MINE DRAINAGE CHALLENGES FROM A TO Z IN THE UNITED STATES[1]

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Abstract. Scientists, mining companies, and governments are trying to ameliorate the environmental effects of acid rock drainage (ARD), and abandoned mines, and to address sustainablity issues to the mining community nationally and internationally. Failures to adequately address mine drainage issues have occurred at relatively high rates over the past several years. Many of these failures have resulted in massive damage (both real and perceived); with severe economic impact to both taxpayers and companies. This personal summary of lessons learned of mine sites from A to Z has been compiled to identify commonalities and to illustrate the primary issues encountered when dealing with mining influenced waters. Clear trends regarding the need for good baseline information, development of innovative technologies and common issues arise from objectively reviewing a multitude of case histories. Understanding these trends greatly assists in enhancing current and future design, construction, operation, and closure of mining facilities. Ignorance of past failures can be overcome by lessons learned thus contributing to the knowledge base and avoiding similar problems in the future.

Additional Key Words: abandoned mines, environmental protection agency, mine monitoring, prediction, water balance, water treatment, historic mines, lessons learned

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Introduction

The purpose of this paper is to provide, in general terms, a brief overview of environmental challenges encountered at mine sites throughout the United States. Business at most mining sites is conducted in an environmentally sound manner. However, those mine sites that become familiar to staff from the U.S. Environmental Protection Agency (USEPA) tend to be associated with environmental or human health problems. A great many mine drainage problems (and the valuable lessons learned from them) go undocumented due to scientists' and mining companies' sensitivity to criticism, mining companies' paranoia with respect to publicity, and potential legal implications by governments. Conducting a postmortem on sites and issues encountered in the United States will present new options and opportunities in the future to improve the way they do business. The four major themes identified in evaluating mine sites from A to Z (Table 1) are the following: 1) prediction and pre-mining phase of the mine life cycle; 2) water balance and the operational phase; 3) water treatment at closure; and 4) historic mines in post closure. Information is also presented in Table 1 about the lessons learned and directions to more detailed descriptions for most of the mine sites used as examples in this report. Prediction of the potential for acid mine drainage (AMD) and the pre-existence of acid rock drainage (ARD) as a natural background condition is one of the primary challenges faced by the USEPA. Two general types of tests are used to predict acid-generation potential: static and kinetic. Static tests estimate the maximum acid-generation potential (AGP) and neutralization potential (NP) of a rock or waste material. Kinetic tests are conducted for six weeks or longer, use larger sample columns, and are generally more reliable than static tests. Modified humidity cell and column-type tests are the preferred kinetic tests in EPA's 1994 guidance document (USEPA, 1994a). "There are a number of instances where acid drainage has occurred even though it was not predicted or expected. Examples include the Thompson Creek Mine in Idaho (USEPA, 1994a), the LTV Steel Mining Company in Minnesota, (USEPA, 1994a) the Rain Mine in Nevada (USEPA, 1994a), the Zortman/Landusky Mine in Montana in the Federal Register, August 7, 1996" (NRC, 1999) All are or were recently active mines with acid prediction having been addressed in the permit applications.

Another key consideration during permitting and operation is on-site measurement and calculation of water balance. It may also be the most important consideration at final closure. Of recent bankruptcies resulting in additions to the EPA Superfund list, all had poor or non-existent water-balance evaluations (Probst et al, 2001). Many mines that became problems have had no evaluation of precipitation, flow pathways, year-round data collection or data collection for a sufficient period of record. Risk assessments from both an economic (insurance) standpoint and from a biological standpoint should be taken into consideration before opening a mine (Smith et al, 1999)

The information presented herein attempts to provide a broad perspective of the challenges encountered by the USEPA. References to individual mine sites are meant to be illustrative, and not definitive. This paper is merely my point of view and may not represent the perspective of the USEPA or the associated mining companies. This information was compiled for summary purposes only and additional information should be obtained before making judgments about these summaries. Further information and additional perspectives are available through other agencies and mining companies.

