HYDROGEOLOGIC ASPECTS OF THE ABANDONMENT OF AN UNDERGROUND LEAD-ZINC MINE

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ABSTRACT

Acid mine drainage related to pyrite oxidation is a serious environmental and economic concern. During the productive life of a mine, the costs of acid drainage including pump corrosion and water treatment are part of the operating overhead. An abandoned mine, however, produces no income to pay for the necessary water treatment.

Research on minimizing poor quality drainage after abandonment of an acid producing mine is taking place at the Bunker Hill Mine, located in northern Idaho. The Bunker Hill is a large underground lead-zinc mine nearing the end of its operating life. It discharges acid water by a combination of gravity drainage and pumpage amounting to about 95 liters per second. The pH is 2.8 and zinc concentration averages 120 milligrams per liter. The objective of this 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 to minimize acid water discharge after abandonment.

Graphs of flow and zinc loading at six sites demonstrate the flow/quality characteristics of the mine. The temporal variations of flow and zinc concentrations vary with depth in the mine. There are seasonal variations in flow and zinc loading in the shallow workings. The data from the deep workings in the mine exhibit much less seasonal variation in flow and a relatively constant zinc loading. The upper workings appear to be dominated by shallow flow systems; poor quality water appears to be flushed annually out of the drifts, stopes and ore chutes in the upper workings. The lower workings appear to be controlled by longer flow systems with little evidence of seasonal flushing.

The mechanisms controlling flow and zinc concentrations have major implications regarding abandonment alternatives for the Bunker Hill Mine. The deeper portions of the mine can be flooded; this will decrease both the amount of water discharged and the zinc loading from the mine. However, the main acid producing areas in the upper workings cannot be flooded because of the large number of portals and the fractured nature of the rock mass.

Research is continuing on the diversion of surface water and groundwater away from localized acid producing areas in the upper workings to reduce the flushing of acid reaction products into the mine drainage system.

INTRODUCTION

Acid mine drainage is a serious environmental and economic concern. The costs of acid drainage, including pump corrosion and water treatment, are part of the operating overhead during the productive life of a mine. 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 directed toward evaluation of alternative procedures to minimize drainage of poor quality water from a mine upon abandonment. The study site is at the Bunker Hill Mine, located 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 Mine discharges acid water by a combination of gravity drainage and pumpage amounting to about 95 liters per second. The pH is 2.8 and the zinc concentration averages 120 milligrams per liter. The discharge is treated and released to the south fork of the Coeur d'Alene River after meeting federal discharge standards. The Bunker Hill is one of the first acid producing, hard rock mines facing closure since the establishment of the NPDES federal discharge standards. These standards, which require that water treatment continue as long as the poor quality discharge exists, were designed for industrial sites where the discharge would cease with the closure of the plant. It is therefore important to study and understand the long-term aspects of abandonment of an acid producing mine under the NPDES standards.

The objective of this 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. The goal is to minimize drainage of acid water from the mine upon abandonment.

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 Supergroup of metamorphic rocks. The country rock is primarily metaquartzites 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: 1) downward movement of water under saturated/unsaturated conditions within the cone of depression created by the mine, or 2) lateral ground water movement to the margins of the mine.

