*International Journal of Mine Water*, Vol. 3 (4), (1984) 39-53
Printed in Madrid, Spain

# THE HYDROGEOLOGY OF AN UNDERGROUND LEAD-ZINC MINE : WATER FLOW AND QUALITY CHARACTERISTICS

John A. Riley, Daniel L. Erikson,
Dale R. Ralston, and Roy E. Williams

College of Mines and Earth Resources,
University of Idaho, Moscow, Idaho 83843.

## ABSTRACT

Acid mine drainage is a major environmental and economic problem. The abandonment of acid-producing mines is of particular concern. The University of Idaho is conducting a detailed investigation of the Bunker Hill Mine, in north Idaho, to determine the mechanisms controlling mine recharge and acid production and their impact on abandonment alternatives.

The Bunker Hill Mine disturbs 20 cubic kilometers of highly fractured quartzites of the Revett and St. Regis formations (Belt Supergroup). The mine comprises 240 km of tunnels and drifts and 9.6 km of major inclined shafts, raises and winzes. The mine has 31 levels extending nearly 1830 m in depth. An average of 190 l/s of water is discharged from the mine. The discharge typically has pH about 3.0 and zinc concentrations in the 100 milligrams per liter range. Gravity drainage accounts for about 30 percent of the flow. Pumpage from lower levels accounts for the balance.

Recharge to the mine occurs from fractures, exploration drill holes, and areas where mine workings extend to land surface. Understanding the temporal and spatial water flow and quality characteristics within the mine is essential to the design and abandonment procedures to mitigate long-term environmental and economic impacts.

Research has been conducted underground in the Bunker Hill Mine since early 1983. Discharge/quality monitoring sites have been established to document both gravity drainage through the upper workings and pumpage from lower levels. Preliminary evaluation of data show differing temporal patterns of flow and quality within the mine. Data collection is continuing with specific emphasis on identifying specfic areas and controls for recharge and the flow patterns in acid-producing areas of the mine.

## INTRODUCTION

Acid mine drainage is a serious environmental and economic concern. During the productive life of a mine, the costs of acid drainage, including pumr corrosion and water treatment are part of the operating

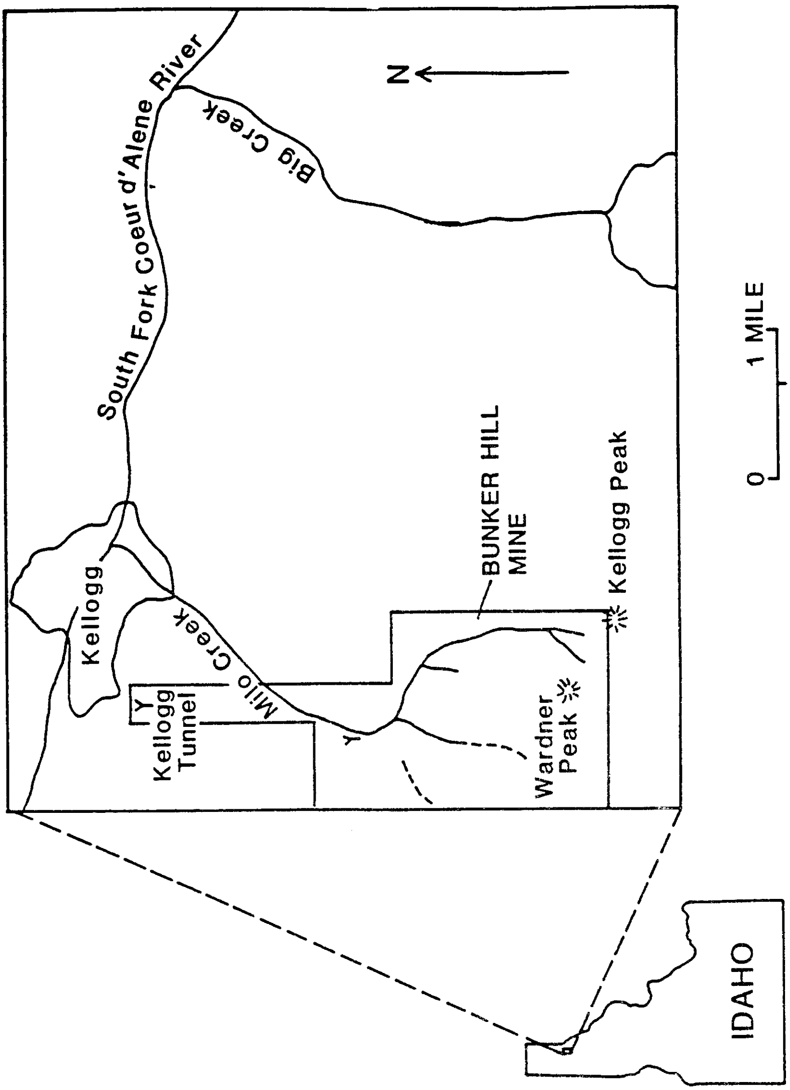


Figure 1. Location of the Bunker Hill Mine in Northern Idaho.

overhead. An abandoned mine, however, produces no income to pay for the necessary water treatment. Pyrite oxidizes when air and water come in contact with it and sulfuric acid is produced. This lowers the pH of the water and increases the solubility of many metals.

