GROUND WATER HYDROLOGY - A TOOL FOR MINE PLANNING, OPERATION AND ABANDONMENT

Ralston, D. R.* ; Trexler, B. D. Jr.**, Williams, R. E.*

ABSTRACT : Most hydrogeologic problems from mining activities are related to the modification of existing ground water flow systems or the creation of new flow systems. Hydrogeology has not generally been included in past mineral resource development decisions because of : 1) the historical lack of economic incentive, 2) the lack of hydrogeologic understanding and data base, and 3) the lack of expert hydrogeologists. We believe that hydrogeologic planning for mining today is less than fully effective because it is either responding to the specific short term stress on the part of industry or it is impact oriented planning done by public agencies. For Hydrogeology to be an effective input into the mine decision process, it must be included in the economic consideration of mine planning.

RESUME : La plupart des problèmes hydrogéologiques dérivés des activités d'exploitation des mines présentent quelque relation avec la modification des systèmes d'écoulement existants des eaux telluriques et aussi avec la création de nouveaux systèmes d'écoulement. L'Hydrogéologie n'a généralement pas été incluse dans les décisions se rapportant au développement des ressources minérales du passé en raison de : 1) l'absence historique de ressources économiques, 2) l'absence de connaissances hydrogéologiques et de données de fond, 3) le manque d'hydrogéologues expérimentés. Nous croyons que la planification hydrogéologique pour l'exploitation des mines à présent est loin d'être totalement effective parce que d' un côté elle obéit à la pression de l'industrie avec ses demandes à court terme ou bien elle est aussi une planification orientée vers l'impact préparée par les agences publiques. Afin que l'Hydrogéologie soit d'une portée efficace dans les processus d'étude des décisions se rapportant à l'exploitation des mines, elle doit être comprise parmi les considérations économiques de la planification.

RESUMEN : La mayoría de los problemas hidrogeológicos, derivados de las actividades mineras, están relacionados con la modificación de los sistemas de flujo de las aguas subterráneas, o con la creación de nuevos sistemas de flujo.

* College of Mines, University of Idaho, Moscow, Idaho 83843, U. S. A.
** Konnecott Copper Corporation

En el pasado la Hidrogeología no ha sido tenida en cuenta, generalmente en las decisiones relacionadas con el desarrollo de los recursos mineros debido a la falta de : 1) incentivos económicos históricos, 2) conocimientos hidrogeológicos y de información de base, y 3) hidrogeólogos expertos. Creemos que la planificación hidrogeológica en minería, hoy día, no es totalmente efectiva porque, o responde a las presiones de la industria, con sus demandas a corto plazo, o es una planificación orientada al impacto realizada por las agencias públicas. Para que la Hidrogeología sea incluida efectivamente en los procesos de decisión de la mina, deberá ser incluida en las consideraciones económicas de la planificación minera.

INTRODUCTION

Some of the most serious ground water quality problems faced today are associated with mining. The basis for these historical problems was largely a lack of understanding and consideration of ground water in the decision process of mineral resource development. The purpose of this paper is three-fold: 1) to examine past mining decisions that lead to pollution problems, 2) to consider the role of hydrogeology in todays mining operations, and 3) to suggest the role that ground water hydrology should play in future mineral resource development.

HYDROGEOLOGY OF PAST MINING DECISIONS

Most hydrogeologic problems resulting from mining activities are related to modification of existing ground water flow systems or creation of new flow systems. Mining can make complex chemical reactions possible that with water movement can create a discharge of poor quality water. Two examples are discussed in this paper to illustrate the actual and potential problems resulting from modification of ground water flow systems.

BLACKBIRD MINE

The Blackbird Mine in north central Idaho is an example of a site where a lack of hydrologic planning precipitated a major water quality problem upon closure (Figure 1). The mine was developed to remove a copper cobalt ore body from a mountainous site that receives an average of about 23 inches of precipitation per year. The Blackbird mining complex consists of 12 underground levels, 8 portals, an open pit, 3 major waste piles, a tailings pile, a mill and concentrator and support facilities. The mine was operated from 1917 to 1967. The present mine owner has maintained a small crew at the site since 1967 for maintenance and exploration.

