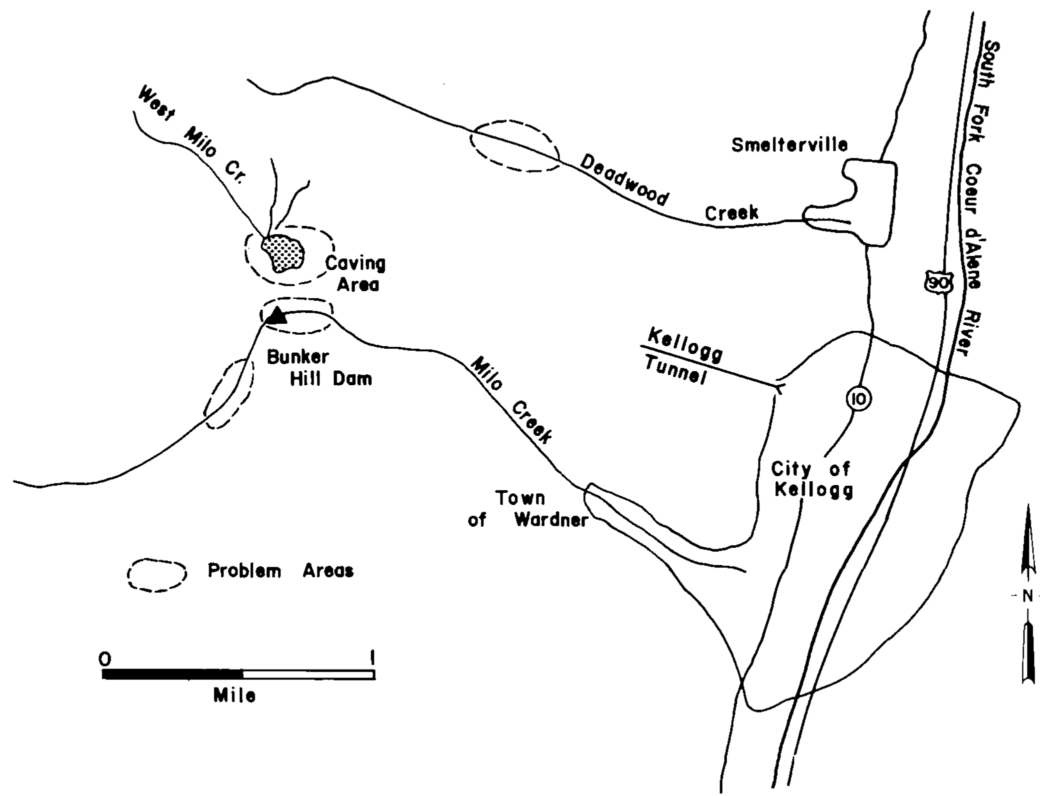

Figure 2. LOCATION OF BUNKER HILL MINE AND THE MILO CREEK AND DEADWOOD CREEK PROBLEM AREAS.

As the mining activity extended downward from the upper levels, a vertical zone of high permeability was developed. The porosity is secondary, formed from multi-level stopes and other interconnections. As the water drains down the man-made openings, some of it moves through stopes containing ore and waste fill rich in pyrite. The water becomes acidic as it passes over the waste. The upper levels of the Bunker Hill Mine shown in Figure 3 constitutes a typical example of this vertical zone of high permeability.

Block caving, used in the upper levels of the mine, forms another vertical zone of high permeability. The surface depression caused by the subsidence brought about by the caving creates a major surface recharge site. This surface feature channels three small intermittent tributary valleys of Milo Creek directly into the caved area where the water freely moves on down through the old workings.

Hydrograph Similarity Between Mine and Surface Flows

It was noted that certain areas in the mine discharge water only during periods which correspond to high surface flows. Hydrographs from the Kellogg Tunnel (the main drainage path from the mine), the Cherry Ditch (drainage into the Kellogg Tunnel from the levels of the mine above level 9), and a surface stream are presented in Figure 4. The hydrograph of Milo Creek is shown in Figure 4 for the water year from October 1972, to September 1973. The difference of water volume between the Kellogg Tunnel and Cherry Ditch hydrographs is the water pumped from levels 10 and below and the sand-fill tank overflow.