This research is taking place at the Bunker Hill Mine, located at Kellogg in northern Idaho's Coeur d'Alene mining district (Fig.1). The Bunker Hill is a large, underground lead zinc mine nearing the end of its operating life. The mine is not presently in production but is being operated on a care and maintenance basis. The Bunker Hill discharges acid water by a combination of gravity drainage and pumpage amounting to about 152 l/s. The pH is 2.8 and the zinc concentration averages 120 milligrams per litre. The discharge is treated and released to the south fork of the Coeur d'Alene River after meeting NPDES standards. The Bunker Hill is one of the first acid producing, hard rock mines facing closure since the establishment of the NPDES standards; it is therefore important to study and understand.

The objective of this portion of the research is to describe quantitatively the water flow systems and water quality distributions in the mine in order to evaluate the benefits of alternative reclamation plans. Concurrent research includes investigation of surface features which may control recharge to the mine and application of computer modelling to evaluation of alternatives for reclamation.

## HYDROGEOLOGY

The geologic setting of the Bunker Hill Mine is complex. The mine is located along the contact of the Burke and St. Regis members of the Belt group of metamorphic rock. The country rock is primarily meta-quartzites with some argillite. The ore minerals are predominantly galena and sphalerite in a gangue that contains considerable calcite. Pyrite is associated with the ore minerals. Hydraulic conductivity is fracture controlled. Water enters the mine by one of two mechanisms : either by interception of surface water by mine workings or by interception of ground water by drifts, shafts, stopes and exploration drill holes.

The Bunker Hill is a large mine that contains more than 240 km of drifts on 31 levels; the drifts are connected by 96 km of inclined shafts reaching a depth of more than one mile. The main haulage entrance to the mine is the Kellogg Tunnel on the 9 level. Water originating above this level gravity drains through a maze of shafts, stopes, ore chutes, and manways down to the 9 level. Water from the deeper workings is pumped up to 9 level. All water from the mine discharges through the Kellogg Tunnel.

## DATA PRESENTATION AND DISCUSSION

The water flow and quality characteristics at six sites in the Bunker Hill Mine for 1983 are presented in this section. The sites are discussed in order of increasing depth in the mine. The first three sites are gravity drainage sites above 9 level; the remaining sites are pump discharges which contribute water made below 9 level.

The flow and zinc concentration at the Becker Weir are presented on Figure 2. This weir measures flow derived from surface and near surface

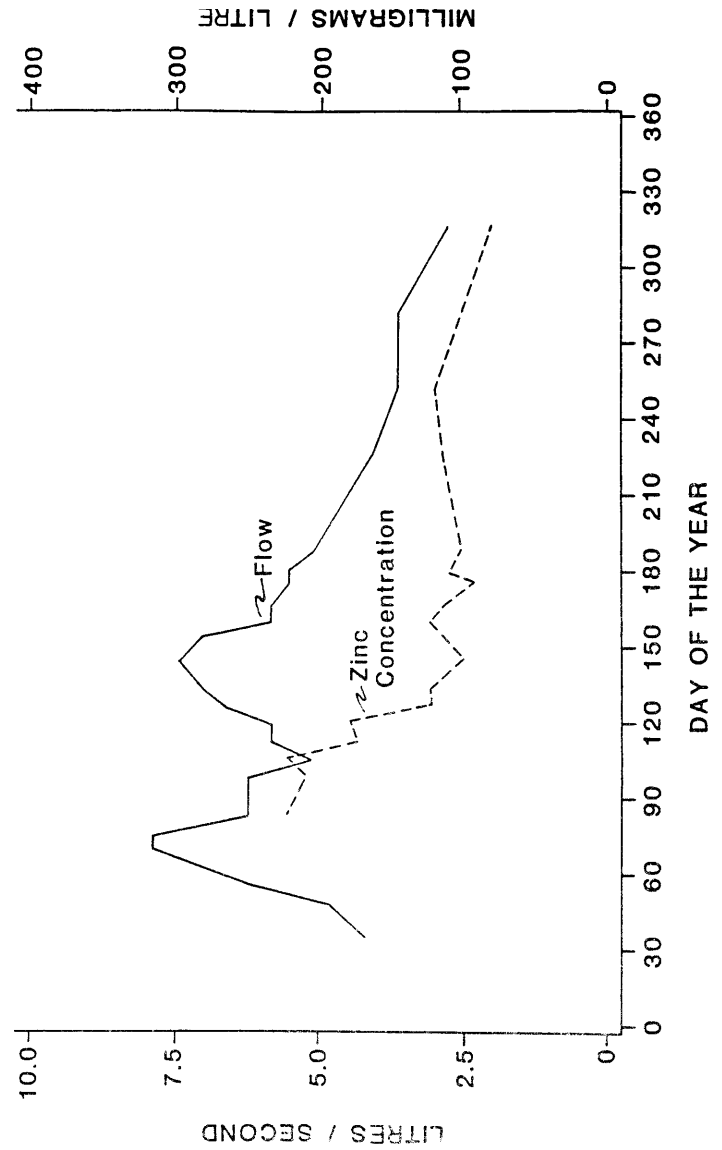


Figure 2. Becker Weir Flow and Zinc Concentration During 1983, Bunker Hill Mine, Idaho.