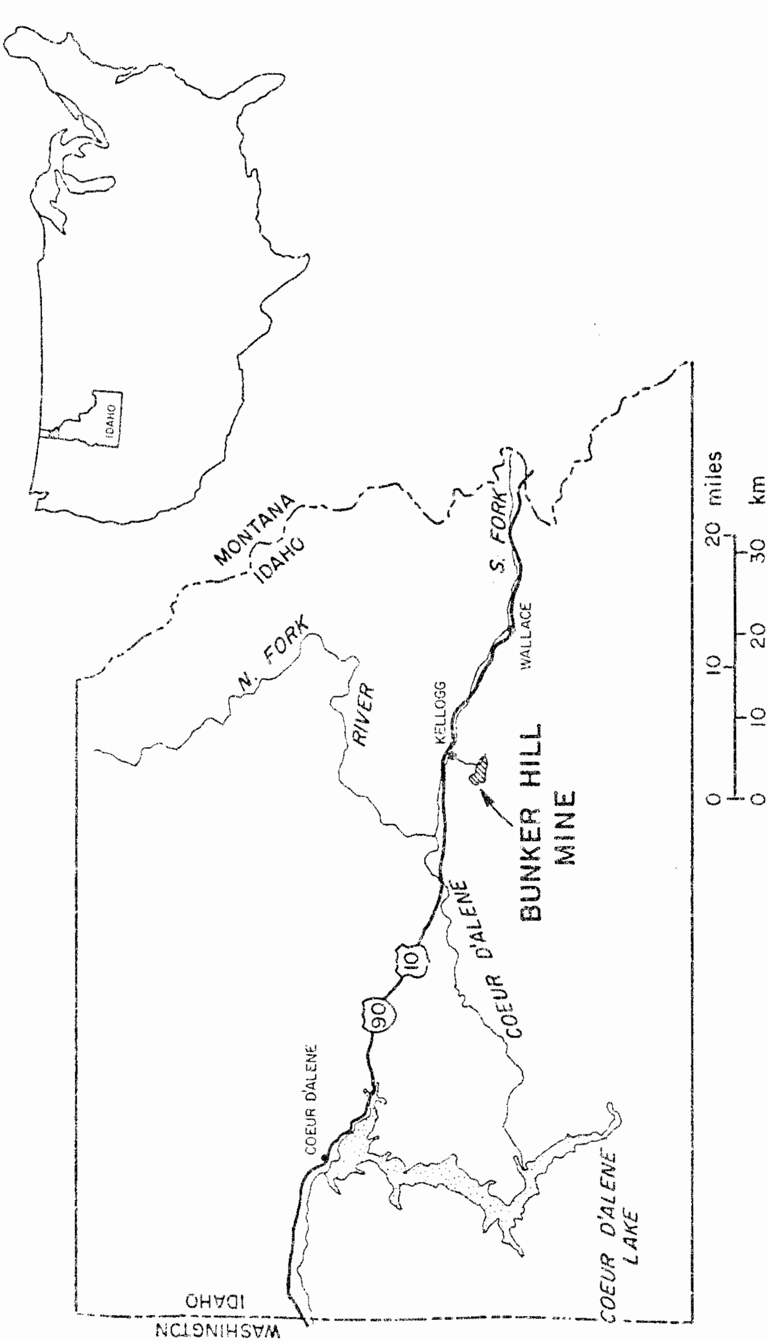

Figure 1. Location of the Bunker Hill Mine in Northern Idaho.

The Bunker Hill is a large mine that contains more than 240 km (kilometers) of drifts on 31 levels; the drifts are connected by 10 km of inclined shafts reaching a depth of more than one km. The main haulage entrance to the mine is the Kellogg Tunnel on the 9 level. The levels are numbered downward. Water originating above the 9 level gravity drains through a maze of shafts, stopes, ore chutes, and manways down to this 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 investigation of the Bunker Hill Mine has focused on identifying the acid producing areas within the underground workings, understanding the mechanisms and areas of recharge to the acid producing areas and documenting the movement of both good and poor quality water through the mine workings. These efforts have resulted in the delineation of several alternative ways to reduce the drainage of poor quality water from the mine.

The water flow and quality characteristics at six sites in the Bunker Hill Mine are presented in this paper. These sites illustrate the mechanisms of movement of acid reaction products within the mine. The first three sites are gravity drainage sites above 9 level where most of the acid production occurs (Becker Weir, Williams Weir and Cherry Weir); the remaining sites are the pump discharges from below the 9 level (10 level pump, 15 level pump and 17 level pump). Zinc is used as an indicator of acid water production.

The flow and zinc concentration at the Becker Weir are presented on figure 2. This weir measures flow derived from surface and near surface colluvium and fractures as well as underground stope drainage. Two distinct peaks in flow occurred in 1983. The 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 first day of sampling. The second peak in flow dilutes the zinc concentration. The implications 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 products and pooled poor quality water were available for flushing. 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 (Fig. 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.

