REMEDIAL INVESTIGATIONS, DECISIONS, AND GEOCHEMICAL CONSEQUENCES AT IRON MOUNTAIN MINE, CALIFORNIA[1]

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Abstract: Extremely acid mine waters ($pH \leq 1$) have issued from the Richmond mine at Iron Mountain where underground seeps have been found with pH values as low as -3.0 and nearly 1000 g/L dissolved solids. Without remediation, discharges would continue for more than 2000 years at the current weathering rates. Other acid discharges include additional portal effluents, waste rock drainages, and eroded tailings piles. Numerous remediation alternatives have been discussed including capping the mountain, mine plugging, air sealing, ground-water interception, surface-water diversions, increasing impoundment capacity of a downstream reservoir, effluent neutralization, and mineral resource extraction. Geochemical consequences for mine plugging were found dangerous and uncertain. Present status of remediation has incorporated surface water diversions, partial capping, copper cementation, and effluent neutralization. Geochemical modeling was instrumental in influencing decisions on mine plugging and neutralization alternatives.

Key Words: acid mine drainage, acid mine water, remediation, geochemical modeling, Superfund

Introduction

Iron Mountain is located in Shasta County, California, approximately 9 miles northwest of the town of Redding (Fig. 1) along the southeastern border of the Klamath Mountains. "Iron Mountain Mine" is really a collection of mines within Iron Mountain that include Old Mine, No. 8 Mine, Confidence-Complex, Brick Flat Open Pit, Mattie Mine, Richmond and Richmond Extension Mine, and Hornet Mine. Gold, silver, copper, zinc, iron, and pyrite were mined at various times during a one-hundred-year period beginning in the early 1860's and ending with the termination of open-pit mining in 1962. Iron Mountain was the largest producer of copper in the state of California, and now it produces some of the most acidic waters in the world. Approximately 300 tons of dissolved copper, zinc, and cadmium drained into Spring Creek every year before remediation began, ultimately entering the Sacramento River below Shasta Dam and above Keswick Dam (Fig. 1). At the confluence point of Spring Creek with the Sacramento River, the acid waters are neutralized upon mixing, the metals are precipitated, and large sediment piles have formed in Keswick Reservoir (1). Metal discharges from Iron Mountain pose a potential threat to the residents of Redding, California because their source of drinking water is the Sacramento River below Keswick Dam. During periods of high runoff, sudden surges of acid mine waters into the Sacramento River have caused massive fish kills which state and federal agencies have investigated since 1939. The site was officially listed by the U.S. Environmental Protection Agency (EPA) on the National Priorities List as a Superfund site in 1983 and has undergone partial remediation. Final remediation for the Boulder Creek Operable Unit is currently underway based on a second Record of Decision reached in September, 1992 (2, Rick Sugarek, oral comm., 1994-95). Remediation on two more operable units is being planned. Site characterization on the fourth and final unit began in 1994.

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Hydrology and Geology

The topography of Iron Mountain is steep and rugged; Iron Mountain rises about 3000 feet above the Sacramento Valley (approximately 3585 feet above sea level). The summers are hot and dry, the winters cool and rainy with occasional snow. Average annual rainfall at the top of Iron Mountain is estimated to be about the same as that measured at Shasta Dam: 60 inches over a 47-year period (range on annual average for 1944-90 is 28-130 inches, see Alpers and others, 3). Slickrock Creek and Boulder Creek drain the south and north sides of Iron Mountain, respectively. These two tributaries of Spring Creek carry the acid mine drainage and eroding waste and tailings piles from the mountain and the Spring Creek drainage transports them to the Sacramento River (Fig. 1). Before reaching the Sacramento River, Spring Creek is retained by the Spring Creek Debris Dam built in 1963 as part of the Central Valley Project. The releases from this dam are metered at an amount that should be sufficiently diluted by Shasta Dam releases so that no fish kills should occur. On several occasions since 1963, however, the capacity of Spring Creek Reservoir has been exceeded and uncontrolled releases over the spillway have caused fish kills. During February/March, 1992, an additional 100,000 acre-feet of water were released from Shasta Dam to provide the necessary dilution of a Spring Creek Reservoir spill and to prevent fish kills below Keswick Dam on the Sacramento River. This event occurred when deliveries of water to farmers from the Central Valley Project were at an all-time low due to 6 years of consecutive drought, so the cost to the Bureau of Reclamation in terms of lost revenue was substantial. Natural landslides as well as erosion of waste piles and tailings piles have also occurred on the 4,400 acres of mining property.