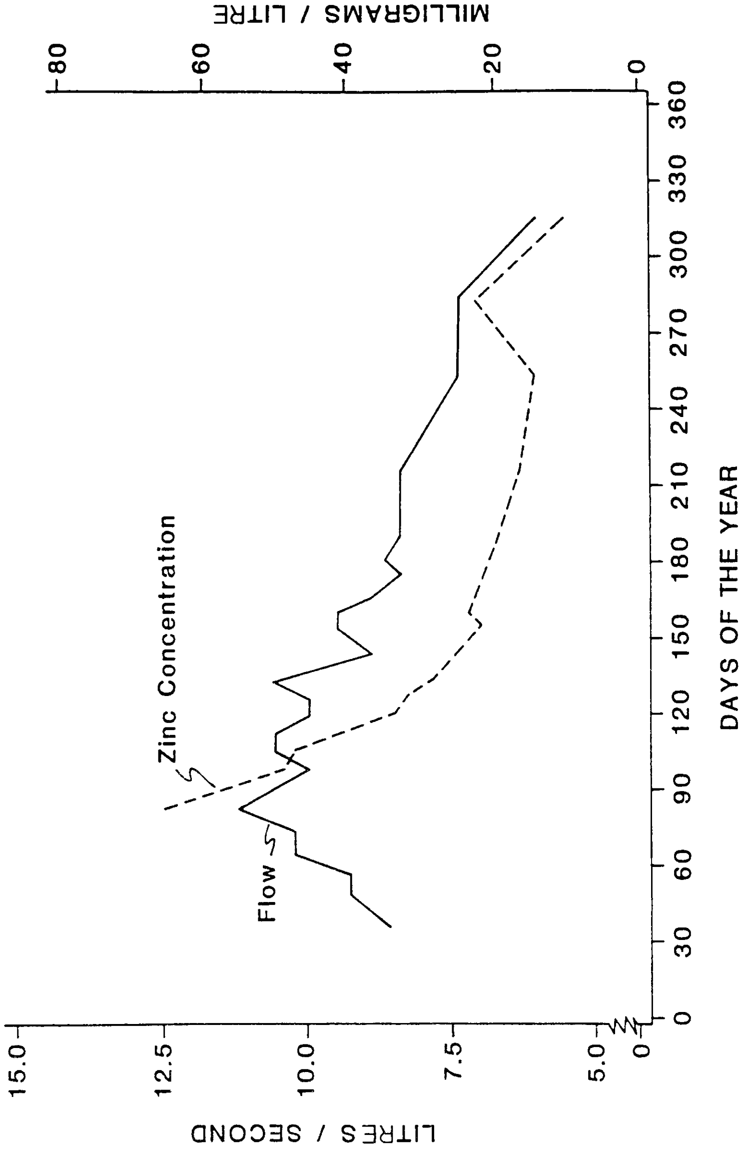


Figure 3. Williams Weir Flow and Zinc Concentration During 1983, Bunker Hill Mine, Idaho.

colluvium and fractures as well as underground stope drainage. Two distinct peaks in flow occurred in 1983. A peak in zinc concentration from our samples occurs at the same time as the first peak in flow. The absolute peak in zinc concentration probably occurred prior to the sampling on day 83. The second peak in flow dilutes the zinc concentration. The implication of these points are noteworthy. The initial high zinc concentration occurring near a peak in flow indicates a flushing of reaction products from the drift and stope walls and/or a flushing of poor quality water pooled on the drift floors. The floors of the drifts undulate and stagnant pools of very poor quality water collect in the low areas. The specific electrical conductance of some of these pools is over 20,000 micromhos per centimeter. The dilution occurring at the second peak in flow indicates that much less reaction product and pooled poor quality water were available in the flow path. The nature of the hydrograph indicates that the flow at this site is influenced by surface water or near surface ground water flow systems.

The Williams Weir measures flow from underground drill holes and fractures with a small contribution from surface water (Figure 3). The flow peaked early in the year. High zinc concentrations occurred at nearly the same time which suggests a flushing mechanism similar to the Becker Weir. The zinc concentrations are relatively insensitive to minor fluctuations in flow later in the year. The peak in flow early in the year followed by a gradual decrease is indicative of a shallow ground water flow system.

The data from the Cherry Weir are presented in Figure 4. The water measured by the Becker Weir and Williams Weir are tributary to the Cherry Weir but account for only about half its discharge. The flow shows an early peak followed by small fluctuations and a gradual recession after day 133. The initial zinc concentration peak probably was missed. The early high zinc concentration is similar to the tributary gravity drainage sites. A gradual decline in zinc concentration follows except for a peak near day 150. This peak is associated with no measurable increase in flow. It is probable that this relationship is caused by a small increase in flow from some source of very poor quality water. Some sources tributary to the Cherry Weir have zinc concentrations of over 20,000 milligrams per litre. Seasonal fluctuation and recession are evident at this site.