The primary water resource problem at the Blackbird Mine is the discharge of low pH water with high concentrations of dissolved iron, copper and cobalt (Baldwin, Ralston and Trexler, 1978). About one-half of the metal load can be traced to point discharges such as portals. The remainder of the metal load in

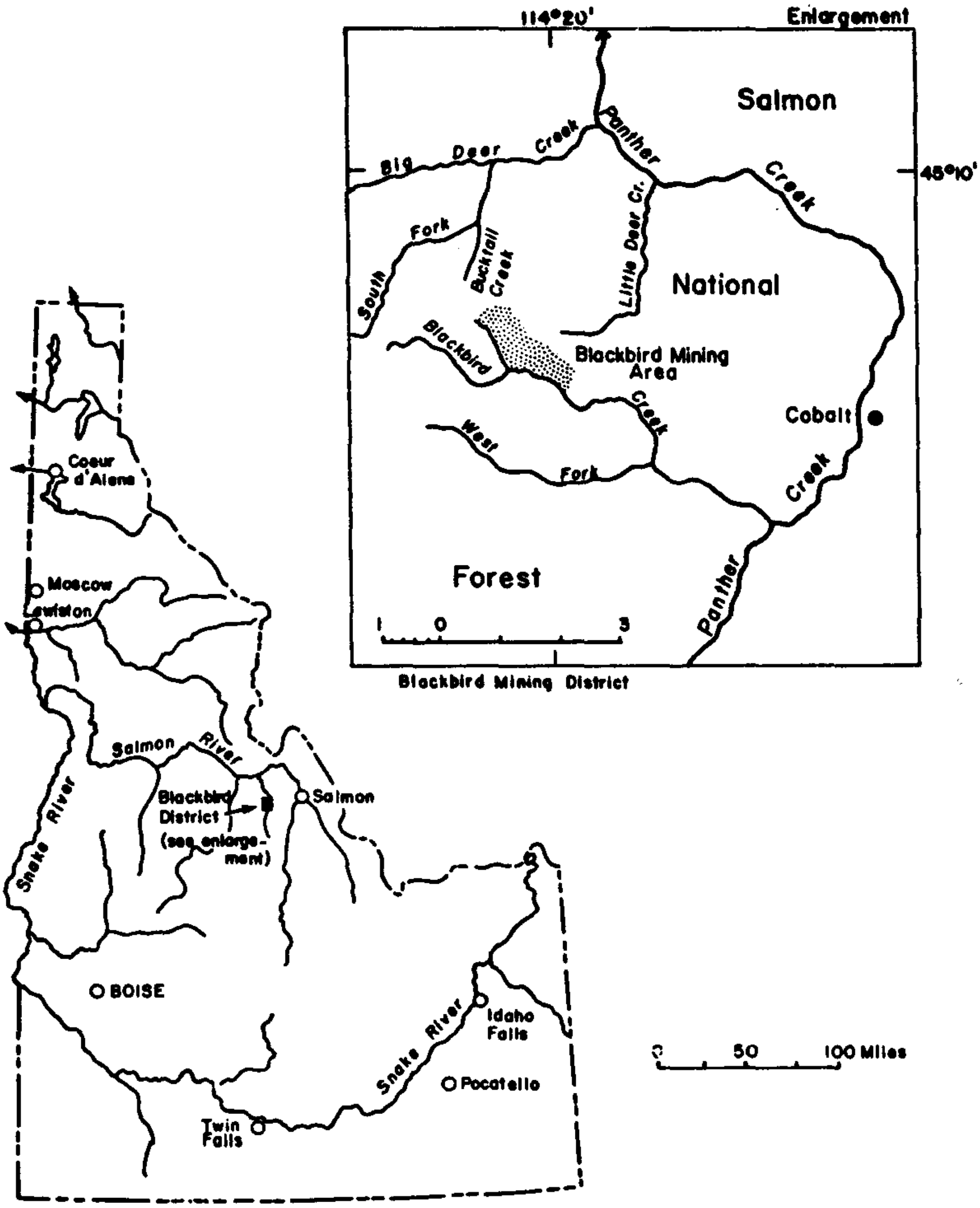

Figure 1. Map of Idaho showing location of the Blackbird Disrtict and the Blackbird Mining area.

the streams is from non-point discharge sources such as waste piles, the tailings pile and wastes along the stream channels.

Two small streams, Blackbird Creek and Bucktail Creek, receive the poor quality drainage from the mine area. Both of these streams are tributary to Panther Creek which discharges into the Salmon River. This portion of the Salmon River has been designated as a National Wild and Scenic River. The total discharge from the Blackbird mining area for the 1976 water year was about 7.3 million cubic meters (5,900 acre-feet) with about 7.2 million cubic meters (5,800 acre-feet) from Blackbird Creek.

Less than 740,000 cubic meters (600 acre-feet) of the discharge in the two streams during the 1976 water year was acid drainage. The remainder of the water was from Blackbird Creek above the mill and from small tributaries unaffected by mining. Although the total volume of acid drainage is small, the impact on downstream water uses is great.