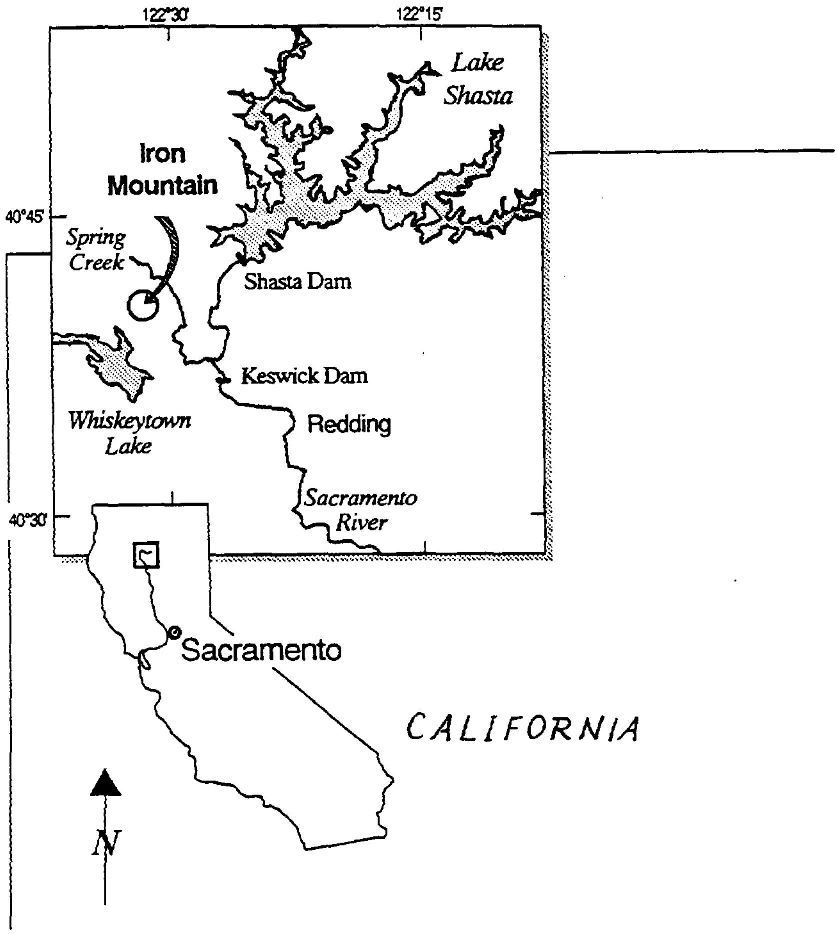

Figure 1. Location of Iron Mountain in northern California (modified from Alpers and others, 3).

The mineral deposits are primarily massive sulfides, composed of large single masses of up to 95% pyrite with variable amounts of chalcopyrite and sphalerite to average about 1% copper and about 2% zinc. Some disseminated sulfides occur along the south side of Iron Mountain. Trace quantities of several other metals and metalloids occur in the mineral deposits including gold, silver, lead, cadmium, arsenic, antimony, vanadium, cobalt, and thallium (based on relative concentrations of these constituents in the acid effluent). The deposits are of the Kuroko type having been formed along an island-arc in a marine environment (4). The country rock is the Balaklala rhyolite, a keratophyric Devonian rhyolite that has undergone regional metamorphism during episodes of tectonic collisions of oceanic crust with continental crust. The nature of the altered igneous bedrock gives rise to a predominance of fracture-flow hydrology at Iron Mountain. The Copley greenstone, an altered basalt, underlies the rhyolite and is approximately contemporaneous. Part of the region shown in Figure 1 to the south of Iron Mountain is the Mule Mountain stock, a trondhjemite-albite granite, considered to be cogenetic with the Balaklala rhyolite (5).

The mineral composition of the rhyolite is albite, sericite, quartz, kaolinite, epidote, chlorite, and minor calcite. Studies by Kinkel and others (6), by Reed (7), and those in the special issue of Economic Geology (1985, vol. 80, no. 8) have documented the chemical composition of both the ore minerals and the non-ore minerals. These studies also provide information on relative abundances of minerals and isotopic compositions.