A similarity exists between the hydrographs from the Kellogg Tunnel, Cherry Ditch and Milo Creek. The high flows in the mine correspond to high flows in the surface streams resulting from snowmelt; little lag time is noted. Daily discharge measurements show a lag time between 12 to 24 hours. The similiarity of the hydrographs implies a rather direct connection of the mine to the surface.

A similar pattern exists between the hydrographs of the pumping levels of the mine when compared to Milo Creek (Figure 5). Sharp distinctive peaks are seen on each pumping level. The lower the pumping level from the 20 level, the less sharp the similarities between surface and mine flows. This implies less direct interconnection of the lower levels to the surface. However, there is sufficient

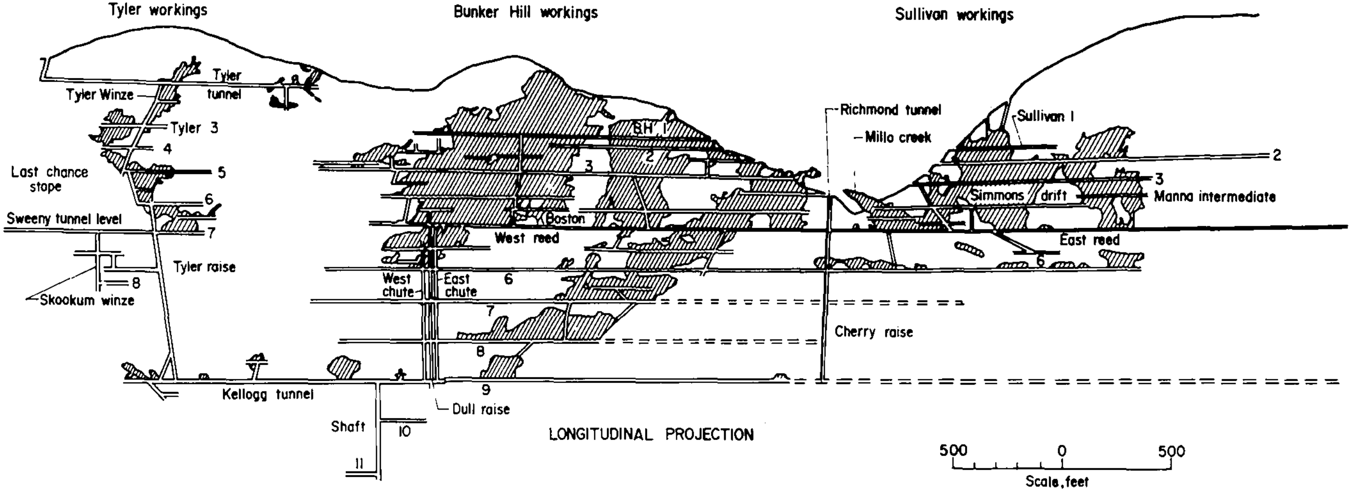

Figure 3. CROSS SECTION OF UPPER COUNTRY OF BUNKER HILL MINE SHOWING STOPED AREAS.