Stream discharge and water quality are closely interrelated in the Blackbird mining area. Heavy metal concentrations are: 1) low during winter months, 2) increase sharply during the initial spring runoff period, 3) are very low during the latter part of spring runoff, and 4) rise gradually during the later summer months (Figure 2). As much as 75 percent of the total metal discharge from the mine area occurred during April and May of 1976. This large output of heavy metals occurs during a short time period each year.

Acid production from the underground workings and surface wastes is controlled by: 1) oxygen, 2) availability of pyrite and other heavy metals, 3) moisture in the mine atmosphere, 4) availability of water to transmit oxidation products, 5) mine or waste pile characteristics, and possibly 6) iron bacteria. Variables 4 and 5 (availability of water and mine or waste pile characteristics) can be managed to reduce acid drainage from the underground workings. Recharge to the underground workings occurs primarily from water movement into raises, stream loss to mine levels and seepage from the open pit to the underlying levels. Movement from level to level is primarily through man-made openings. The factors controlling acid production in surface waste piles are the same as those listed above for the underground workings. Recharge to the waste piles is mostly from precipitation; however, some piles are recharged by acid water from upstream mine features.

The April-May peak in metal production from both surface and subsurface waste features results from flushing or washing of oxidation products from the metal rich wastes. Reclamation techniques to reduce the acid drainage are centered on limiting the movement of water through the mine features. Techniques that have been suggested to reduce acid drainage include: 1) sealing of raises at and near the surface, 2) sealing or regrading the mine pit, 3) maintenance of selected drainage ways underground to minimize ponding and to route water around stopes and raises containing oxidized ore, 4) isolation of the point sources of acid water from the large volumes of good quality water,