Case Studies

Argo Tunnel

The first official example of the need for a water balance in ARD evaluation is the Argo Tunnel. Completed in 1910 this 6.69 km drainage tunnel passes from Idaho Springs to Central City, Colorado. The Argo Tunnel provided dewatering and ore haulage-ways draining over 300 mines. It is the largest single source of ARD and metals contamination to Clear Creek (CDPHE, 2002). As part of a Superfund remediation project, construction of a 2650 liter per minute conventional sodium hydroxide treatment facility was completed in 1998. Although the plant has been successful in meeting the effluent-quality goals, it has been at much higher costs than estimated partly because of inaccurate flow measurements for ARD. Initial flows were measured at the portal, whereas, the flow captured several meters within the tunnel area is twice the previously measured flow (USEPA, 2002a). Differences in flow were due to fracture flow from the weathered surface near the tunnel exit and seasonal variations in flow that were not accurately measured. The plant was designed as a dual-train system with one filter press. Rather running one train while a second was being maintained, both trains must function all of the time necessitating more oversight and much more costly maintenance. In addition, another filter press was purchased in a rush and there was more filtration sludge than expected, causing increased disposal costs. Nevertheless, more than 453 kg of metal is removed each day from the ARD before discharging to Clear Creek (CDPHE, 2002). One document recently published by EPA titled Performing Quality Flow Measurements at Mine Sites (USEPA, 2001a) may assist with more accurate measurements of ARD. Recently the plant was reconfigured to a lime neutralization to increase efficiency and to enable the diversion of other sources to the treatment plant.

Beal Mountain Mine

In 1999 the Montana Department of Environmental Quality and the U.S. Forest Service took over the water treatment for the bankrupt Beal Mountain Mine, near Butte, Montana. A trustee was appointed to oversee disbursement of funds including bond money for mine water treatment. Approximately one billion liters of heap-leach process solutions have been reduced to 50-million with the use of a biological-treatment plant and a land-application system (McCollough, personal communication, June 2003). Although the solution met the state water-quality standards after treatment for pH and for Weak Acid Dissociable (WAD) cyanide (CN), all vegetation died within the land-application test area within a short time. The operator determined, through greenhouse tests of the water that the phytotoxicity was due to thiocyanates (B. Parker, personal communication, 2002). During treatment for metals and pH, many of the breakdown compounds of CN, while generally less toxic than the original CN, are known to be toxic to aquatic organisms and may persist in the environment for significant periods of time. Some of these toxic breakdown forms include cyanates and thiocyanates. Unfortunately, these compounds are not identified in the typical total CN or Weak Acid Dissociable (WAD) CN analysis in the United States. For example, water samples from mining sites where cyanide is used as a process chemical may have WAD and/or total CN concentrations that are quite low or undetected, yet when the same samples are analyzed specifically for cyanates and thiocyanates, they show tens of milligrams per liter (mg/L) or more of these compounds (Moran, 2002). The lesson learned is that when characterizing and treating ARD, new compounds can form that need to be evaluated for toxicity. Recent work by Little Bear Laboratories indicates that cyanates may inhibit the production of acid in reclaimed heap-leach facilities.

Chalk Creek

Chalk Creek, in central Colorado, drains an area of approximately 24,864 ha, including the primary source of ARD, the Mary Murphy Mine. Lode mining developed on the valley slopes producing Au, Ag, Pb and Zn from sulfide vein deposits through an extensive system of underground workings. The Golf Tunnel was constructed to transport ore to the mill and to provide drainage to the 670 m (vertical) mine workings of the Mary Murphy Mine. Work by the Colorado Department of Minerals and Geology (CDMG), their consultant Cambrian Groundwater, and USEPA characterized the ARD groundwater flow systems. Multiple dyes were introduced into the fractured bedrock mountain/mine pool system. Results from the tracer studies indicate four discrete groundwater flow systems: 1) a relatively slow-flow system in the high mountain faulted bedrock, very high in Zn; 2) rapid flow through the cavern-type systems of the interconnected mine voids and fractures lower in the mountain; 3) a weathered, shallow fracture system in the upper 8m of bedrock; and 4) infiltration of precipitation through the tailings repository into the near-surface system, also very high in Zn (USEPA, 2002b). After reentry into one of these adits, mining specialists from CDMG found that ARD was coming from only a few fractures in the rock. In fact, most of the mine drainage originated from the very back of the Golf Tunnel from a winze drilled vertically to intercept the mine workings some 245m above. Very little ARD was coming into the tunnel except from this site even though many other sulfide vein systems were mined. For remediation, mine inflows were segregated into clean water that could be piped out directly without treatment, and ARD at one site that can be readily collected for passive treatment. The major lessons learned are that if uncontaminated water can be intercepted and diverted before it enters mineralized areas of mine workings and becomes ARD, the total loadings of metals will be diminished significantly (Dunn, 1995).