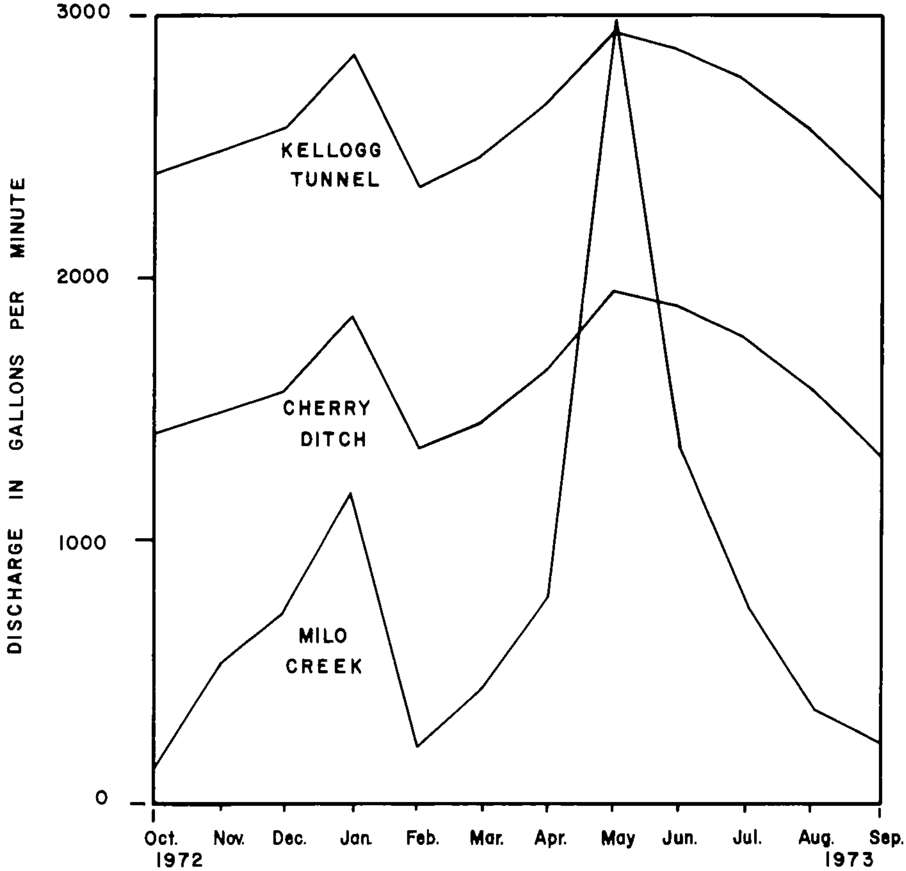

Figure 4. MEAN MONTHLY DISCHARGE OF MILO CREEK AND MINE DRAINAGE.