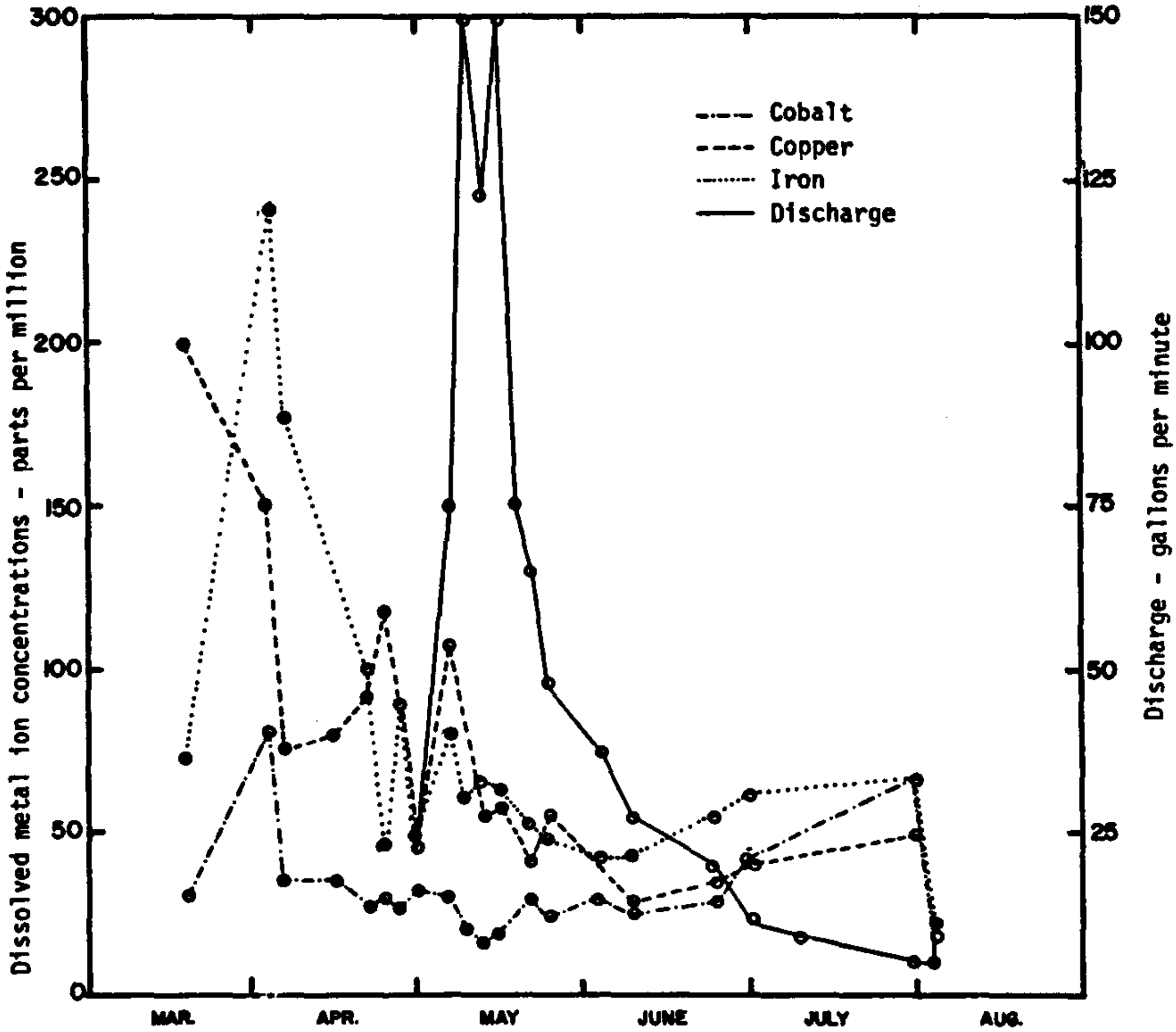

Figure 2. Dissolved cobalt, copper, and iron concentrations at station 10 (7100 waste pile) for 1976.

5) revegetation of surface waste piles to limit erosion and deep percolation and 6) construction of lined surface diversion channels to prevent recharge of water to waste piles and underground workings.

Water quality problems associated with any future mining activities in the Blackbird area can be minimized by designing the mine facilities to limit water movement through pyrite rich areas. Some discharge of poor quality water is probably unavoidable in this mining area. However, the magnitude of the problem and the ease of treatment of any drainage both benefit by hydrologic input into the decision process of mine design and construction.

BUNKER HILL MINE

The Bunker Hill Mine consists of lead-zinc mining properties located along the Coeur d'Alene River near Kellogg in northern Idaho (Figure 3). Initial mining began in 1885 in the form of many shallow, small tunnels and stopes around the original discovery site. The mine now includes more than 241 kilometers (150 miles) of workings to a depth of almost 1.6 kilometers (one mile) below land surface (Figure 4). The block of ground disturbed by mining includes a volume of approximately 21 cubic kilometers (five cubic miles). The development averages about 6.4 kilometers per year (four miles per year) of drifting and about 18,300 meters per year (60,000 feet per year) of diamond drill holes.

Acid drainage from the Bunker Hill Mine is discharged into the mine's tailings pond and constitutes a major portion of waste water that must be treated prior to discharge into the South Fork of the Coeur d'Alene River. The drainage from the Kellogg Tunnel of the Bunker Hill Mine averages about 158 liters per second (2,500 gallons per minute) of flow with a pH of about 4.0 to 4.7. The pH occassionally dips to about 3.3. The mine discharge is a major contributor of acid, heavy metals and suspended solids to the treatment plant.

The discharge from the Kellogg Tunnel includes surface and ground waters intercepted by mining facilities and water introduced during mining activities such as drilling and sand backfilling. The largest contributors to this flow are: 1) surface recharge through mine features, 2) water pumped into the mine with sand backfill and 3) water intercepted from the regional ground water flow system by the underground workings.

The quartzites and argillites that host the mineralized zones in the mine area have extremely low hydraulic conductivities except where faulted or fractured. Water from the regional ground water flow system discharges into the mine through drill holes and drift and stope areas. A total of about 850,000 cubic meters per year (690 acre-feet per year) discharges from flowing drill holes. Some of this water is used for drilling. Much of the excess flow from these drill holes could be eliminated by effective plugs and valves.

The water needed to transport sand fill into the mined stope areas amounts to about 530,000 cubic meters per year (430 acre-feet per year). This water is the major source of suspended solids for the mine discharge. The water used

SIAMOS-78. Granada (España)