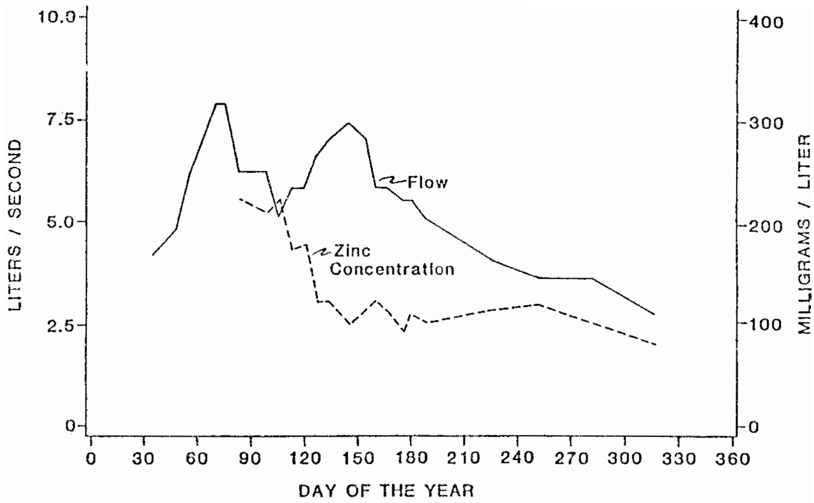

Figure 2. Becker Weir Flow and Zinc Concentration During 1983, Bunker Hill Mine, Idaho.

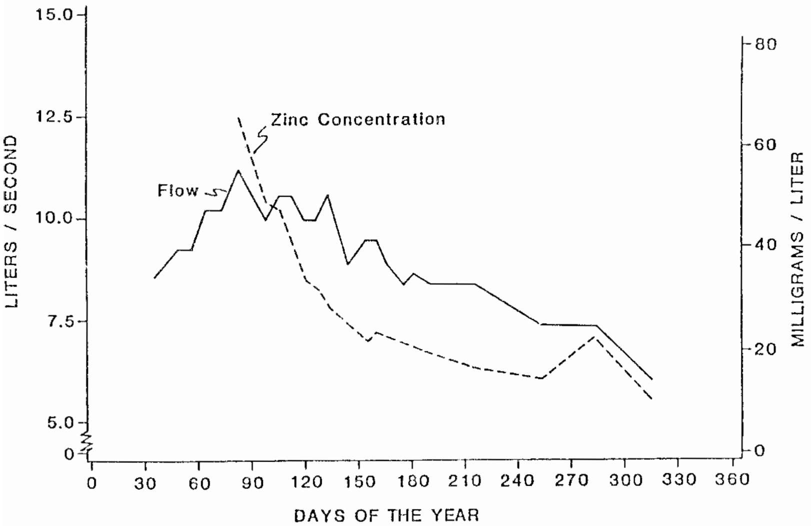

Figure 3. Williams Weir Flow and Zinc Concentration During 1983, Bunker Hill Mine, Idaho.

The data from the Cherry Weir are presented in figure 4. The flows measured by the Becker Weir and Williams Weir are tributary to the Cherry Weir but account for only about half of 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 liter. 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 poor quality mine water with good quality surface water. 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 11 through 15 levels. The hydrograph 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 on the 9 level that drains or is pumped to the 17 level from 16 through 29 levels. This pump represents water from the deepest workings in the mine. Water pumped across from a neighboring mine also 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 log 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 other sites.

The characteristics of the flow and quality at the six sites can be compared by presenting the data 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. Zinc loading is the result of multiplying the zinc concentration times the flow at a site. The results are presented

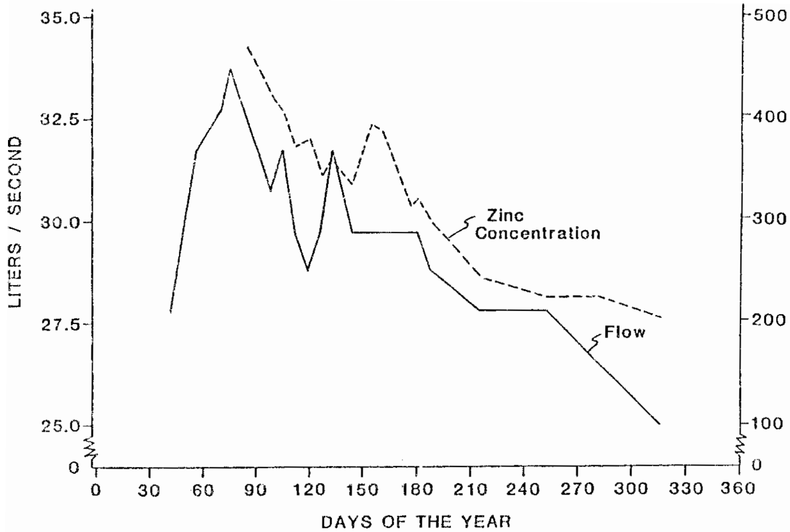

Figure 4. Cherry Weir Flow and Zinc Concentration During 1983, Bunker Hill Mine, Idaho.