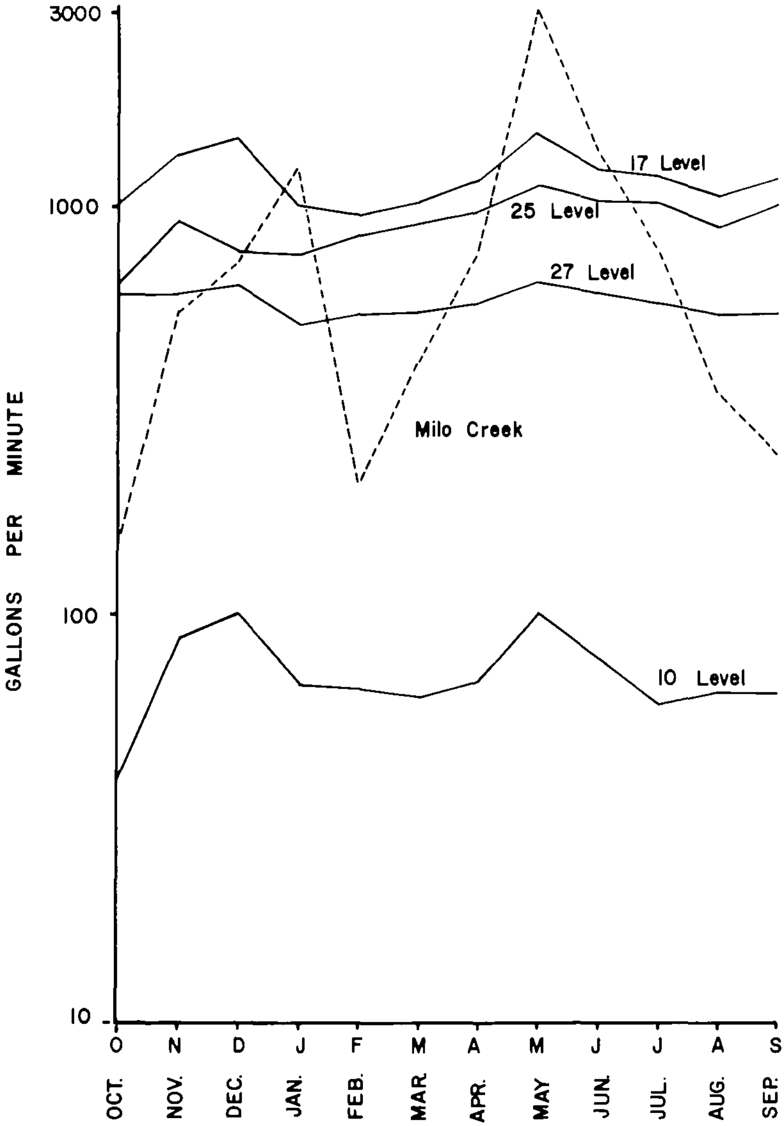

Figure 5. HYDROGRAPHS OF MEAN MONTHLY PUMP FLOWS FOR THE PERIOD 1972-73 FOR THE BUNKER HILL MINE, PUMP FLOW VALUES DERIVED FROM POWER CONSUMPTION VALUES. (27 AND 25 LEVEL PUMPS ARE INTERMEDIATE LIFT STATIONS)

interconnection to warrant an investigation to stop or direct this water higher in the mine to save on pumping cost.

Recharge Potential in the Milo Creek Basin

Many of the old workings on the upper levels of the Bunker Hill Mine are located in the Milo Creek drainage. Much of the recharge to the mine occurs in this area. Most of the precipitation in the upper parts of the drainage is in the form of snow which generally remains well into the spring. The average snowwater equivalent on April 1 is 33.5 inches. The surface area above the potential recharge areas consists of 2,200 acres. This gives a potential runoff (assuming that runoff is 50 percent of total water) of 3,070 acre-feet.

Small Hopes Drift Dye tracer tests were conducted to determine any potential hydrologic interconnection of surface water with underground workings. The procedure was to collect background samples from selected sites, the Reed Tunnel and the Small Hopes drift. The Reed Tunnel is the major drainage path of water from the 5 level, especially the east 5 level and stopes paralleling Milo Creek. The Small Hopes drift is on the 4 level of the mine and drains into the east 5 level. Rhodamine WT dye was injected in Milo Creek for two 5-minute intervals. Samples were periodically collected from the Reed Tunnel and the Small Hopes drift. The results of the trials, shown in Table II, show that seepage loss does occur from Milo Creek from the reach investigated and that recharge does occur to the mine workings. The lag time was less than one hour. The interconnection is thus very direct. Hydrograph records from the Small Hopes drift show a pattern similar to the Milo Creek hydrograph at the Bunker Hill dam.

TABLE II

Fluorescent Tracer Analysis for the Recharge Potential of Milo Creek to the Underground Workings

Time	Small Hopes	Reed Tunnel
Background count	0.0096	0.044
8:25 a.m.	Dye injected into Milo Creek	
8:25 a.m.	0.0096	0.044
8:40 a.m.	0.0220	0.110
9:10 a.m.	0.0132	0.175
9:25 a.m.	Dye injected into Milo Creek	
9:25 a.m.	0.0096	0.044
9:45 a.m.	0.0230	0.078
10:10 a.m.	0.0106	0.230

Milo Creek Dye dilution measurements of the streamflow were conducted upstream from the Bunker Hill dam. The purpose of the dye dilution measurements of the stream was to detect stream losses that could be correlated with recharge to the mine.

Milo Creek was then divided into sections for a distance of a few thousand feet above the Bunker Hill dam for the investigation of stream loss. This reach of the creek was selected because the Cate Fault is known to strike approximately parallel to Milo Creek in this area. The Cate Fault is associated with most of the water being discharged from the natural fracture system underground.