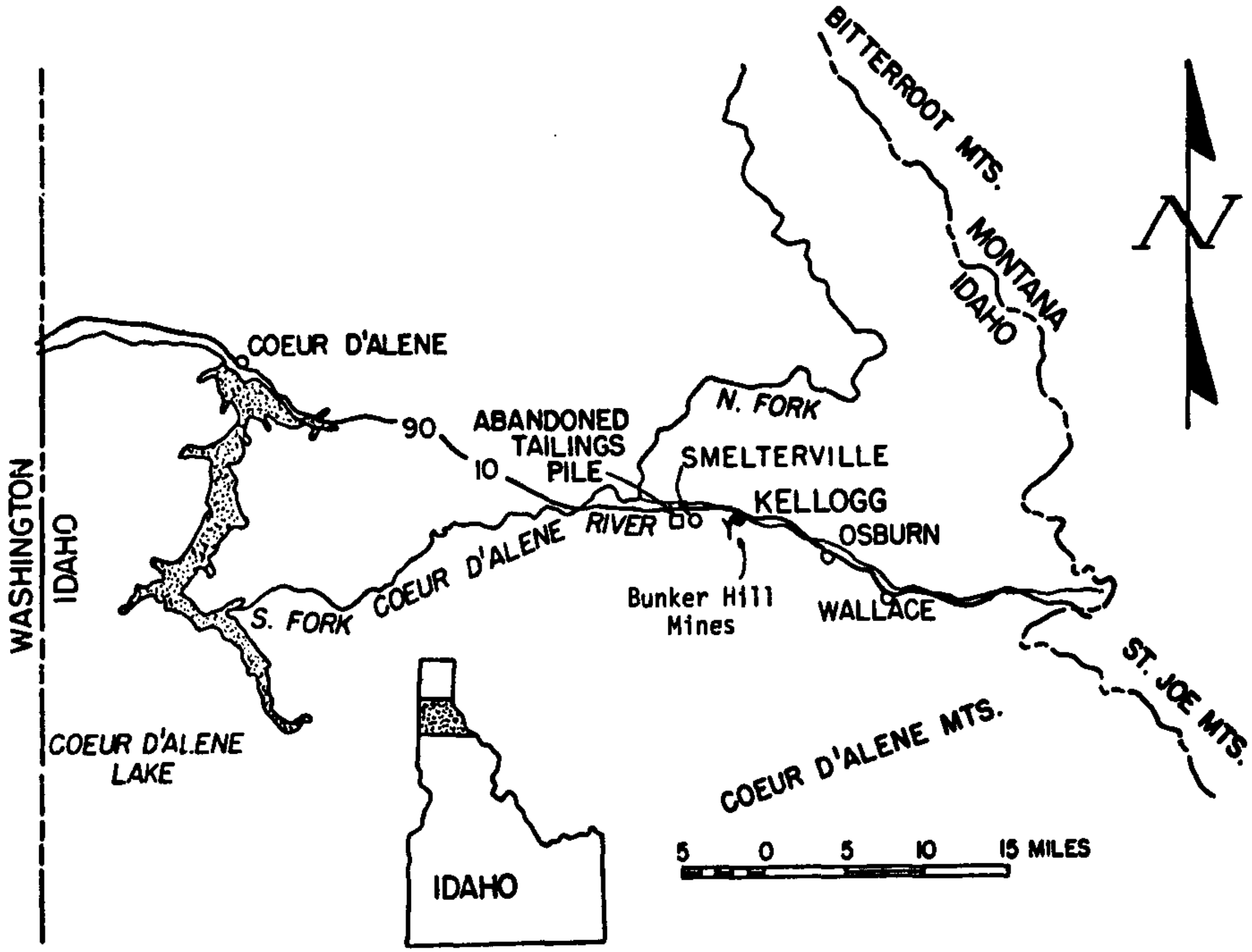

Figure 3. Map of part of northern Idaho and adjacent areas showing the location of the Bunker Hill Mine and Page tailings pile.