Weathering of massive sulfides near the surface has given rise to a large gossan outcrop at the top of Iron Mountain, enriched in gold and silver. The extent of the exposure suggests that significant quantities of sulfides were oxidized during weathering and eroded before humans discovered the site. Some of the gossan material is found several hundred feet below the surface (6). Secondary enrichment in the upper zones of the massive sulfides and just below the gossan resulted in high concentrations of copper (5-10%) and silver (about 1 oz/ton). These observations suggest that large quantities of metals have been mobilized over geologic time.

Three main massive sulfide mineral bodies, known as the Brick Flat, the Richmond, and the Hornet occur at Iron Mountain. These are thought to have been a single massive sulfide body about a half-mile long (well over a half-mile if the offset Old Mine mineral deposit is included) over 200 feet wide and over 200 feet high but offset by two normal faults (see Fig. 2). All three of these bodies have been mined and the consequences of mining include altered groundwater conditions and highly contaminated surface waters originating from portal effluent waters.

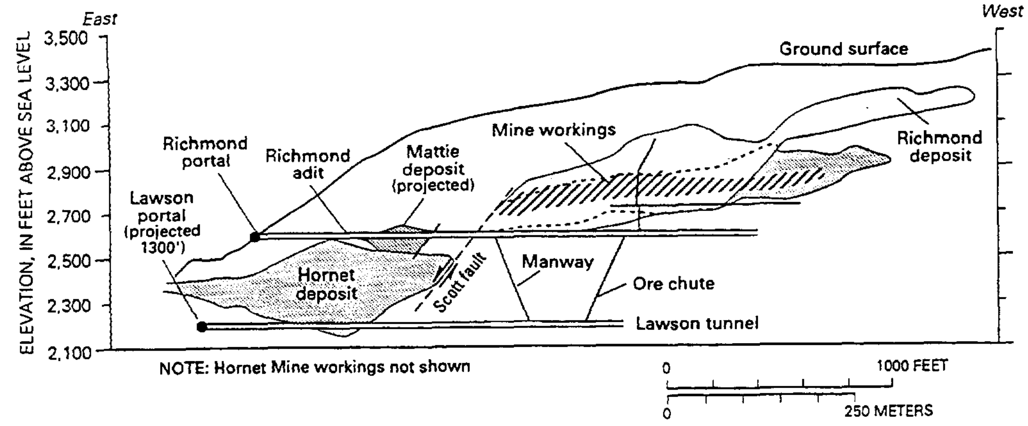

Figure 2. Cross section through Iron Mountain with Richmond and Hornet deposits and tunnels (from Alpers and others, 3).

Mining History

A brief history of mining has been compiled from the review by Kett (8), the reports of CH2M Hill contracted to the EPA, and various publications of the California Department of Mines and Geology.

Gossan outcropping was discovered in the 1860's and Iron Mountain was secured as an iron mine, although nothing was mined at that time. It was not until 1879 with the discovery of silver in the gossan that plans for mining began. From 1879 to 1894 silver was mined from the gossan by three partners and in 1894 it was sold to British interests who formed the Mountain Mining Company, Ltd. in 1895. Large massive sulfide deposits were discovered beneath the gossan in 1895, and smelters were built at nearby Keswick to process the ore which was transported on a narrow-gauge railroad from Iron Mountain to Keswick. In 1897, the property was transferred to Mountain Copper Company, Ltd. of London who maintained the operations until 1967 when it was purchased by Stauffer Chemical Company. Iron Mountain Mines, Inc. took over the property from Stauffer at the end of 1976.

Copper mining ceased in 1919 due to a decrease in the market price of copper and only very limited and intermittent copper mining took place until World War II, when the U.S. Government subsidized the production of copper and zinc. About 5.2 million tons of sulfide ore have been mined by underground methods from Iron Mountain. From 1955 to 1962, 9.5 million tons of waste from the top of Iron Mountain were removed, and 600,000 tons of pyrite were open-pit mined for sulfuric acid production. More than 2.6 million tons of gossan were mined for gold and silver. Most of the gossan was mined and processed by cyanide extraction from 1929-1942. Copper cementation was also used to extract copper from the effluent mine waters. From 1962 to the present, cementation has been the only active process for metal recovery but it has also served as a remediation measure to decrease the discharge of copper to the Sacramento River.