The next three figures show the flow and zinc concentrations from the pumps which dewater the lower workings of the mine. All the water from the mine flows out through the main haulage portal on the 9 level. Figure 5 presents the data for the 10 level pump; this water is pumped from 10 level to 9 level. The 10 level pump discharge has high flow early in the year with a very steep recession. This hydrograph is indicative of a flow system dominated by direct recharge of surface water. This hypothesis is supported by the temporal pattern of the zinc concentration. During high flow, the zinc concentration is low and during low flow the zinc concentration is high, indicating a dilution of the poor quality mine water with clean water from the surface. This mechanism is substantially different than the flushing mechanisms characteristic of the upper levels.

The flow and zinc concentration characteristics of the 15 level pump are shown on Figure 6. This discharge consists of water pumped up to 9 level from drainage collected on 1[illegible] through 15 levels. The hydrograph

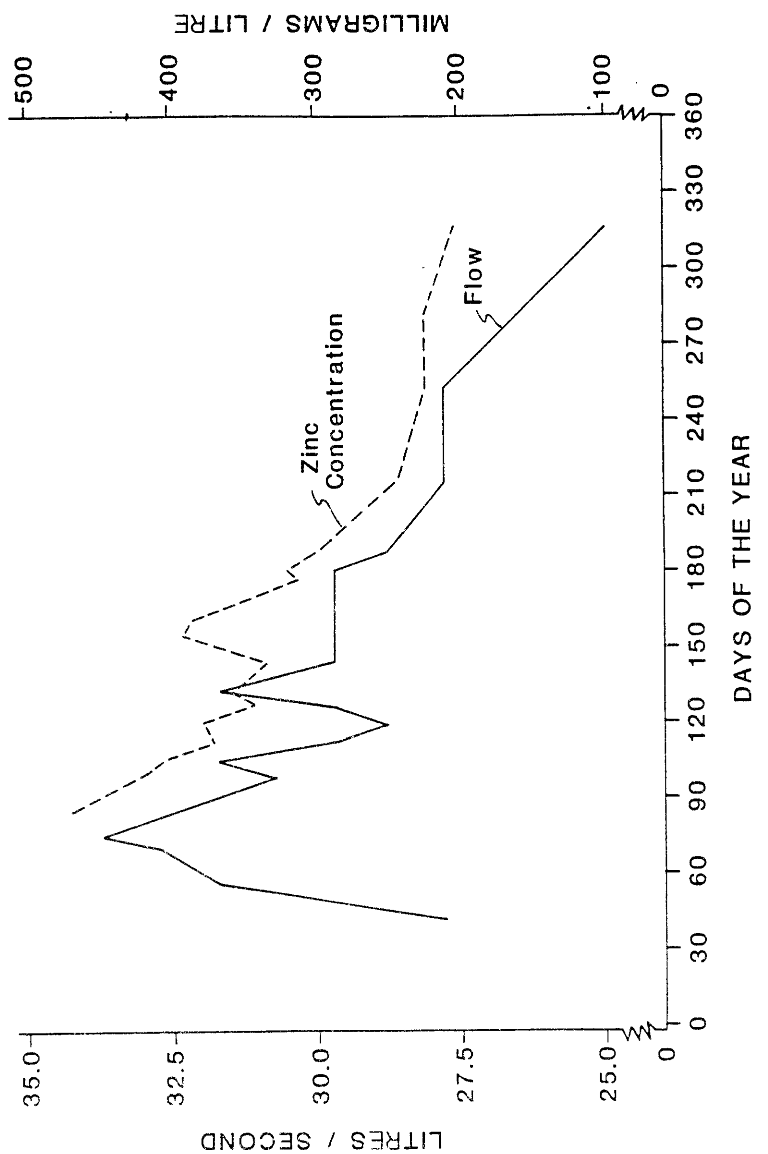


Figure 4. Cherry Weir Flow and Zinc Concentration During 1983, Bunker Hill Mine, Idaho.