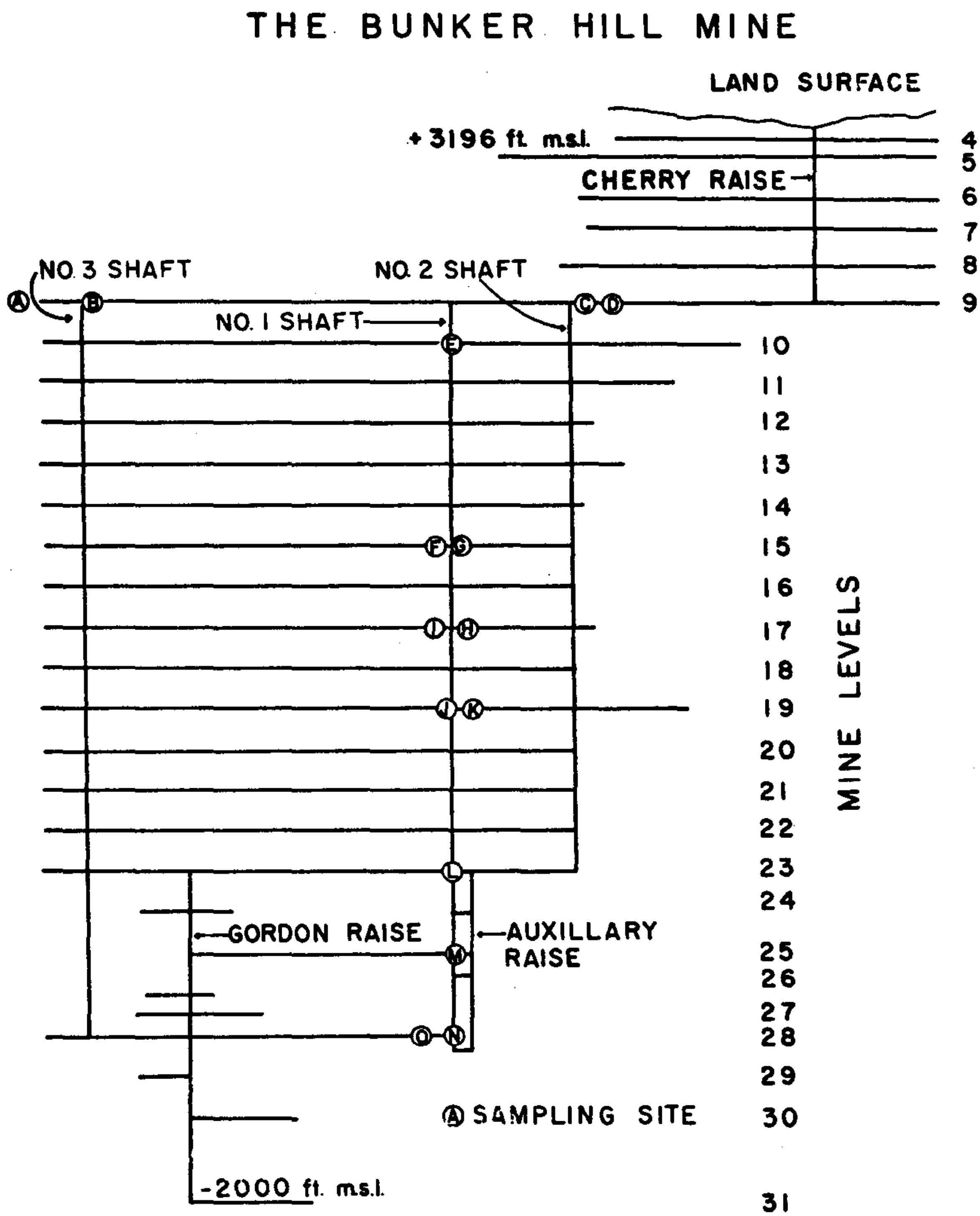

Figure 4. Generalized diagram of the Bunker Hill Mine showing location of sampling stations in the Mine's pumping system.

for sand fill and the drill hole drainage total about thirty percent of the total drainage in the Kellogg Tunnel.

The largest source for the mine drainage is surface water which recharges the mine. As the mining extended downward along the ore bodies, vertical zones of high permeability were created. Local ground water flow systems developed along these vertical permeable zones. Four areas of recharge to this local flow system within the mine were detected: 1) leakage from a small reservoir on a small creek which is located near some of the shallow stoped areas, 2) losses in an upper reach of the same stream which parallels the fault along which the mine is located, 3) an area where underground caving has resulted in major surface depressions in the bottom of several small drainages and 4) an area where stoping extended upward to intercept the channel of a small intermittent stream. The four areas have a total potential of 5.9 million cubic meters of recharge per year (4,800 acre-feet per year). The movement of water down through the mine provides the transport mechanism for acid salts formed in the old stoped areas.

The acid drainage problem in the Bunker Hill Mine is formed by the movement of water from surface recharge down through old stope areas that have been backfilled with waste that is rich in pyrite. The same variables control acid production here as were described for the Blackbird Mine (Figure 5). The ore was hand sorted during the early years of mining to insure that the highest grade of concentrates was shipped to the lead smelters. The hand sorting led to a waste rich in ore by present standards with some areas having high concentrations of pyrite. Acid production is mainly in the upper levels of the mine containing the ore rich wastefill. Surface water enters the mine and then moves downward through the interconnected stopes between the mine levels. The water washes acid salts from the highly oxidized ore and wastefill that is rich in pyrite. An examination of water quality throughout the mine shows that the acid production occurs primarily along one ore body in the upper portion of the mine (Figure 4).

Two reclamation techniques may be applied to reduce the large discharge of poor quality water from the Bunker Hill Mine. The first alternative is to reduce recharge to the mine. This involves diversion of water around the localized areas of surface recharge. The Bunker Hill Company and the University of Idaho are continuing to evaluate alternative diversion plans to achieve a reduction in water movement into the mine. The second alternative is to reduce water movement through areas of pyrite rich wastes in the underground workings. This reclamation technique is difficult because of the complex pattern of man-made openings in the upper portion of the mine.

The case histories show the magnitude and extent of problems that result when consideration of the ground water resource is not incorporated in the decision process of mineral resource development. We believe that there are three basic reasons for the lack of consideration of hydrogeology in past mine decisions.