The first trial was to determine the amount of seepage through the Bunker Hill reservoir. The difference between upstream and downstream measured rates show a loss of about 60 gallons per minute. The seepage loss was caused by the removal of a fine silt-sediment cover by the mining company in an attempt to gain more storage behind the dam. The removal of the fine sediments allowed water movement through the reservoir bottom and down through the Small Hopes drift and the Reed Tunnel. As the fine sediment cover is being redoposited, the seepage volumes into the workings have slowly declined.

Other discharge measurements were made in Milo Creek above the dam for several thousand feet. A reach of stream beginning approximately 1,000 feet from the reservoir and continuing for about 1,000 feet showed statistically significant losses. The losses are shown in Table III along with the volume of water flowing in the stream at the time of measurement. The higher losses are due to greater mean flow in the stream. At high flow, the creek spreads out five to ten times the normal width. The recharge potential may be increased because of the larger surface area of the stream and the greater head. The low loss occurred when the stream was confined to its smallest stream bottom areas.

TABLE III

Losses from Milo Creek Above the Bunker Hill Dam

Time Period	Loss, in gpm	Stream Flow, in gpm
10-5-73	450	1530
17-5-73	1470	4810
11-7-73	1390	2150
23-7-73	560	740

The significant aspect of the recharge from the Milo Creek area is the volume of water entering the mine. This water is not believed to recharge any major acid-producing areas in the mine. The recharge water dilutes the poorer quality water in the underground workings. The additional water from Milo Creek water contributes to several problems. These problems are: 1) additional water to pump or drain, 2) additional water volume to treat, 3) "wet" working environment, and 4) potential water to flush any acid-producing area that might become exposed in the future.

Guy Caving Area A second area of recharge to the mine is located in the West Milo Creek drainage (Figure 2). Recharge occurs through a surface depression formed from block caving. Caving mining methods were initiated on the 4, 5, and 6 levels of the mine in the late 1940's. Once caving is started, it continues until it reaches a stable condition. In the West Milo Creek basin, the caving has extended to land surface leaving a crater about 200-300 feet across and 40 feet deep. The movement initated by caving is continuing in the area. The caving feature is very important with respect to recharge to the mine as it provides a highly permeable vertical connection between 4, 5, and 6 levels of the mine and the surface. Warm moist air rises as a vapor cloud from the caving area through portions of this highly permeable, vertical zone during the winter. The source of the vapor cloud is the exhaust ventilation from the deeper mine areas. The presence of the vapor cloud confirms that this highly permeable zone is connected with the lower mine workings.

The caving area is located at the intersection of three small valleys, all tributaries of Milo Creek. Much of the runoff from this area is funneled into the depression formed by caving. No signs of surface outflow from the depression are present. The potential surface runoff to this area is significant. The average water content of the snowpack at the head of the valley is 33.5 inches as measured on April 1. The snowpack covers approximately 230 acres in the drainage. A total of about 300 acre-feet of potential runoff (using runoff as 50 percent total water) is thus available for recharge to the caving area.

The mining company attempted to divert surface flows from the caving area through use of several dams and raises connected to the Phil Sheridan adit (Figure 6). The Phil Sheridan adit is located about 300 feet north of the caving area. The elevation of this level is approximately the same as the upper part of the caving area. There are two drifts which join near the portal. The left drift follows a path around the caving area and connects with two raises which were driven to the surface to collect and divert surface water from the caving area. These raises are located in the bottom of small draws to intercept surface runoff above the caving area.

A sharp-crested, V-notch weir and a continuous recorder were installed in the West Milo Creek drainage to obtain an estimate of the potential flow into the caving area. The weir becomes operational at about the same time that snowmelt begins in the upper part of the drainage. The hydrographs show a steady rise in flow because of increased snowmelt during the period. The water discharging over the West Milo weir is lost to ground water about 3,000 feet downstream from the weir.