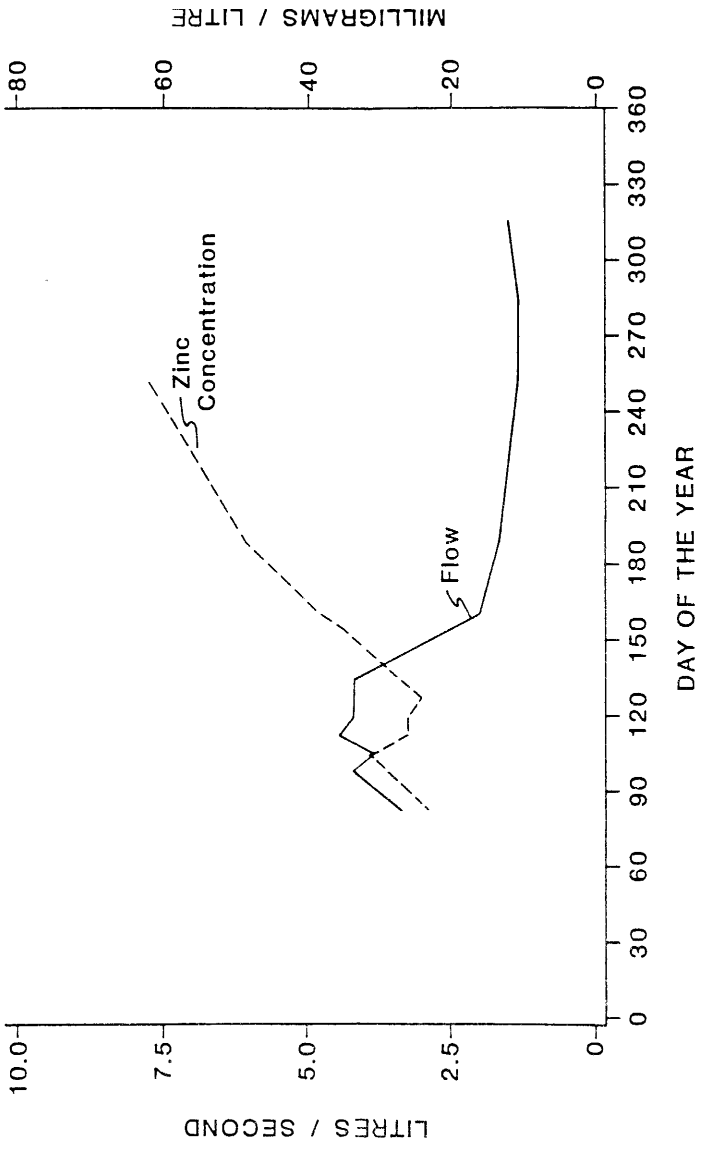


Figure 5. Level 10 Pump Flow and Zinc Concentration During 1983, Bunker Hill Mine, Idaho.

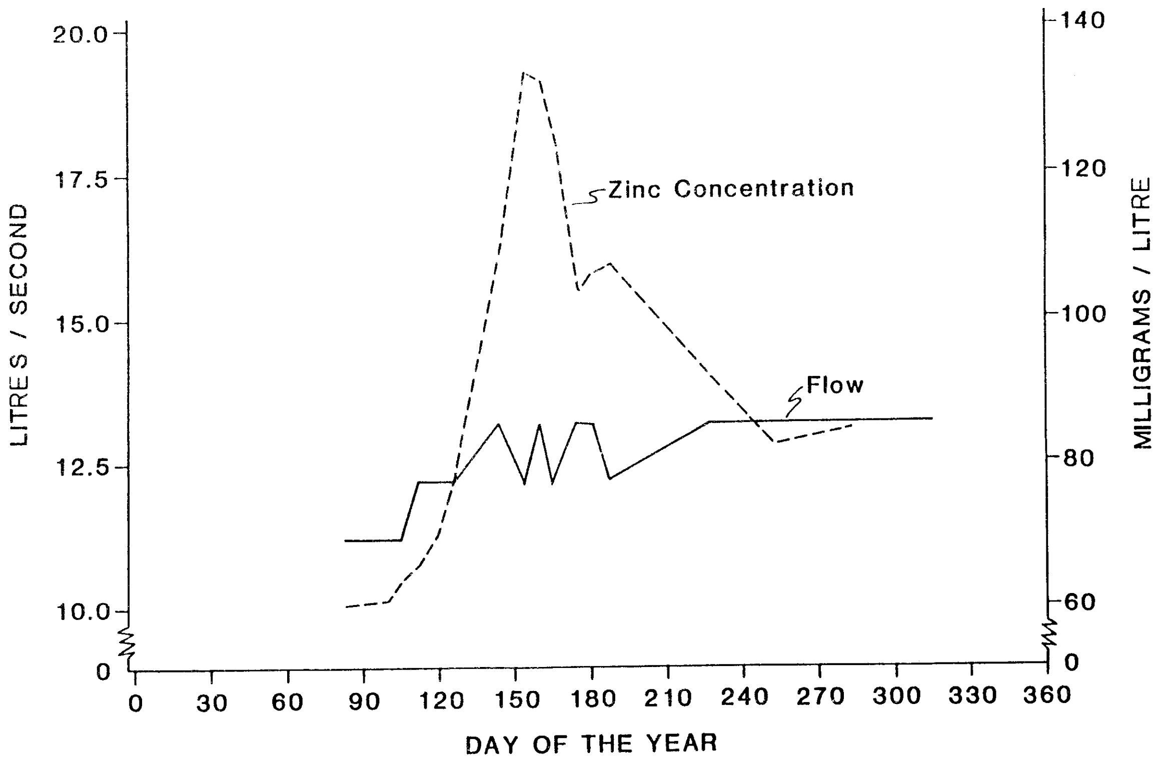


Figure 6. Level 15 Pump Flow and Zinc Concentration During, 1983, Bunker Hill Mine, Idaho.