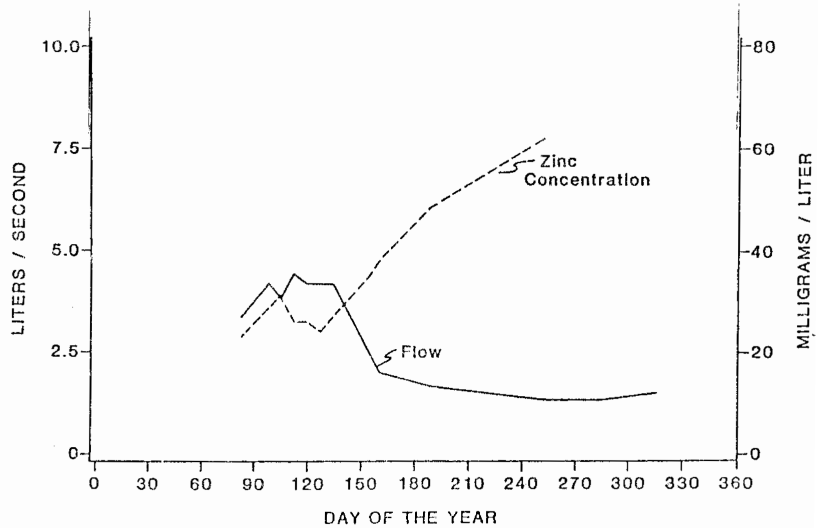

Figure 5. Level 10 Pump Flow and Zinc Concentration During 1983, Bunker Hill Mine, Idaho.

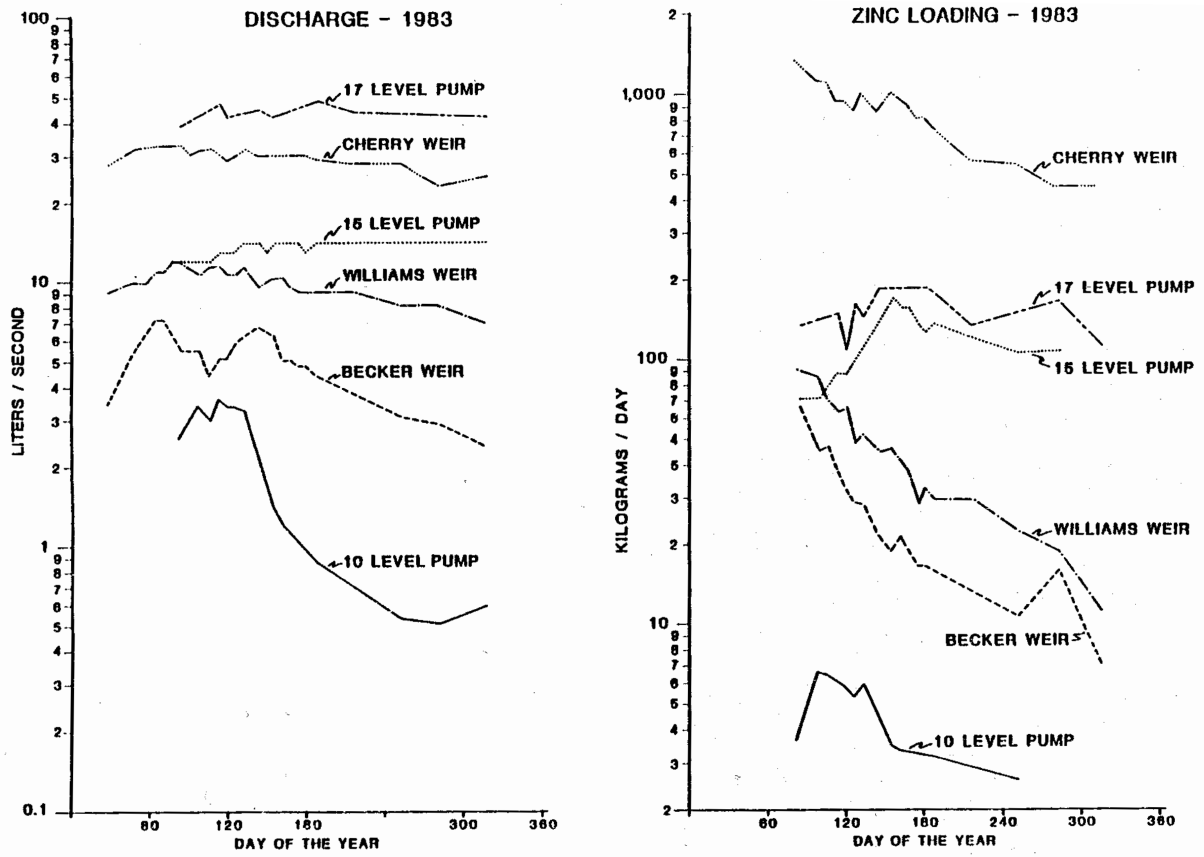

Figure 8. Six Site Composite Graph Showing Flow and Zinc Loading During 1983, Bunker Hill Mine, Idaho.