Ducktown/Copper Basin

The Copper Basin Mining District Site (also known as Ducktown) is located in southeast Tennessee in Polk County, and northern Georgia in Fannin County, near the state border with North Carolina. The Copper Basin is the site of extensive former Cu and sulfur mining operations that date back to the early 1800s. For more than 150 years, numerous companies and individuals were involved in various mining, refining and manufacturing operations in the area. Mining operations ceased in 1987, and sulfuric acid production was discontinued in 2000. Mining and related activities have resulted in the environmental degradation of portions of the Copper Basin, including the North Potato Creek Watershed, the Davis Mill Creek Watershed, and parts of the Ocoee River (USEPA, 2002c). Presently the site is being investigated and cleaned up through a collaborative three party effort that was formalized on January 11, 2001, between EPA, the Tennessee Department of Environment and Conservation and OXY USA, Inc. This agreement divided the site into operable units of which OXY USA has agreed to conduct lime treatment of one creek and U.S. taxpayers would pay for remediation of the other sites. Recently a very large diversion tunnel under one of the enormous waste rock piles was found that diverts water from the area to be treated by OXYUSA to the drainage to be treated by the USEPA (USEPA, 2001a). Major infiltration of ARD from the waste rock pile into the diversion results in waters that will need to be treated by USEPA and the State. A conceptual plan of hydrology at the site, including a calculation of water balance, would have uncovered this major source (USEPA, 2004). The lesson learned is to develop a conceptual hydrologic model so that sampling efforts can adequately characterize a site before entering into binding agreements.

Elizabeth Mine

The Elizabeth Mine is an abandoned copper mine located near the Town of Strafford, Vermont. Deposits at the Elizabeth Mine were discovered in 1793 immediately after the American Revolutionary War. The mine operated from the early 1800s until its closure in 1958. The ore was initially valued for its Fe content, and then its pyrrhotite content from which copperas $Fe_2(SO_4)_3$ was produced for use in the tanning industry (USEPA, 2002d). The historic mining structures and the evidence of ancient roasting processes are valued very highly in the community. However these same piles are major sources of ARD. After much effort and discussion, locals have become more convinced that both environmental cleanup and historic preservation can go hand in hand. The more recent tailings piles have been reclaimed focusing on stability and reduction of water flux through the piles. The historic roasting piles may be remediated in place possibly using tinted cement to retain their historic appearance (C. Russell, field notes 2001).

Ferris-Haggerty Mine

Throughout the western United States, the USEPA encounters abandoned mines at high elevation without year-round access and without power. One example is the Ferris-Haggerty Mine, an inactive, underground Cu mine located about 40 km west of Encampment, Wyoming at an elevation of approximately 3,000 m. The harsh climate limits mine access to four months a year via a 6.6 km (4.1 mile) four-wheel-drive road. The mine consisted of a number of working levels of which the Osceola Tunnel served to dewater the mine. The discharge is near-freezing, near neutral pH, and generally has Cu concentrations ranging from 3 to 5 mg/L (Reisinger and Guzek, 1998). The Wyoming Abandoned Mine Land Program, with the assistance of Knight-Piesold, constructed an underground, pilot-scale passive treatment test utilizing sulfate-reducing bacteria. Test results show significant decreases in Cu concentration in the near-freezing mine water (Reisinger, et al, 2000). The lesson learned was that even at very high elevations Sulfate-Reducing Bacteria (SRB) reactors can work if placed underground to prevent freezing.

Gilt Edge Mine

The Gilt Edge Mine is located in the Black Hills near Deadwood, South Dakota. It is a 1.04 km^2 (258-acre) open pit, CN heap-leach Au mine, developed in sulfide (acid-generating) rock material. The operator went out of business, leaving behind over half a million liters of acidic, heavy metal-laden water in three open pits. Also left behind were millions of cubic meters of acid-generating waste rock that need cleanup and long-term maintenance. This example emphasizes alternatives analysis as a mode of decision-making. Side-by-side evaluations of treatment technologies funded by EPA's Superfund programs are shown in Table 2. A comparative analysis of the retained alternative indicates a range of present worth costs from $476,000 (USD) in Alternative 1 to approximately $10 million for the water-treatment alternatives. In addition to cost, USEPA must take the following aspects into consideration: 1) protection of human health and environment; 2) compliance with applicable laws and regulations; 3) effectiveness and permanence; 4) reduction of toxicity or volume; 5) short-term effectiveness; and 6) implementability. Converting the existing caustic water-treatment plant to a lime process shows an overall cost saving. Simple modification of the existing system from sodium hydroxide to lime treatment with system enlargement is the most cost-effective options (USEPA, 2001c).