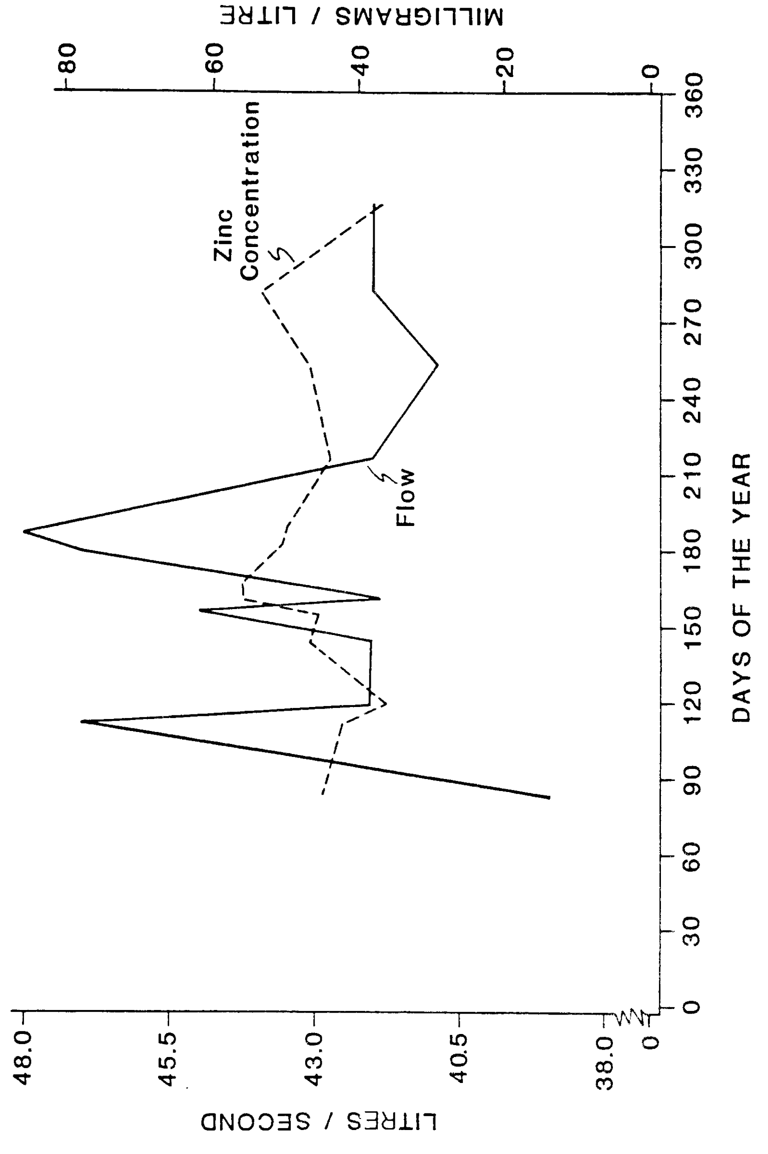


Figure 7. Level 17 Pump Flow and Zinc Concentration During 1983, Bunker Hill Mine, Idaho.

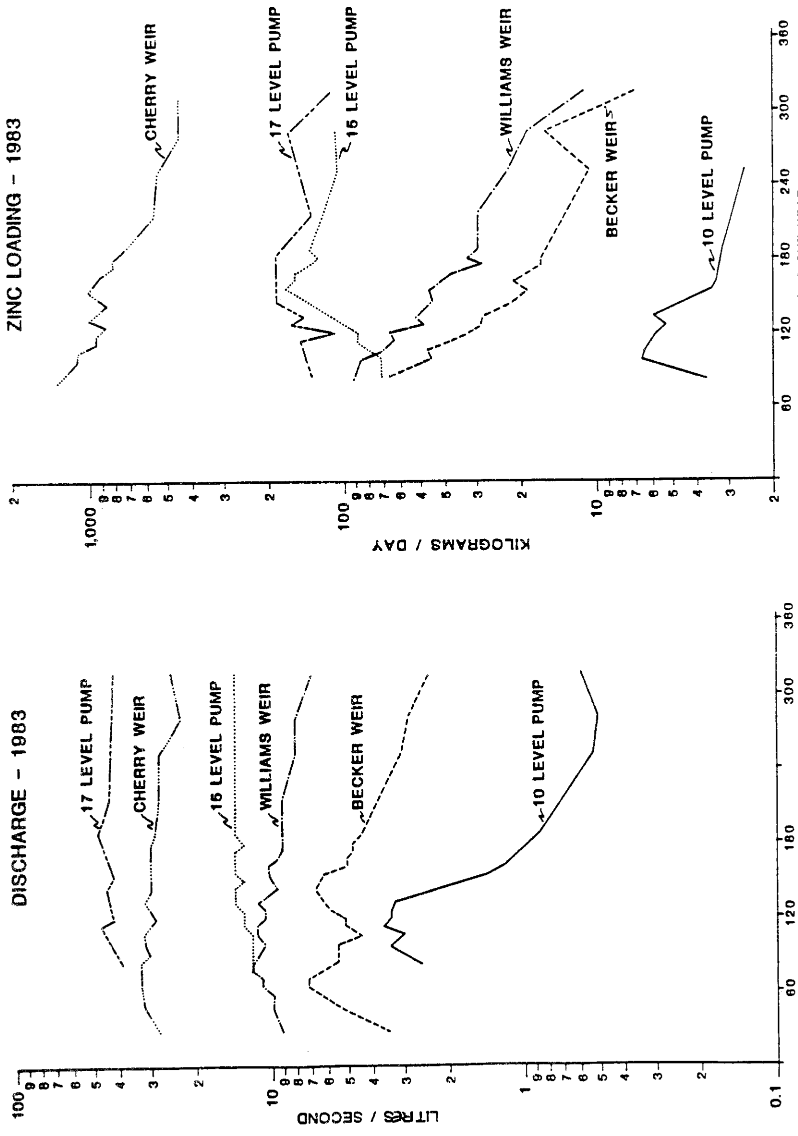


Figure 8. Six Site Composite Graph Showing Flow and Zinc Loading During 1983, at the Bunker Hill Mine, Idaho.