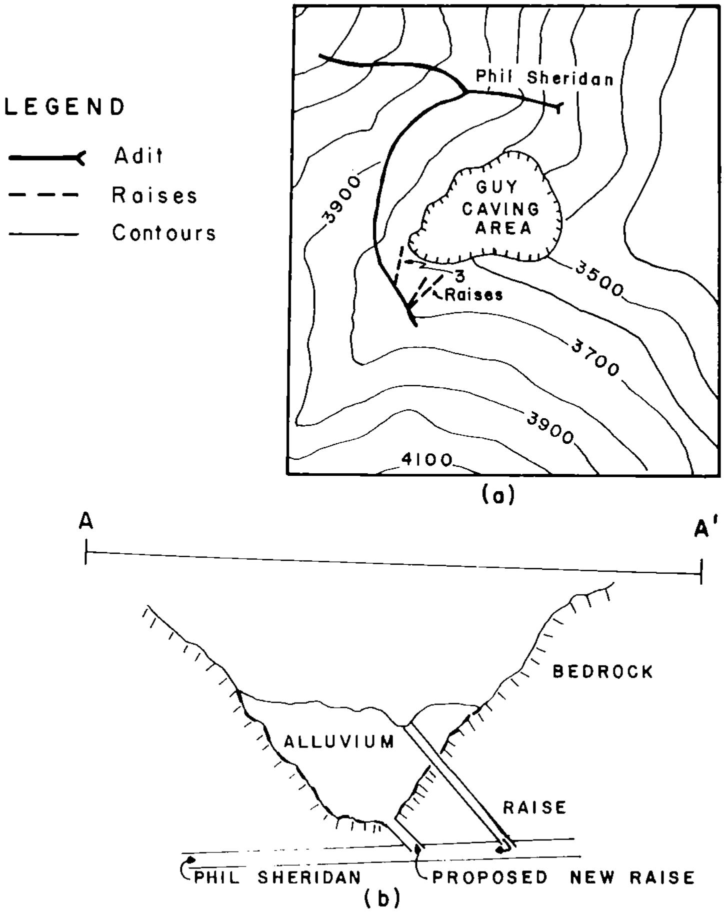

FIG. 6. (a) MAP VIEW OF GUY CAVING AREA AND PHIL SHERIDAN ADIT. (b) CROSS-SECTION SHOWING PROPOSED NEW RAISE.

One of the raises that connects to the Phil Sheridan adit is located a few hundred feet down drainage from the recharge point. Some of this runoff is collected by the two raises and is diverted through the Phil Sheridan around the caving area (Figure 6). The two raises are located near the two largest drainages and have cobble dikes to divert the water into the raises.

The dikes which were constructed to divert water into the raises are only partially effective. The dikes are high enough (about 4 feet) and the raises large enough (about 5-feet diameter) to capture much of the high flow runoff. These dikes do not capture the ground water flowing in the shallow alluvium. Leakage through the dikes probably occurs because of the cobble material making up the embankments. Water passing the dikes recharges the underground workings through the caving area. Some evapo-transpiration occurs in the area, but the loss is believed to be small. Ground-water outflow from the west drainage to the lower drainage is considered negligible. Much of the area consists of exposed bedrock, and any ground water in fractures would most likely be intercepted by mine workings before it could reach the lower drainage.

An unknown quantity of water seeps from the drifts of the Phil Sheridan adit. The water must pond and fill up the tunnel to a depth of several feet in some areas before it will flow out the adit. This ponding disappears after flow occurs indicating downward seepage. Evaporation from ponds in the drift would probably be small because the air is nearly saturated from the exhaust from the lower sections of the mine.

An attempt was made to determine the effectiveness of the diversion system around the caving area by measuring the discharge from the Phil Seridan adit. A sharp-crested, V-notch weir and a recorder were installed at the portal of the Phil Sheridan to record the amount of runoff diverted by this system. The volume of water discharged through the Phil Sheridan weir during the 1973 flow period totaled 0.13 acre-feet. Some seepage probably occurs out of the drift leading to the raises because of its proximity to the caving area. The recorded discharge is thus only a minimum estimate of the water entering the raises.

The area of surface caving consists of about 1.3 acres. This area receives the runoff that is not intercepted by the diversion raises plus direct precipitation. There is no apparent surface water discharge from the caving area. Water entering the depression must either evaporate or move downward into the underground workings. Evaporation is believed to be nil from the caving area. No signs of ponding are evident in the depressions.