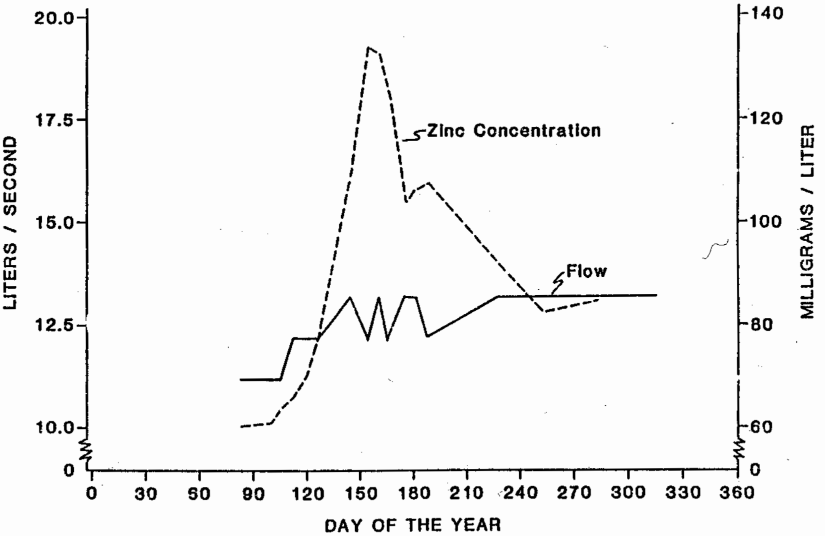

Figure 6. Level 15 Pump Flow and Zinc Concentration During, 1983, Bunker Hill Mine, Idaho.

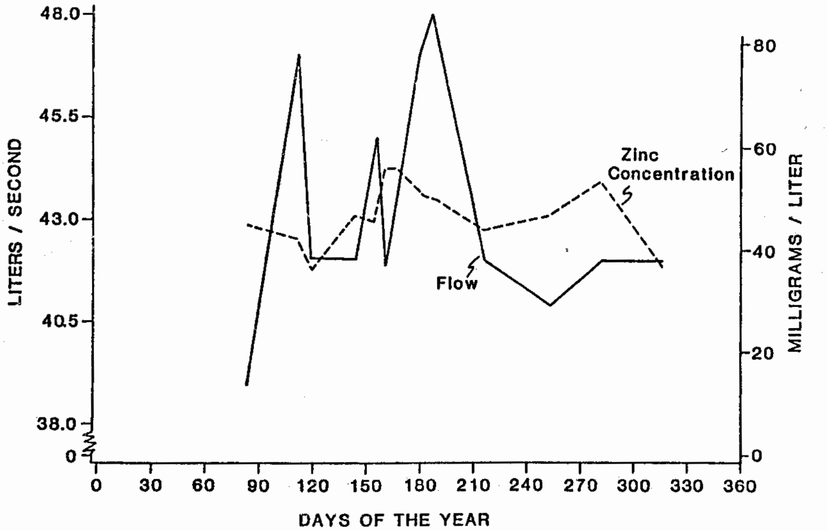

Figure 7. Level 17 Pump Flow and Zinc Concentration During 1983, Bunker Hill Mine, Idaho.

A comparison of the zinc load above and below the 9 level reveals two noteworthy characteristics (Fig. 9). The loading at the Cherry Weir, which represents gravity drainage from the upper workings of the mine, 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. This is very important with respect to reduction of acid drainage from the mine upon abandonment.

IMPLICATIONS ON ABANDONMENT ALTERNATIVES

The flow and quality characteristics just presented have major implications with respect to evaluation of abandonment alternatives to reduce acid drainage from the Bunker Hill Mine. Two abandonment techniques which may have application at the Bunker Hill Mine are: 1) decreasing or eliminating recharge to the mine, and 2) flooding the mine. Sealing the mine entrances to keep air away from the pyrite also has been used to decrease acid production. Too many portals to the old upper working exist at the Bunker Hill Mine for air sealing 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 Bunker Hill Mine would be effective in improving the quality of mine drainage only if acid producing areas are identified and the recharge reduction directly affects these areas. Much of the acid production in the upper portion of the Bunker Hill Mine appears to be associated with one orebody. Continuing research is centered on identifying the locations and controls for recharge to this small portion of the underground workings. Reclamation alternatives include surface diversion works and shallow ground water collection systems underground but above the acid producing areas.

