Interdisciplinary Approach to the Analysis of Acid Mine Drainage at an Underground Lead Zinc Mine

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ABSTRACT

Acid mine drainage is a serious environmental and economic concern, resulting in regulation of the mining industry and significant water treatment costs. An interdisciplinary approach is needed to analyze the many aspects of a complex acid drainage problem. This paper describes the integrated application of techniques from the following fields to the characterization of acid drainage at a large underground lead-zinc mine: 1) hydrogeology, 2) surface stream analysis, 3) structural analysis of fracture distribution, 4) hydrochemistry, 5) geostatistics, and 6) multivariate statistics.

The Bunker Hill Mine in northern Idaho, is developed in highly fractured and faulted quartzites and discharges 95 L/sec of water with an average pH of 2.8 and an average zinc concentration of 120 mg/L. Research has been conducted on all aspects of the acid water production and drainage problem. Recharge to the mine has been investigated using geophysical techniques and tracer studies. Fracture mapping and geostatistical analysis of the fracture data have been used to determine characteristics of inflow to the mine workings. Hydrograph analysis techniques have been applied to water flow data within the underground workings. Chemical sampling and analysis have been used to identify acid producing workings, and better understand mechanisms controlling acid water production. Multivariate statistical techniques have been applied to analyze the quality and flow data. Research results from the many subprojects of the Bunker Hill study reveal the importance of an interdisciplinary approach to the analysis of acid mine drainage problems.

INTRODUCTION

Mine water inflow and contaminated mine water production constitute major problems during the production, inactive and abandonment phases of most hard rock mines. Contaminated mine drainage may be the most serious consequence of mine abandonment. The flooding of mines has been used in some cases to decrease the production of acid water after abandonment. However, some mines are nearly impossible to flood because of local topography and patterns of mine development. Such mines require detailed investigations to delineate procedures to reduce acid production and drainage. This paper describes the research steps taken or underway as part of the investigation of a complex mine site in northern Idaho within the mountainous western portion of the United States.

The Bunker Hill Mine is a large underground lead-zinc mine developed in fractured quartzites which discharges an average of 95 l/sec of poor quality water (figure 1). The average pH is 2.8; the zinc concentration averages 116 mg/l. The discharge water also contains high concentrations of other dissolved and suspended constituents. The mine drainage is treated and released to a stream after meeting federal standards for point discharges. Adits on a number of mine levels in an area of steep topography prevent flooding the acid producing portions of the underground workings. At present, the mine is beginning operation after a long period of stand-by maintenance and dewatering.

The acid mine drainage research at the Bunker Hill mine may be divided into four parts. The first part investigates the temporal and spatial distribution of water quality and quantity within the mine. The second part addresses the factors that control the production and movement of acid water within the mine. Delineation of alternatives for mitigating the acid drainage constitutes the third part of the research. The fourth part evaluates implementation of measures to minimize acid drainage from the mine.

THE PROBLEM

Controlling the acid drainage from a mine when flooding is not possible requires an understanding of the water flow and water quality conditions within the mine workings. Techniques typically applied in investigations of surface watersheds are applicable to study of the gravity flow of water within an underground mine. These techniques include discharge and quality monitoring at various sites within the drainage network. Flow and water quality data are analyzed using both graphical and statistical methods.

Discharge rates and/or pressures have been measured at 24 sites underground within the Bunker Hill mine for a period of about 6 years (figure 2). The monitoring sites measure both flow within drifts and flow/pressure in fractures and drill holes discharging into the drifts. Most of the monitoring sites are on the 5 and 9 levels. The main gravity discharge point from the mine is an adit on the 9-level. The 5-level is the most accessible portion of the upper mine workings. The gravity drainage within the workings above the 9-level has been documented in great detail.