Contaminant Hydrogeochemistry

The production of acid mine waters has three essential ingredients: pyrite, oxygen, and water. Although these are necessary constituents, the amount and rate of acid production can depend on many factors such as the concentration of pyrite, the temperature, the availability of alkalinity-producing or neutralizing agents (such as carbonate strata), the oxygen transport rate, the water flow rate and flow path, and the microbial growth rate conditions.

Conditions at Iron Mountain are nearly optimal for the maximum production of acid mine waters from pyrite oxidation. The concentration of pyrite is nearly 100% in large masses excavated by tunnels, manways, and stopes that allow rapid transport of gaseous oxygen by advection. The massive sulfides are at or above the water table so that moisture and oxygen are always present. The airflow is probably aided by thermally driven convective cells due to the high heat output from pyrite oxidation. About 1,500 kilojoules of heat are released per mole (or about 120 grams) of pyrite. The average discharge from the Richmond portal indicates that about 2,400 moles of pyrite oxidize every hour, producing about 1 kiloWatt of power or almost 9,000 kiloWatts per year! In the early days of mining the Iron Mountain massive sulfides, fires were frequent and before proper ventilation was installed, temperatures of 430°F (221°C) were recorded at the ore surface (9). Water temperatures as high as 47°C were recorded in the Richmond mine workings in 1990 (Nordstrom and Alpers, written communication, 1990).

The presence of the mine workings draws down the water table and pulls water toward the sulfide deposits at Iron Mountain where the pyrite oxidation reaction occurs. The resulting acid mine waters drain by gravity flow out the major portals of the Richmond mine, the Hornet mine (Lawson tunnel), the Old Mine, and the No. 8 mine. Sulfide oxidation in the Richmond mine workings has led to the most acid effluent (pH = 0.02 to 1.5) and the highest concentrations of metals and sulfate for any surface water in the area; sulfate has been measured as high as 118 grams per liter (3). In addition, the Richmond portal discharge has had the highest recorded flow rates (as high as 800 gallons per minute) of any mine portals on Iron Mountain. The composition of the Richmond effluent from a sample taken on September 11, 1990 is given in Table 1. Note that the major cations are iron, aluminum, and zinc, and that most trace metals are present at very high concentrations. There is very little capacity of the bedrock to neutralize these highly acidic waters. Other important discharges of metals are the seep from the vicinity of the Old Mine and No. 8 mine portals, the "Big Seep" discharge in Slickrock Creek, and discharges from the Brick Flat open pit. Just under 2,000 pounds of these three metals are leaving the site per day, about 300 tons per year. In terms of pyrite weathering it has been estimated that 2,500 tons of pyrite are oxidizing every year from the Richmond mine workings alone (Nordstrom and Alpers, written communication, 1990).

Table 1. Composition (in g/L) of Richmond portal effluent on September 20, 1990

pH	T°C	Fe	Al	Zn	Mg	Cu	As	Cd	Pb	Sb	SO_4
0.4	28	18.6	2.3	2.1	0.85	0.29	0.06	0.02	0.004	0.004	122

During the second Remedial Investigation phase (1986-1992) of EPA's Superfund activities, the Richmond tunnel and part of the Richmond mine workings were made accessible to underground surveys. On September 11, 1990, water and mineral samples were collected during one of these surveys that resulted in the discovery of extremely acidic seeps with pH values as low as -3.4 and a total dissolved solids concentration of about 935 grams per liter. These acid iron-sulfate waters were precipitating or efflorescing soluble iron-sulfate salts, often coating tunnel walls and muck piles with a colorful array. Analyses of the three most acidic samples found are provided in Table 2. These waters are the most acidic ever reported anywhere in the world. The only other recorded pH values of natural waters comparable in magnitude are acid crater lakes in active volcanoes found in Japan, New Zealand, Alaska, and Costa Rica. The development of such extreme acidic conditions is due to optimal conditions for pyrite oxidation combined with considerable evaporation from the heat released during oxidation and several years of drought conditions in California. The formation of extensive efflorescent salts means that acid solutions are being temporarily stored in a solid form until climatic conditions become wetter. Wet climate conditions will cause dissolution of the salts and some flushing of the stored acidity out of the mine workings. Rapid increases of copper concentrations up to a factor of 2 or 3 have been reported as a result of heavy rainstorm events early in the wet season (3).