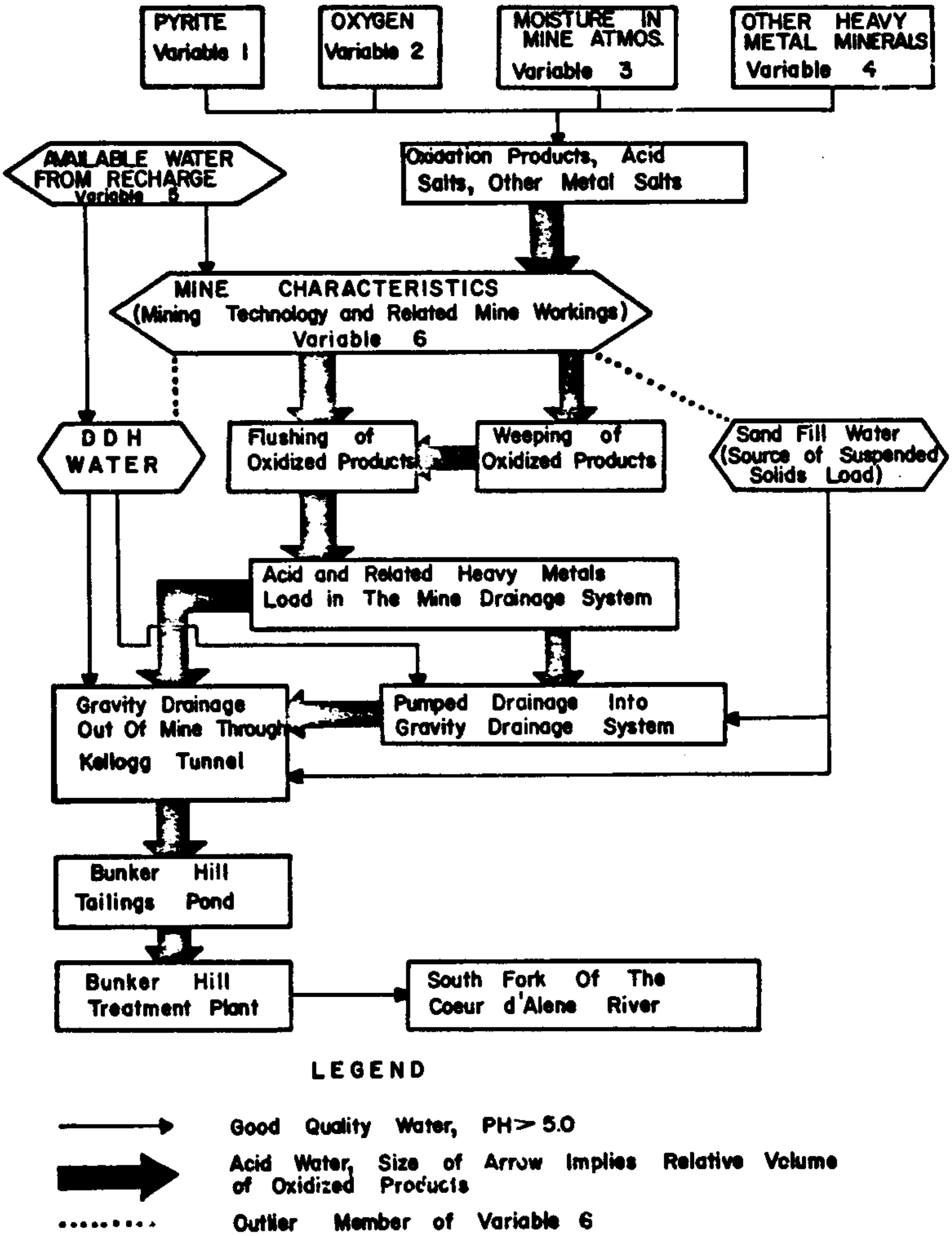

Figure 5. The variables' roles in the production of acid mine drainage in the Bunker Hill Mine.

First, there has been a historic lack of economic incentive to include hydrogeology because of the low monetary value of subsequent water resource impacts. Second, there has been a lack of hydrogeologic data upon which to base a decision. Third, there has been a lack of hydrogeologic expertise to guide either data collection or to make hydrogeologic input into the decision process. Much work is being done today to find ways to reverse the impacts from this historic lack of consideration of hydrogeology in mine development. The reclamation alternatives for problems such as those described above are limited by both physical constraints and economic constraints. The past mining activities have often created complex networks of underground openings which make physical reclamation alternatives difficult. Many of these sites also have been mined to the extent there is no longer an economic mineral base upon which to support the costs of reclamation activities. The reclamation of many abandoned sites thus becomes a federal or state problem.