The discharge and/or pressure data in the fractured rock show decreasing temporal fluctuations with depth. Annual head fluctuations in shut-in drill holes in a drift more than 200 m below land surface

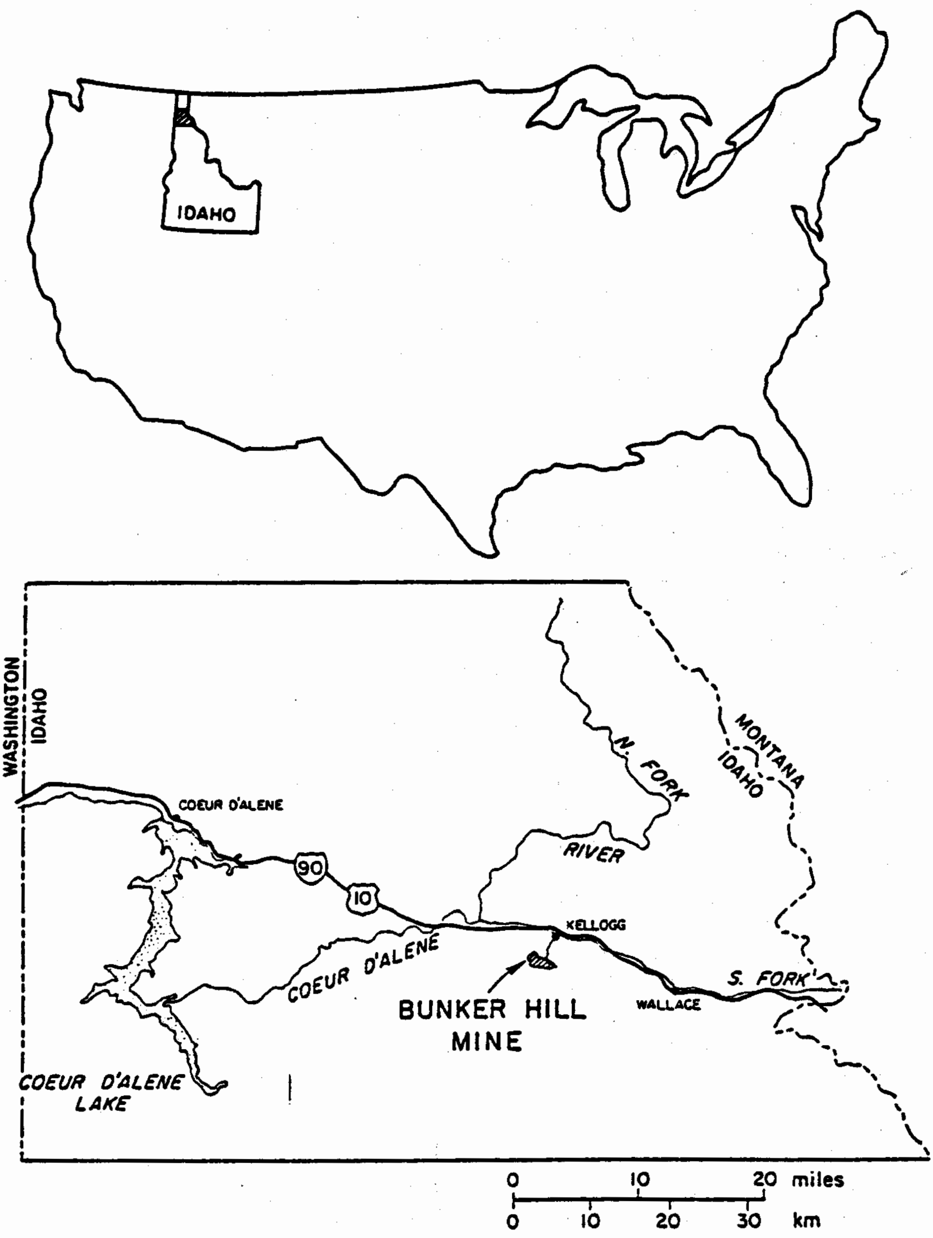

Figure 1. Location map of the Bunker Hill Mine, Idaho, USA.