Table 2. Three of the most acidic waters found at Iron Mountain (concentrations in g/L).

pH	SO_4	Fe_T	Fe(II)	Zn	Cu	As	Cd	Pb
-2.6	760	124	34.5	23.5	4.8	0.34	0.21	0.012
-2.6	650	141	34.9	20.0	3.2	0.22	0.17	0.011
-3.4	-	16.3	9.8	-	-	-	-	-

Waters with high concentrations of metals, especially copper, zinc, and cadmium, have drained from the mine portals and leached from tailings and waste piles, entering Boulder and Slickrock Creeks and joining the Spring Creek drainage. The Spring Creek Reservoir, built in 1963, receives the discharges from Boulder and Slickrock Creeks with some dilution and iron oxidation. Waters stored in Spring Creek Reservoir typically have pH values in the range of 2.5 to 3.5, but they are not always well-mixed and often show chemical gradients with depth. Detailed temporal depth measurements to investigate the seasonal patterns have not been done. From the reservoir, the waters are released in controlled amounts so that the dilution with water released upstream from Shasta Dam prevents fish kills (10). More than twenty fish kill events have occurred since 1963 with at least 47,000 trout killed during one week in 1967 (11). The fish kills have occurred because the reservoir capacity has been overwhelmed by high-rainfall events, flash flooding, and a large load of metals discharged. These high metal flows, even during low-flow conditions, have led to adverse aquatic conditions in Keswick Reservoir and the Sacramento River. Water-quality objectives for the Sacramento River basin, based on laboratory and on-site toxicity studies of chinook salmon, have been adopted and approved by the Regional Water Quality Control Board (RWQCB), the California State Water Resources Control Board, and the EPA to protect against both chronic and acute toxicity to aquatic life. Using these criteria, both acute and chronic toxicity, studies on chinook salmon, steelhead, and rainbow trout in the Sacramento River system have shown both actual and potential harm to these species from the acid mine drainage originating at Iron Mountain (12).

Regulatory Investigations and Remediation

The first ore processing for copper was open-air heap roasting on timbers burned along the south and southeastern slopes of Democrat Mountain just upslope from the mouth of Spring Creek. In 1895 smelters were built nearby in the Spring Creek drainage. The heap roasting and the smelter operations resulted in toxic emissions that created air pollution, destroyed vegetation for miles around, contaminated soils, increased soil erosion, and increased turbidity and sedimentation rates in the Sacramento River. Volatile constituents likely to have been released into the air include arsenic, antimony, and lesser amounts of lead, cadmium, and zinc. Lawsuits were filed by private parties and by the U.S. Forest Reserve (now the U.S. Forest Service) and by 1907 all the smelters had shut down. The ore was then shipped to Martinez for smelting and refining. The lack of regulatory action from 1919-1942 probably reflects the economic difficulties of the Great Depression and the general lack of mining. Gossan mining, however, was very active during this period of history, but this would not have effected any production of acid mine waters.

From 1939 to the present, various studies of the environmental impact of Iron Mountain have been conducted by the California Department of Fish and Game, the U.S. Fish and Wildlife Service, the RWQCB, the U.S. Geological Survey, the Bureau of Reclamation, and the EPA. Since 1983 studies have been conducted as part of the Superfund investigations authorized by the Comprehensive Environmental Recovery Compensation and Liability Act (CERCLA). These studies have documented discharges of metal from Iron Mountain, the occurrence of fish kills, the results of toxicity tests on anadramous fish and other test organisms from the Sacramento River, the lack of benthic and aquatic organisms in parts of the drainage system, the siltation problems of the drainage, the geology, hydrology, and geochemistry of the area, and the effects of water management engineering practices on the drainage system.

In 1950, Keswick Reservoir was completed to provide further flood control and hydroelectric power below Shasta Dam. Much sediment deposition had occurred in the Keswick Reservoir and the Spring Creek Debris Dam was constructed to reduce these high sedimentation rates as well as to provide some regulation for the acid mine drainage entering the Sacramento River (1). Continued fish kills have kept the RWQCB actively pursuing remediation of the site. Following a thesis study at the site (13), a cleanup and abatement order was issued to the mine owner, Stauffer Chemical Company. On December 17, 1976, the property was purchased by Iron Mountain Mines, Inc., the present owners. From 1977 to 1989 six orders were issued to reduce toxic metal discharges that were in violation of state law. The orders to cease and desist as well as for emergency treatment measures have been through courts in both Shasta County and the State of California. Stauffer Chemical Company has become associated with Rhône-Poulenc which then became potentially liable for remediation costs at the site under CERCLA.