shows very little variation and no discernable peak in flow. A very high peak in zinc concentration near day 150 is evident in the 15 level data. The timing of this peak is just slightly later than the similar peak at the Cherry Weir, and like the Cherry Weir event, it is accompanied by no measurable increase in flow. The flow characteristics at this site suggest a relatively constant discharge from the lower workings in the mine with little seasonal variation.

The 17 level pump discharges water that drains or is pumped to the 17 level from 16 through 29 levels. This pump, discharging on 9 level, represents water from the deepest workings in the mine. Water pumped across from a neighbouring mine contributes to this discharge. Figure 7 presents the 17 level pump flow and zinc concentrations. The apparent variation in flow reflected on this graph is deceiving because of the scale on which it is drawn. The percentage variation, from high flow to low flow, is very nearly the same as that of the 15 level pump just discussed. Peaks in flow from this pump occur later in the year than at any other site. Peaks in zinc concentration are later and less distinct than at any of the other sites.

The characteristics of the flow and quality at various sites can be compared by studying the data from the six sites presented on a single graph. Figure 8 shows a plot of the log of discharge and the log of zinc loading plotted versus time on the arithmetic scale. Loading is the result of multiplying the zinc concentration times the flow at a site. The results are presented as kilograms per day. This gives an indication of the magnitude of the problem at the site and the associated treatment cost. The hydrographs with clear seasonal peaks and recession characteristics are those of the Becker Weir, Williams Weir, and 10 level pump. These hydrographs are indicative of a short flow path and recharge from a surface water or shallow ground water flow system. The Cherry Weir has a more subdued hydrograph; however, peak discharge occurs at this site early in the year with a gradual recession during the year. The 15 level pump shows very little variation in flow and no recognisable peak during the year. The 17 level pump hydrograph shows some variation in flow. However, the response is damped. The damped characteristics of the 15 level and 17 level pumps are to be expected because longer flow systems feed the deeper levels of the mine.

The graphs of zinc loading demonstrate clearly the flow/quality characteristics of the mine. The sites which are influenced most by near surface recharge (Becker Weir, Williams Weir) show a high peak in loading early in the spring followed by a gradual decrease throughout the year. The Cherry Weir graph also has a peak zinc load early in the spring. Secondary peaks are evident at the Cherry Weir later in the year, suggesting that recharge also is coming from systems with longer flow paths. The 10 level pump graph shows a peak load occurring slightly later than the Becker Weir and Williams Weir; less seasonal change is evident, and the magnitude of the load is small. The peak zinc load from the 15 level pump occurs later, and less seasonal variation is evident here than at the higher levels. The zinc loading from the 17 level pump exhibits the latest peak and very little temporal variation.

A comparison of the zinc load above and below the 9 level reveals two noteworthy characteristics (Figure 9). The loading at the Cherry Weir, which represents gravity drainage from the upper workings of the mine,