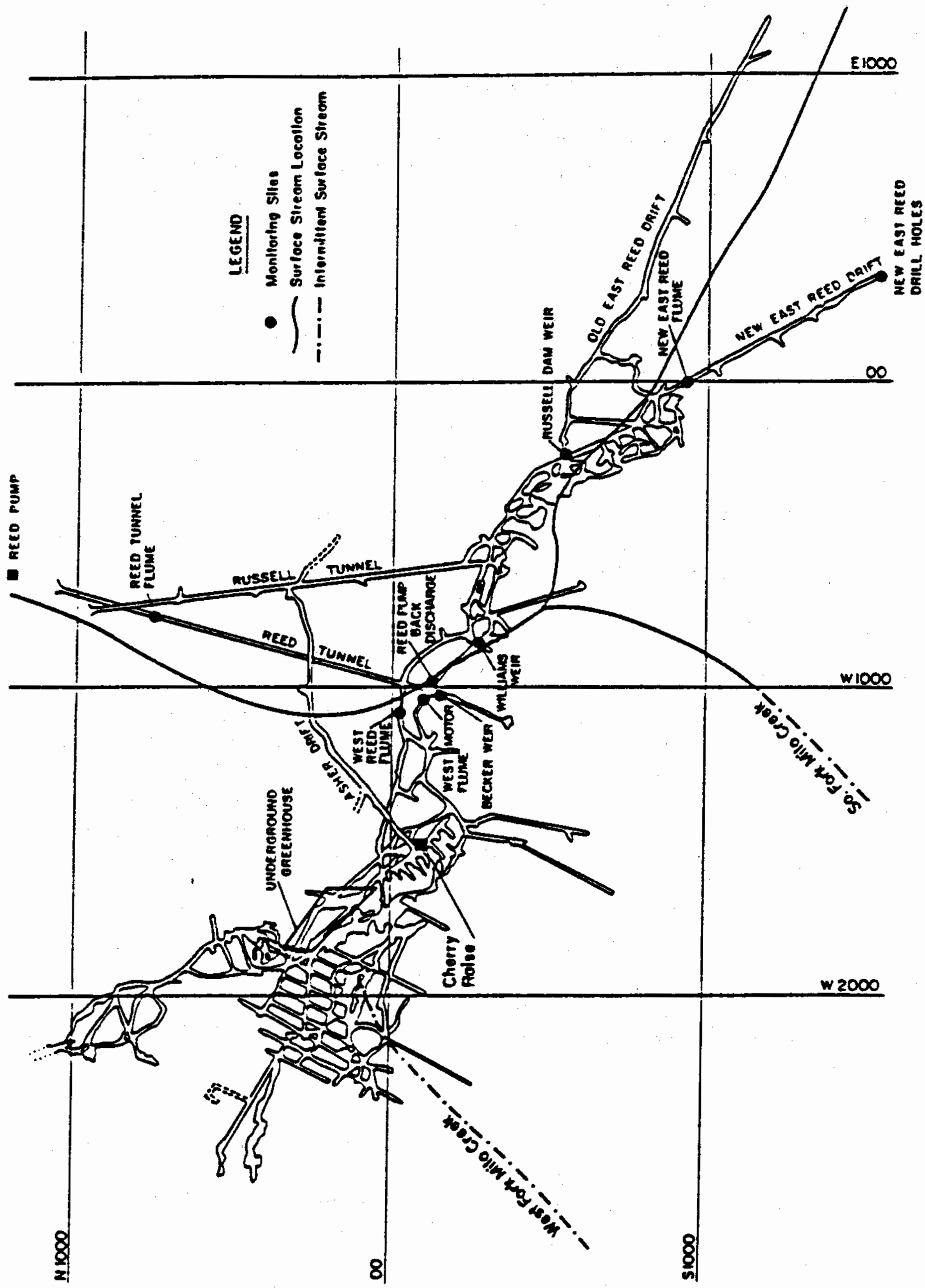

Figure 2. 5 Level monitoring sites, Bunker Hill Mine.

are as much as 20 m. Discharge data from near-surface measurement sites within the mine workings show an increase in flow caused by recharge from snowmelt in the spring of each year. Conversely, discharge measurement sites deeper in the mine show more uniform flow throughout the year.