Table 2 - Gilt Edge - Summary of Alternatives Screening (costs in 2002 US dollars) Modified from (USEPA,2001c)

	Alternative	Protection of human health and	Compliance	Effective-ness and permanence	Reduction of toxicity or volume	Short- term effectiveness	Implimentablity	Present worth (95% probability)
1	No Action	Low	Low	Low	Low	Low	Very High	$476000
6a	Upgrade existing caustic treatment with additional treatment train and filtration	High	High	High	Very high	Very high	High	$9789000
6b	Convert existing caustic treatment to lime with additional treatment train and filtration	High	High	High	Very high	Very high	High	$8527000
6c	Construct new proprietary micro-encapsulation treatment plant	High	High	High	Very high	Moderate	Moderate	$8681000
6d	Construct new optimized chemical precipitation using proprietary metals coordination and micro-filtration	High	High	High	Very high	Moderate	Moderate	$8195000

Henderson Mine

An example of the complications encountered when an endangered species appears to prefer an ARD environment, such as a mine tailings pond, is illustrated by the Henderson Mine in central Colorado. The boreal toad (Bufo boreas boreas), listed as a State Endangered Species and is a candidate for federal protection under the Endangered Species Act, only breeds in still or slow moving acidic water such as the water found in a tailings impoundment. Scientifically rare species tend to inhabit rare ecosystems. Mineral deposits that produce ARD are one of those rare habitats that support endangered species. The mine's reclamation plan required capping of the tailings pile thus eliminating the pond of acidic water. The mine took on the toad as their mascot and actively participated in the efforts to establish new (non-mine) habitat (USEPA, 1991). The lesson learned is if you can’t beat them, join them.

Iron Mountain Mine

From the 1860s through 1963, the Iron Mountain Mine site in northern California periodically was mined for Fe, Ag, Au, Cu, Zn, and pyrite. Many kilometers of streams, tributaries and reservoirs within the Sacramento River Basin are impacted by ARD from the mine. Underground mine water was found with pH values as low as –3.6 (Nordstrom et al, 2000). Salmon and trout kills have been noted since 1899. Releases of stored ARD into the reservoirs are timed to coincide with the presence of diluting releases of water from Shasta Dam.

One option for remediation was to plug the mine portal. Studies predicted that if the mine portals were plugged, a pool of water would develop with extremely acidic pH (near 1) and high metal concentrations (grams of dissolved metals per liter). The flooded mine pool would have a volume of approximately 600,000 cubic meters and would present a high risk to the environment and to the local community because of the potential of catastrophic plug failures, faulty plug seals releasing mine water, and acid seeps developing in other locations. Based on this information plugging of the mine was dropped from consideration. Instead a combination of remediation activities was chosen with the clear understanding that new technologies are needed. The options chosen were an acid neutralization treatment plant (lime/sulfide high density sludge (HDS) treatment process), capping of selected areas and surface water diversions. An agreement regarding the payment to state and federal governments of close to one billion dollars has been structured using a unique funding mechanism of combined financial assurance and insurance (USEPA, 2001d).

Jerrit Canyon

The Jerrit Canyon Mine, located 68km north of Elko, Nevada uses fluidized bed roasters to oxidize sulfide and C minerals to increase Au production from the CN leach facilities and, secondarily, to reduce ARD. Both roasting (heating of the finely ground ore to a high temperature) and autoclaving (oxidizing the ore by a combination of heat, O_2 and high pressure) are primary sources of Hg emissions if not controlled (Newmont, 2002). Operations throughout Nevada were identified as sources of Hg discharge in EPA's 2000 Toxic Release Inventory (TRI). Mining companies worked cooperatively with EPA and the Nevada Department of Environmental Protection to form a voluntary partnership to reduce Hg emissions below the levels required by current regulations. Mining companies undertook detailed investigations to better characterize their Hg sources and explored pollution-prevention approaches (USEPA, 2002e). Mercury-emission reduction was achieved through operational improvements and additional pollution-control equipment while ARD can be reduced by maintaining the roasting process (D. Baker, personal communication, November, 2002).