Iron Mountain was officially listed on the EPA's National Priorities List for Superfund in 1983 and the first remedial investigation/feasibility study (RI/FS) began. The remedial investigation report (14) identified the five major point sources of pollution discharges through a comprehensive surface water sampling survey. The greatest discharge source was identified as the Richmond portal effluent. EPA (14) also documented the occurrence of increased concentrations of copper, zinc, and cadmium from portal effluents following heavy rainstorm events and related this phenomenon to rapid flow of surface water into the mine workings through areas of subsidence.

The feasibility study (15) considered more than a dozen alternative treatment possibilities and estimated the costs and anticipated benefits from each individual alternative as well as several possible combinations. The alternate options are listed below in simplified form:

1. No action.
2. Diversion of surface flows: divert upper Spring Creek to Flat Creek, upper Slickrock Creek around Big Seep, and South Fork Spring Creek to Rock Creek.
3. Lime/limestone neutralization: treat major point sources with conventional neutralization treatment plant.
4. Capping: implement partial or complete capping of the mountain to prevent infiltration to the underground mine workings by laying down an impermeable barrier.
5. Enlargement of the Spring Creek Debris Dam.
6. Intercept groundwaters through a system of drainage tunnels and drillholes surrounding the ore body.
7. Mine plugging.
8. On-site leaching and mineral extraction technologies (proposed by owners).
9. Combined alternatives.

A Record of Decision, issued by EPA in 1986, initiated five main recommendations:

1. Partial capping of cracked and caved ground above the Richmond ore body.
2. Construction of surface water diversions for upper Spring Creek, Slickrock Creek, and South Fork Spring Creek.
3. Initiate hydrogeologic studies and produce a ground water model for the site. This step would include rehabilitation of the Richmond mine for subsurface investigations. The subsurface investigations were motivated by the decision to test and demonstrate the feasibility of filling mine workings with low-density cellular concrete.
4. Install perimeter controls as necessary to avoid direct contact with contaminants.
5. Evaluate other source controls as appropriate based on the hydrogeologic investigations.

At that time, mine plugging was not considered a serious option because of questions relating to the physical integrity of the mountain to contain the mine water. When Rhône-Poulenc acquired Stauffer Chemical Company's assets through a complicated and proprietary arrangement with ICI Americas, ICI Americas (now doing business as Zeneca, Inc.) began working on the remediation possibilities and mine plugging was seriously reconsidered. The initial alternative was to plug the Richmond workings and to allow them to fill up and flood the ore body to prevent further oxidation.

At the request of the EPA, the U.S. Geological Survey investigated the subsurface conditions in the mine workings that had been renovated. The study found enormous growths of efflorescent acid sulfate salts, acid mine waters and seeps of extremely low pH and high metal concentrations, and substantial amounts of caving and scattered muck piles (Nordstrom and Alpers, 1990, written communication, 16, 17, 18, 19). Identification of the soluble acid sulfate salts combined with an estimate of their volume made it possible to consider the consequences of mine plugging for the Richmond mine. The conclusion was that a mine pool of about 20 million cubic feet might be created and could have a composition very similar to the present Richmond effluent composition with $pH \leq 1$. This acid mine pool would be sitting on top of the current water table and could travel to Boulder Creek through fractured bedrock in something less than 100 years. This concern led to the development of a highly refined plugging scenario in which lime would be added before plugging, a lime slurry and various additives would be injected to neutralize and immobilize the acid waters and their dissolved metals after plugging. Considerable debate ensued as to the effectiveness and costs of such a procedure. The geochemical calculations, however, made it clear that mine plugging at Iron Mountain was very risky and dangerous proposition. Indeed, the most difficult tasks have been to assign defendable risks and to develop methods that would evaluate the effectiveness of any of the proposed alternative treatments and their various combinations.