Different relationships have been observed between discharge and water quality at various sites within the mine (figure 3). Gravity drainage from the shallow workings exhibit the greatest seasonal variation in metal loading. Pumpage from deeper in the mine show a relatively constant metal loading. The upper workings are dominated by shallow ground water flow systems that respond quickly to recharge events. Poor quality water flushes or surges annually out of the drifts, stopes and ore chutes in the upper workings. These annual flushing events dominate the rate of movement of metals from the mine. The principle acid production occurs in a localized portion of the upper mine workings in a single ore body.

Studies are underway to analyze the flow and quality data in a more comprehensive fashion using multivariate statistical techniques. Water quality is a multivariate concept and is not defined by any single constituent or summary value. Weighted combinations of chemical constituents are being used as indicators of water quality. A canonical variable may be a weighted contrast of zinc and manganese versus sulfur and pH.

CONTROLS FOR ACID PRODUCTION

The general chemical reactions important in acid generation are described in the literature. Studies at the Bunker Hill Mine have focused on how the variables (pyrite, oxygen and water) are in combination in the underground workings. Particular emphasis has been placed on the physical locations of the acid producing reactions within the mine workings and how water moves through these areas to become acid mine drainage.

An orebody in the upper portion of the Bunker Hill Mine appears to be responsible for most of the acid production. It is largely inaccessible because the underground workings in this area are unstable. Most of the acid production occurs in old stopes and drifts that were backfilled with pyrite-rich and zinc-rich low-grade waste material.

Limited exploration of the primary acid producing orebody has shown that large pools of very poor quality water form in the drifts during the winter. Spring recharge events caused by snowmelt flush out these pools and move very poor quality water into the lower mine workings. The importance of this aspect of water movement within the mine has been the subject of one of the research projects within the Bunker Hill Mine. Measurement of the quality of water within the mine atmosphere has been done also to identify the sources of acid to the pools. Preliminary results suggest that condensate in the exhaust portion of the mine ventilation system has low pH and high metal

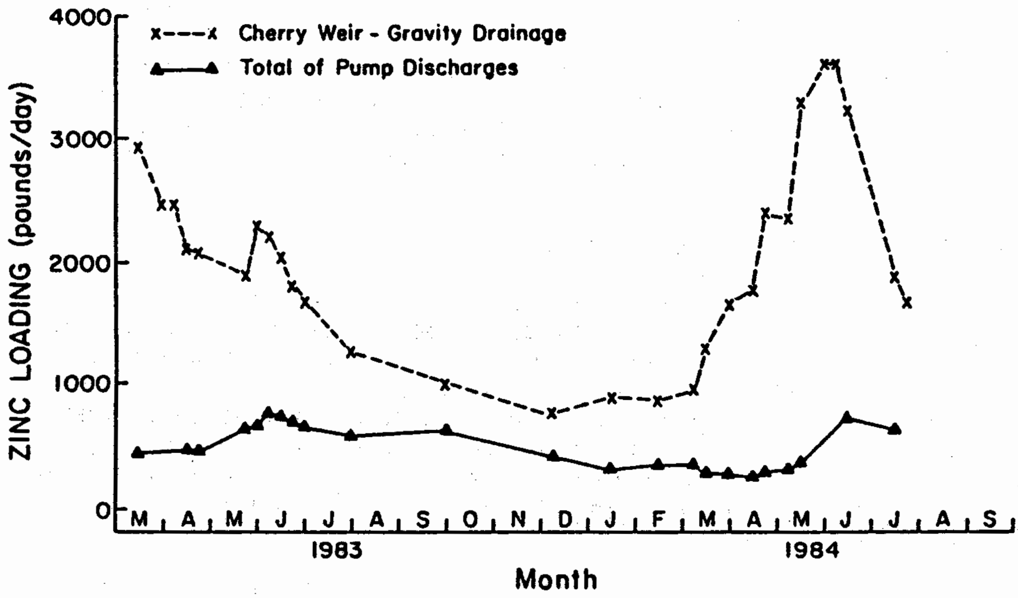

Figure 3. Zinc loading vs time during 1983-1984 for the Cherry Weir drainage and the combined pump discharge, Bunker Hill Mine.

content. These results illustrate the complexity of the acid mine drainage problem.