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. The diversion of the gravity drainage from above 9 level to the lower levels during flooding would eliminate acid discharge from the mine for a number of years but would result in a poorer quality mine pool. Flooding the lower levels of the mine would essentially stop acid production below the 9 level. The mine drainage from the 9 level after flooding of the lower levels would consist of the gravity drainage from the upper levels plus a flow from the mine pool from the lower levels. It is possible to install a hydraulic plug in the Kellogg Tunnel on 9 level. This would allow flooding of the workings to the 8 level, about 65 meters higher. There are six 8-level portals. Plugging these to raise the water level in the mine to the 7 level would probably not be economically feasible and would probably result in acid seeps at the surface in several highly fractured areas. It is important to recognize that flooding to the 9 or 8 levels would not inundate the major acid producing areas in the upper workings. Acid discharge from the mine thus would occur under maximum flooding levels.

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 recognizable 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 of loading is evident, and the magnitude of loading is small. The peak zinc load from the 15 level pump occurs later; 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.

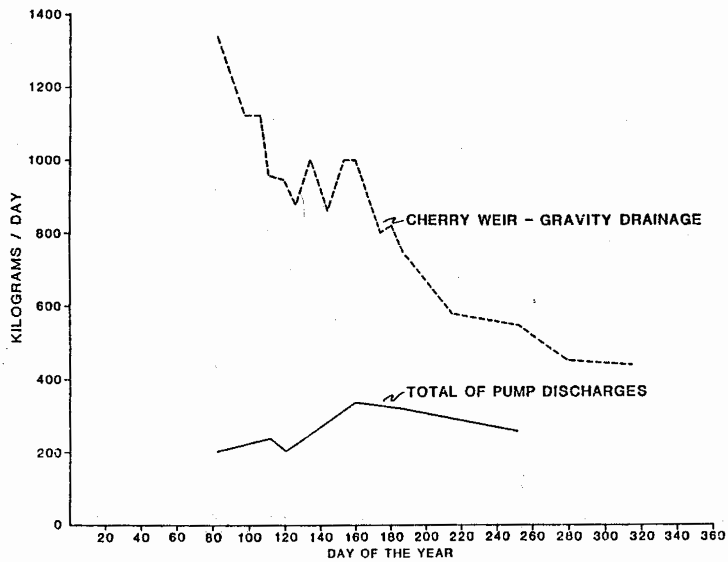

Figure 9. Zinc Loading Contribution from Gravity Drainage and Pumped Discharge During 1983, Bunker Hill Mine, Idaho.

CONCLUSIONS

Several conclusions are indicated as a result of the research completed to date at the Bunker Hill Mine. 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. The upper workings appear to be dominated by shallow flow systems; 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 with little evidence of seasonal flushing.

The mechanisms controlling flow and zinc concentrations have major implications regarding abandonment alternatives for the Bunker Hill Mine. The deeper portions of the mine can be flooded; this will decrease both the amount of water discharged and the zinc loading from the mine. It is not possible to eliminate acid discharge from the mine by flooding for two reasons. First, the main acid producing areas in the upper workings cannot be flooded because of the large number of portals and the fractured nature of the rock mass. The upper portion of the mine would continue to produce very poor quality water. Second, some discharge would occur from the pool of poor quality water in the flooded lower workings. One mine volume of poor quality water would need to be removed before this discharge would be of good quality.

It may be possible to divert surface water or reroute the shallow ground water flow systems recharging localized acid producing areas in the upper workings to reduce the flushing of acid reaction products into the mine drainage system. More research is needed to further delineate the locations and mechanisms responsible for recharge to the acid producing areas.

This type and intensity of research is needed on all acid producing mines facing abandonment to determine which abandonment technique(s) would be most successful in reducing the undesirable environmental and economic consequences of long term drainage of poor quality water. Regulatory agencies must come to recognize that point discharges from mines constitute much different problems than typical industrial plant discharges when abandonment is considered.

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 ground water discharge point would greatly simplify the eventual abandonment of the mine.