Kennecott-Bingham Pit

Located near Salt Lake City, Utah, the century-old Bingham Canyon Mine is one of the largest integrated open-pit Cu mining, smelting and refining operations in the world. Cumulative Cu output from this facility exceeds that of any other mine. Bingham Canyon is also one of the world's most up-to-date facilities: major investments during the past 15 years have ensured environmental compliance (Kennecott, 2002). In 2002, the initial tests of the in-situ bioremediation projects were performed treating a portion of a plume in an alluvial aquifer contaminated by selenium. The original concentration of the ground water was 5000 µg/L Se. Soon after the injection of the microbes and the addition of a molasses-based mixture, the concentration was reduced to between 50-600 µg/L Se. The removal rate, (after correction for dilution) was approximately 90% (USEPA, 2002d).

Leviathan Mine

The Leviathan Mine located near the California - Nevada border, was first developed in 1863 as a source of $CuSO_4$ for processing Ag ore at the Comstock Mines in Virginia City, Nevada. There are two different areas of treatment at this mine site: 1) Lime treatment of approximately ten million liters of the evaporation pond water, and 2) five million gallons of recent ARD. No one lives near the site and land is readily available for remediation activities. Because of limited access, cold temperatures and potential breaches in spring, it was decided to implement a buried semi-passive treatment system to prevent it from freezing and to collect water in winter for treatment in summer (USEPA, 2002g). Thus the problems of limited access in winter and spring to deal with an active treatment system and potential overflows were overcome by the use of a passive system (K. Mayer, personal communication, December 5, 2002). However, it should be mentioned that the initial remediation effort in the early 1990's (drainage ditches and collection ponds for settling) was not sufficiently successful and that led to another phase of remediation consisting of the semi-passive, active, and passive treatment systems.

Mogul Mine

The Mogul Mine is one of two thousand mines within the Animas Watershed that drains the area surrounding the town of Silverton, Colorado. The area has been mined for Ag, Au, Pb and Zn for over a century using underground methods. Another mine within the watershed, the Sunnyside Mine, produced ore through the American Tunnel and was the most recent operation to close in 1991. In 1995, Echo Bay received permission to plug the American Tunnel to eliminate the water being discharged, thus eliminating the responsibility for water treatment. Approximately five years after plugging the American Tunnel, the discharge for the Mogul Mine (85 meters higher in elevation), had a significant increase in flow and major increases in metals loading. Three possible reasons may explain the Mogul flow increase: 1) flow through geological connections as the level of the water in the Sunnyside Mine rose to pre-mining levels, 2) physical changes in the Mogul Mine itself such as slope collapse, or 3) reestablishment of the original piesiometric surface without any direct hydrological connections. In addition to flow of ARD, chemical effects of plugging were explored (USEPA, 1999). Recent sampling shows the concentrations of metals in flow from the Mogul are similar to pre-plugging metals levels. Yet approval of the plugging of the American Tunnel required the addition of hydrated lime into the mine pool as the level rose. The pH of the mine pool was initially near 5.26, rose to a pH of 12.5 after lime addition, fell to 2.7 and rose again to 5.34 before sampling was curtailed (C. Russell, field notes, 2002). Long term effects of this tunnel plugging have not been evaluated. More lessons could be learned from this site because of the pre-plugging data compilation.

New World Mine

When the predictions of ARD are questionable and the natural resource values are high, conflicts may result. The New World Mine was proposed in 1990 in a previously mined area near Cooke City Montana just northeast of Yellowstone National Park (Moss, 1997). The proposed mine was to have included a 1 088 metric tons per day, underground Au, Ag, and Cu mine including a work camp, mill, and a 32 ha tailings impoundment for storage of 4,989 million metric tons of acid-generating tailings. National Park Service commented extensively regarding surface and subsurface water quality, wetlands and wildlife impacts and seismic instability during the permit review process. The controversy took on national and worldwide significance when in 1995, a delegation from the World Heritage Commission visited the park to investigate the proposed mine and placed Yellowstone on the list of "World Heritage Sites in danger." A New York Times reporter stated that, "This [author] page is convinced that the proposed New World Mine is a disaster-in-waiting that could ruin one of America's leading ecosystems" (Semple, 1995). The end result was the purchase of the mine by the United States government with the U.S. Forest Service taking on the responsibility of ARD and remediation of the previously mined areas. Remediation by the Forest Service is on-going.

Ophir Mine

Ophir, a small mining town located 12 km from Telluride, Colorado was heavily damaged by avalanches in the early 1900s during the mining boom. By the 1960s it was nearly a ghost town, but currently it is experiencing a revival. Active treatment of ARD in this area would be very expensive and is often hampered by liability provisions of the Clean Water Act. Likewise, more passive-treatment strategies, such as diverting ARD through constructed wetlands and bioreactors, must still be regarded as experimental because of the cold temperatures at this elevation and potentially hazardous because of the risk of destruction by snow-slides. This project proposes to analyze regional hydrogeology in alpine areas as it relates to mine workings and recommend strategies to intercept and divert water away from mineralized zones, thereby reducing heavy metal loading to the Howard Fork (Willits, 2001).