DELINEATING MITIGATIVE MEASURES

Considerable research has been completed on alternative procedures to reduce acid mine drainage. Most efforts focus on reducing the availability of oxygen to the reaction sites. Mine flooding is the most efficient procedure. However, flooding of the primary acid producing portions of the Bunker Hill Mine is not possible because of mine geometry relative to local topographic features. Sealing of the mine openings to limite oxygen availability is not viable either because of fracturing associated with near-surface workings and the continuing underground mining activities. Isolation of the pyrite within the workings is not possible because of the inaccessibility of much of the upper portion of the mine.

The availability of water as a transporting agent has been identified as the most viable alternative for reducing acid drainage from the upper portion of the mine. Much of our research effort has focused on understanding the pattern of ground water flow to the primary acid producing area.

Direct Testing of Recharge Mechanisms

One part of the project has focused on evaluating recharge to the mine in the vicinity of Milo Creek using techniques common to surface water hydrology. Research has centered on the portion of the Milo Creek drainage that overlies the so called upper country of the mine. A number of different field techniques have been utilized to evaluate recharge potential. Dye dilution stream measurements, dye tracing techniques, spring flow surveys and piezometer nest installations have been implemented. Important results from these investigations are as follows.

The dye dilution stream measurements suggest that relatively little loss of streamflow occurs along the portion of the stream where it flows parallel to the Cate Fault, the major structural feature along which the mine is constructed. The data indicate that stream loss occurs where the south fork of Milo Creek crosses the Cate Fault.

Dye tracer tests were conducted within the drainage of the West Fork of Milo Creek. These tests were limited to this portion of the drainage because the remainder is used as a public water supply source. The dye was detected with a relatively short time lag on a near-surface drift of the mine that underlies the West Fork. Dye was not detected on lower levels.

The spring survey indicated that no surface discharges exist in the portion of the Milo Creek drainage that is underlain by the upper workings of the mine. However, springs are evident south and east of the mine workings, indicating that the cone of depression created by the mine is relatively small.

Water level data from several piezometer nests installed as part of the research show that head decreases with depth. However, the gradient at several of the sites is greater than unity which indicates a complex pattern of saturated and unsaturated ground water flow.

Sites of direct infiltration into the mine have been located as part of these research efforts. These sites include mine workings directly below perennial streams, intersections of streams and faults and a caved area adjacent to an ephemeral stream. Inflow to the underground workings from the ground water flow system around the margin of the mine may account for more mine water than do sites of direct infiltration.

Evaluation of Ground Water Flow in Fractured Rock

Several different testing and analytical techniques have been applied in order to investigate controls on and patterns of ground water flow in the vicinity of the mine workings. Most of this research has been conducted within a drift of the mine on the 5-level which is relatively isolated from overlying and underlying workings. Research projects have included the statistical analysis of fractures and evaluation of discharge patterns from specific groups of fractures and hydraulic testing of high pressure drill holes. Tritium age dating of water also has been conducted throughout the mine.

Fracture data have been collected in portions of the New East Reed drift on 5-level and analyzed with respect to importance to ground water flow. Fracture data collected include: types of fractures, orientations, lengths and spacings, roughness, waviness, infilling material and the amount of water discharging to the drift. Fractures were classified as joints, bedding planes or faults. The fracture mapping data were analyzed using statistical techniques to identify structural domains.

The results indicate that bedding planes are the primary conduits for ground water discharge into the New East Reed drift. Major joint sets may interconnect individual bedding planes. Thirty-three of the 36 faults mapped in the drift were found to be filled with gouge and not important ground water conduits. However, leakage from one minor fault accounts for about 75 percent of the inflow to the drift. The New East Reed drift does not intersect any of the major regional faults important to mine development.

Tarps suspended in sections of the drift were used to document discharge patterns from different groups of fractures. Several of the tarps were placed under discharging bedding planes while others collected discharge from several different joint patterns. Fluctuations in flow caused by springtime recharge events were evident in all of the tarp hydrographs (figure 4).