A water loss of at least 18.6 acre-feet was noted from a comparison of the hydrographs of the Phil Sheridan and West Milo weirs during the 1973 flow period. Most, if not all, of this water loss is to the mine. This is a minimum estimate of water loss to the mine workings in the caving area because the records from the upper weir include flow from only the upper one-third of the west drainage area. The total runoff cannot be accurately calculated by comparing the drainage areas because the snowfall is greater in the area above the West Milo weir than below. The total runoff above the caving area during this period is estimated to have been about 50 acre-feet.

If the runoff occurs during short periods of high flows when the ground surface is frozen, then the diversion system through the Phil Sheridan adit keeps most of the water out of the mine. However, if runoff occurs at a more moderate rate over a long period of time, the diversion system does not capture much of the water.

Recharge to the mine from the Guy Caving area is important, not only because of the quantity of water but because of the path the water recharge follows in the mined area. The recharge is directed over and through stopes containing pyrite-rich ore. With the addition of large quantities of water to these stopes, acid solutions are washed downward where they leach out heavy metals. This particular recharge area is a major concern for the production of low pH water.

Deadwood Creek The Deadwood Creek area is the third area of recharge. Recharge occurs where older workings have intersected the creek channel. Precipitation is mainly in the form of snow with an average snow water equivalent of 33.5 inches as measured on April 1. Deadwood Creek during late summer and early fall has no low flow component. The surface area above the potential recharge zone includes 1,005 acres. This gives a potential runoff (using runoff as 50 percent total available water) of 1,400 acre-feet per year.

Dye tracer tests were used to determine the extent of hydrologic interconnection between surface waters and underground workings. Sample points established on the 9 level nearly 2,000 feet horizontally and 1,200 feet vertically from the dye injected area. Samples could not be obtained underground at any point closer to the suspected recharge area because of caving of the old workings. The tracer data show a definite interconnection between Deadwood Creek and water discharged on level 9 (Table IV). The differences in lag times are believed to be due to the variation in streamflow rates. These data show the interconnection of surface to underground through the Arizona-Oakland-Inez workings. These workings are located at the extreme west area of the mine and are approximately at the same position as level 4 and level 5 in the Milo Creek area.

TABLE IV

Appearance Time of Injected Dyes on Level 9

Run Number	Concentration (ppm)	Peak Appearance time hours)	Visual Estimate of Surface Flow
1	5,600	20	200 gpm
2	54,000	36	120 gpm
3	200,000	12	200 gpm

CONCLUSIONS

The Bunker Hill Mine discharges approximately 3,600 acre-feet of water yearly. The sources comprising the flow are: 1) ground-water flow (approximately 690 acre-feet yearly), 2) sand-fill water (approximately 430 acre-feet yearly, and 3) surface water recharged to the mine (approximately 2,500 acre-feet yearly). The surface water recharge to the mine is a major factor in the movement of poor quality water in the mine.

Four areas recharging the mine were identified. The potential recharge from these four areas is 4,800 acre-feet yearly. Reduction or elimination or recharge from the four identified areas should reduce the Kellogg Tunnel discharge by about 30 to 50 percent. Reduction measures include:

1. Relocation of raises and construction of cutoff walls above the Guy Caving area.

2. Pipes or flumes with collector inlets to bypass areas of faults and fractures in Milo Creek and areas of mine workings in Deadwood Creek.

3. Elimination of water flowing from diamond drill holes by capping and valving.

4. Reduction in water used in the sand-fill process by increasing slurry density.

ACKNOWLEDGEMENTS

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REFERENCES

(1) Farmer, J, 1974, Bunker Hill Mine Technical Services, personal communication.

(2) Trexler, B. D., Jr., Ralston, D. R., Reece, D. R., and Williams, R. E., 1975, Sources and Causes of Acid Mine Drainage: Idaho Bureau of Mines and Geology Pamphlet No. 165, Moscow, Idaho, 129 p.