HYDROGEOLOGY OF MINING DECISIONS TODAY

The hydrogeology of mining decisions today can be divided into two major parts: the hydrogeologic input into planning and operating an existing mine, and the hydrogeologic input for planning of future mineral resource development.

We will take another look at the Bunker Hill Mine as an example of the type of input that hydrogeology can make in a continuing mining operation. The Bunker Hill Company is continuing to develop new sections of the mine. Mineralogical studies have shown that the pyrite to carbonate ratio is a good indicator of potential acid production from any given ore body (Trexler and others, 1974). Any ore body where this ratio is greater than 0.6 must be considered as a potential acid producing area. This tool can be used in continuing mine development to allow the potential for hydrogeologic problems to be entered into the decision process. Once a potential acid producing area is identified, then this potential can be included in the economic decisions of mining activities. For example, if the area is economically marginal, knowledge of the potential of acid production may favor not mining. If the area is to be mined, then care should be taken to minimize the water drainage in the area and to limit transport of the acid salts.

One of the major problems with the inclusion of hydrogeology into the decisions of mine operation is the relatively low internal cost of quality degradation The cost of acid production within the Bunker Hill Mine was estimated for the years 1972 through 1974. These figures show that significant costs are associated with acid drainage; however, these costs are small in comparison to the operating costs of the total mine.

HYDROGEOLOGIC PLANNING FOR FUTURE MINERAL RESOURCE DEVELOPMENT

Hydrogeologic planning for future mineral resource development may be divided into two broad groups. We note these as: 1) internal industrial planning and 2) external public planning.

Internal industrial planning has been generally in response to public regulations and pressures. Requirements for environmental impact statements and other such documents have often resulted in the hiring of short-term consultants who often turn out reports based upon generally inadequate data and poor understanding of the hydrologic system in the area. The data are inadequate because of a lack of long term data collection by the mining companies. Short term of the employment of the consultant prevents him from developing a detailed understanding of the mine environment. This type of planning is a responding type. Often a decision is made before an adequate hydrogeologic basis for the decision can be established. Only a few companies have hired full time staff hydrologists who can make day-to-day input into the decisions of mine planning and operation.

The second kind of planning is what we call external public planning. External public planning is evident from the local level to the federal level. This type of planning may be technically excellent but generally represents only boundary or impact planning. External public planning is largely based upon some sort of regulatory function. The regulatory function is normally based upon the prevention or monitoring of impacts. The monitoring of possible impacts for planning purposes is a major problem in hydrogeology. Once a hydrogeologic problem is identified, it is usually major and difficult to reverse. The external public planning is not a direct input into the day-to-day decisions of mine planning and operation.

WHAT SHOULD BE THE ROLE OF HYDROGEOLOGY IN FUTURE MINING RESOURCE DEVELOPMENT

The life cycle of a mine includes a number of distinct steps. Hydrogeologic decisions are required in each part of the life of a mine from exploration to development, operation and abandonment. Each decision requires a different level and type of hydrologic understanding and associated data base. The level of the understanding of the created or modified ground water systems must grow with continued mine development. This cannot be achieved by either responding type of ground water planning or an impact type of planning. Hydrogeological planning is best accomplished by a full time mine hydrologist. The water resource factors must be entered into the economics of mining engineering in a cost effective manner. This is possible only with adequately trained and equiped mine hydrologist.

CONCLUSIONS

Most hydrogeologic problems from mining activities are related to the modification of existing ground water flow systems or the creation of new flow systems. This has been shown graphically by the examination of the Blackbird Mine and the Bunker Hill Mine in Idaho. Hydrogeology has not generally been included in past mineral resource development decisions because of: 1) the historical lack of economic incentive, 2) the lack of hydrogeologic understanding and data base, and 3) the lack of expert hydrogeologists. We believe that hydrogeologic planning for mining today is less than fully effective because it is either responding to the specific short term stress on the part of industry or it is impact oriented planning done by public agencies. For hydrogeology to be an effective input into the mine decision process, it must be included in the economic consideration of mine planning. It is our contention that a mine hydrogeologist can be and must be a cost effective component of continued mineral resource development if the past hydrogeologic problems associated with mining are to be avoided in the future.

REFERENCES

Baldwin, J., Ralston, D., Trexler, B. Jr., 1978, Water resource problems related to mining in the Blackbird Mining District, Idaho, Completion Report for USDA Forest Service Cooperative Agreement 12-11-204-11, College of Mines, University of Idaho, Moscow, Idaho, 232 p.

Trexler, B. Jr., Ralston, D., Reece, D., Williams, R., 1975, Sources and causes of acid mine drainage, Idaho Bureau of Mines and Geology, University of Idaho, Moscow, Idaho, Pamphlet No. 165, 129 p.