Pressure response data collected as part of several constant discharge flow tests conducted on long, nearly horizontal drill holes at the end of the test drift illustrate the complex hydraulic system formed by the fracture pattern near the mine. Hydraulic continuity

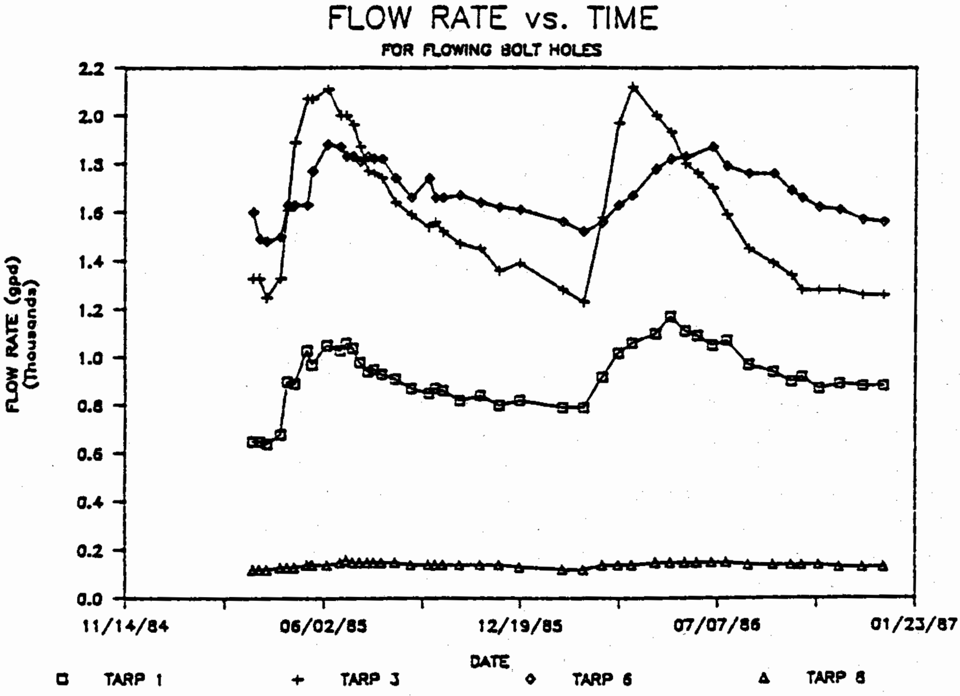

Figure 4. Flow rate versus time for flowing bolt holes in New East Reed.

was noted among the drill holes. The measured pressure responses probably are related to faults intercepted by several drill holes. Responses were not noted in the tarp hydrographs which indicates that the pressure response was not transmitted throughout the relatively unfractured matrix during the length of the test.

Tritium age dating has been utilized to document the rate at which water moves downward within the cone of depression of the mine. A single delineation of pre-bomb versus post-bomb tritium (pre versus post 40 years ago) provided a basis for analysis of the data. Samples were obtained from drill holes and from individual fractures. Research results indicate that relatively young water occurs deep within the mine (greater than 1500 m) at sites related to major faults. Older water was found on a mine level about 200 m below land surface discharging from a bedding plane/joint area.

CONCLUSIONS

No single academic discipline has all the tools needed to analyze a problem with as many complex interrelated facets as characterized by acid drainage. The production of acid mine drainage results from several chemical reactions that are catalyzed by bacteria. All the reactions take place in a heterogeneous geochemical system that consists of both natural fractures and man-made openings.

Characterization of the spatial and temporal characteristics of the acid mine drainage problem requires technologies from hydrology, chemistry and statistics. Evaluation of suitable control methods utilizes techniques from hydrology, solution chemistry and atmospheric chemistry. Delineation of possible solutions draws from the fields mentioned above as well as structural geology, geostatistics and ground water hydraulics.

The key to identifying solutions to the Bunker Hill problem and other similar acid mine drainage problems is the integration of ideas and information from a wide variety of disciplines into the formulation and testing of alternative conceptual models.