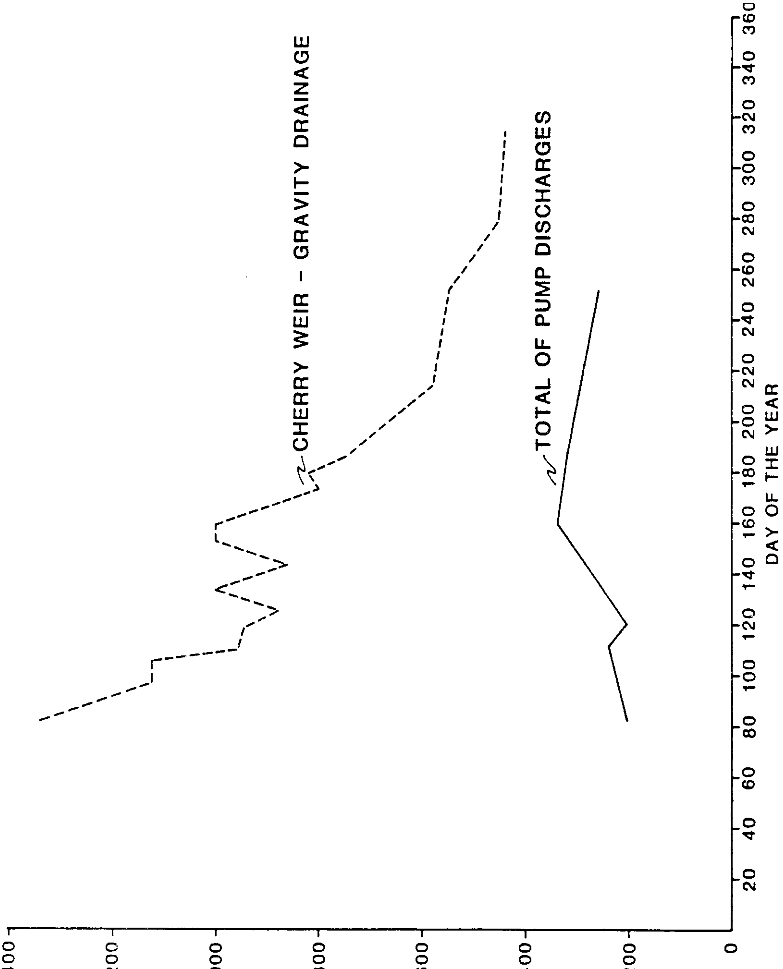


Figure 9. Zinc Loading Contribution from Gravity Drainage and Pumped Discharge During 1983, Bunker Hill Mine, Idaho.

exhibits strong seasonal variation with a peak in the spring and gradual recession through the remainder of the year. The zinc loading of the three pumps which dewater the lower workings of the mine are summed to obtain the second curve. Seasonal fluctuation is much less and the peak occurs later in the year. More important, however, is the magnitude of the zinc loading of the upper workings compared to the lower part of the mine. In the spring, the loading contributed by gravity drainage is five times that being pumped out of the mine. Throughout the year, more than three times as much zinc drains from the upper workings as is pumped from the lower workings.

## IMPLICATIONS ON ABANDONMENT ALTERNATIVES

The flow and quality characteristics just presented have major implications on the abandonment alternatives for the Bunker Hill Mine. Some of the abandonment techniques which have been used at other mines are : (1) sealing the mine entrances to prevent air movement, (2) decreasing or eliminating recharge to the mine, (3) flooding the mine and (4) combinations thereof.

Sealing the mine entrances has been used as a way of keeping air away from the pyrite, thereby decreasing the acid production. Too many portals to the old upper workings exist at the Bunker Hill Mine for that to be a practical alternative. The hillsides are honeycombed with old workings; some are still visible but many are lost due to slumps, slides or cave-ins.

Decreasing recharge to the pyrite rich areas of the minw would also decrease the amount of acid produced. The recharge to the 10 level appears to be controlled by a surface water flow system. It is possible that a surface diversion, at some as yet unidentified location, would decrease recharge to this flow system. All the other underground sites appear to be controlled by shallow or deep ground water systems. Systems of this type are much harder to control or direct. Research is continuing to better understand the flow systems recharging the mine in order to better evaluate recharge diversion as an abandonment alternative.

Flooding has been successful in reducing pyrite oxidation and acid production in many mines. At the Bunker Hill Mine, it is possible to flood the lower workings up to the 9 level without sealing any adits. Water from the lower portion of the mine would eventually discharge onto the 9 level. During flooding production of acid would continue. As a result, at least one mine volume of poor quality water would exist in the mine. The quality of drainage from the lower levels would thus remain poor until one mine volume had been replaced. However, even if flooding the lower workings eliminated all the acid discharge from the lower workings, the gravity drainage from the upper mine would still carry the substantial zinc load that it carries now. The amount of discharge from the mine would be reduced substantially, but the concentration of dissolved ions in the discharge would be much higher. Consequently the necessity to treat the discharge would remain. Flooding the upper portion of the mine would be difficult if not impossible because of the large volume of near surface workings, the many mine openings and the steep topography.

## CONCLUSIONS

Several conclusions are indicated as a result of the research conducted thusfar. Research at the Bunker Hill Mine is continuing. The temporal variations of flow and zinc concentrations vary with depth in the mine. The data from shallow workings exhibit seasonal variations in flow and zinc loading. The data from the deep workings in the mine exhibit much less seasonal variation in flow and a relatively constant zinc loading. Two distinct mechanisms are indicated by this contrast. The upper workings appear to be dominated by shallow flow systems, and poor quality water appears to be flushed annually out of the drifts, stopes and ore chute in the upper workings. The lower workings appear to be controlled by longer flow systems; little evidence of seasonal flushing exists.

The mechanisms controlling flow and zinc concentrations have special implications regarding abandonment alternatives for the Bunker Hill Mine. The deeper portions of the mine can be flooded; this will decrease drastically the amount of water discharged from that part of the mine. It may be possible to reroute or otherwise control the shallow flow systems recharging the upper workings to reduce the flushing of acid water from the mine. More research is needed to further delineate the systems and mechanisms responsible for recharge. This type and intensity of study is needed on all mines facing abandonment to determine which abandonment technique(s) would be most successful in reducing undesirable environmental and economic consequences. Finally, the results of this research carry strong implications with respect to mine planning. The gravity drainage from the upper workings presents the most difficult problem associated with abandonment of the Bunker Hill mine. The many portals to the upper workings prohibit sealing and flooding that portion of the mine. Construction of a mine with the main discharge point below the nearest groundwater discharge point would greatly simplify the eventual abandonment of the mine.

## ACKNOWLEDGEMENTS

The project is directed by Dr. Dale Ralston and Dr. Roy Williams. Funding is provided by the U.S. Bureau of Mines through the University of Moscow, Generic Mineral Research Centre.