The EPA evaluated a modified mine plugging alternative as part of the second RI/FS completed in 1992 and concluded that it was not viable. The EPA has also considered air sealing but has favored a complete capping treatment as the most cost effective solution in conjunction with the surface water diversions that have already been initiated. Emergency treatment procedures, which collect Richmond and Lawson portal effluents during periods of high flow and neutralize them in a temporary lime neutralization plant near the portal, have been instituted. The capacity of this plant was increased from 60 to 140 gallons per minute in December, 1992. This plant has been replaced with a 1,400 gallon per minute plant at the Minnesota tailings site since July of 1994 and will have sufficient capacity to neutralize both Richmond and Lawson tunnel discharges as well as discharges from the Old Mine/No. 8 mine area which are pumped to the treatment plant from the Slickrock Creek drainage. Further enlargement of the treatment facilities is under study to neutralize Slickrock Creek drainage after completion of a dam and pumping station.

The decision to combine Lawson tunnel discharges with those of the Richmond for neutralization was also influenced by the results of geochemical modeling. Consultants representing the industry considered the Lawson tunnel discharges to be primarily overflow from the Richmond mine because manways and ore chutes connected the two mine workings (Fig. 2). The EPA had some question about this opinion because there are nearly a million tons of massive sulfide still residing in the Hornet mine workings (accessed by the Lawson tunnel) and it wasn't clear how much Lawson effluent might be spillage from the Richmond mine *versus* on-site production from the Hornet mine. Alpers and others (3) studied the rainfall-discharge relationships, Cu/Zn variability, and mass balance calculations for the two portal effluents and concluded that not more than about 2% of Lawson discharge is likely to be spillage from the Richmond, most of the Lawson effluent was being produced in the Hornet mine. The strongest evidence for this was the geochemical mass balance approach which could look at the net effect of dissolution, precipitation, and mixing of waters to determine the possible sources and sinks leading to the Lawson effluent chemistry.

Meanwhile, the EPA and the potentially responsible parties remain in legal contention over the appropriate treatment to be used and the consequent costs. Some question of the federal government's share of the liability has also arisen because of the network of dams built by the Bureau of Reclamation in the drainages receiving the acid mine waters. A plan to enlarge Spring Creek Debris Dam has been submitted for consideration. The winter of 1994-95 is a particularly wet season following a long drought and the numerous treatment and diversion options in operation do not prevent the debris dam from filling and overflowing under these extreme conditions.

Concluding Remarks

Control and remediation of the mine waste contamination at Iron Mountain, including prevention and treatment of some of the most acidic mine waters in the world, has proven to be an extraordinarily difficult, complex, and expensive task. The physical and chemical nature of the site with all of its heterogeneities, complexities, and unknown aspects, the difficulty in assessing the effectiveness of any treatment alternatives in various combinations, and the difficulty of assessing the relative risks and costs of various alternatives and their contingencies all contribute to the formidable challenge of remediation. There is no easy solution to the problem and opposing parties will have inevitable differences of opinion on how to proceed and how much it should cost. Under such circumstances, it would seem prudent to proceed with remediation in stages with the most risk-free and least expensive treatments (especially in terms of operating costs) while continuing to monitor the site so that evaluations can be revised and improved.

Modern methods of mining can rehabilitate an area during production and after mining has ended with a considerable reduction of overall environmental remediation costs. The experience gained in studying Iron Mountain certainly underscores this fact. Estimated costs of cleanup at Iron Mountain started at about $25 million and now may be on the order of $150 million for the most effective and politically negotiable combination of treatments.

The other conclusion to be underscored is the advantage of having an independent technical advisory team of representatives from State and Federal agencies to advise on site investigations and remedial alternatives, to review progress, and to address follow-up monitoring and evaluation after remediation. During the course of the Iron Mountain mine Superfund investigations a technical advisory committee offered numerous technical and political recommendations that provided a much more rational basis for decision-making, especially when it become necessary to discuss complex issues with the potentially responsible industry representatives. The need for such a team for guidance on cleanup at every major hazardous waste site cannot be overstated.

The story of this site is not yet over after 100 years of mining activity and 54 years of investigation and regulation. However, more progress has been made at Iron Mountain than at most mining sites in the United States. The recommended remedial measures may be very site-specific, but the general strategy on how the site was investigated and the difficulties uncovered during the Superfund investigations should provide insight and examples that will be useful for other mine sites.

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