Pinto Creek

Unanticipated release of ARD is one of the worst-case scenarios to encounter as illustrated by this scenario regarding Pinto Creek in Arizona. "On October 22, 1997, one of the [Broken Hill Proprietary] BHP tailing impoundments blew out under pressure from rocky debris loaded on top of it. More than 317,000 cubic yards [265,000 m3] of mine waste, the consistency of toothpaste, squeezed from the heap and flowed into Pinto Creek below, filling it rim to rim" (Kiefer, 1998). The usual construction of tailings piles consists of tailings slurry released to form a dam of coarse side-slope. The heavier material forms the dam, the slimes (very fine grained material of low permeability) and the water (either as open water on the surface or as pore water) flows into the center of the dam. The "slimes" component of the tailings, behave as weak, almost fluid deposits. When subjected to loading by placement of materials for a cover, excess pore pressures within the slimes resulted in geotechnical failure. Dr. Andrew Robertson in his paper stated, 'The construction of soil covers on very weak, compressible fine tailings (slimes) often presents a formidable challenge due to the low shear strength, poor trafficability, and high settlement of these under-consolidated tailings at the time of reclamation" (Robertson and Weis, 1999). In some climates, coarse material can provide erosion control and also protection from heat, improving the potential for reclamation and stability. However, overall integrity and stability of the waste facility holding acidic mine waste is paramount. Cleanup of the tailings along several kilometers of stream was dangerous and very costly to both the company and the federal government (C. Russell, field notes, 1999).

Questa Mine

The Questa Mine, located 6.5 km east of Questa, Taos County, New Mexico, is an active molybdenum mine and milling facility. Underground mining operations began in 1920 and the open pit commenced in 1965 and surface mining ceased in 1982. Underground mining began again in 1985 and has continued intermittently to the present depending on the price of Mo. Approximately 328 million tons of waste rock were excavated and deposited in rock piles surrounding the pit (USEPA, 2002e). Results show the majority of the mine rock is acid generating, but it may take more than 20-years for oxidation/acid generating maturity to occur (Shaw et al, 2002). "The majority of the mine rock, where it has been tested, is acid generating. The data further indicated that elevated temperature within the mine rock piles (due to on-going oxidation) and the high elevation gradient (rock piles are up to 490m high) result in high rates of air flow within the rock piles (chimney effect). As a result the rock piles are not O_2 limited and will continue to oxidize for a long time" (Shaw et al, 2002). The mine rock was end-dumped into several steep valleys adjacent to the pit at the angle of repose (Wels et al, 2002). Water balance calculations indicate that only 2% of the water evaporates from the waste piles

(Lefebvre, et al, 2002). The mining company and the USEPA are concerned about the long-term geochemistry with the possibility of clay formation and questionable pile stability. A consortium of universities with the Acid Drainage Technology Initiative (ADTI) acting as an independent review panel at the request of the mining company, are researching the effects of weathering on the long-term stability of the rock piles (McLemore et al, 2006). A confounding issue is the high concentration of acid and metals in ground waters that occur naturally upstream from the mine site. This high background concentration makes it more difficult to discern how much of the contaminants entering the river is from mining sources relative to natural sources. The USGS is completing a study of the pre-mining ground-water quality at the mine site by using a proximal natural analog site (Nordstrom, 2005).

Rain Mine

The Rain facility is located approximately 14.5 km southeast of Carlin in Elko County, Nevada. Most of the Au associated with the Rain ore zone is located near the Rain fault in oxidized and hematite-stained mudstones and siltstones of the Webb Formation. In the permit application, "Of the 57 million metric tons of waste rock expected to be generated by the mine, 70.6 million metric tons is expected to be mostly oxidized mixed sedimentary material (some of which will contain sulfide mineralization); 15.4 percent is expected to be carbonaceous and potentially sulfidic; 4.3 percent is expected to be limestone of the Devil's Gate Formation; and 2.5 percent will be alluvium from surface deposits (SRK, 1990). Precipitation in this area typically occurs in summer thunderstorms or as snowfall. The area is semi-arid with annual precipitation at the site averaging 30.5 cm including approximately 140 cm as snow. Baseline data that predate the Rain facility showed that water of both major drainages were of high pH, bicarbonate concentration, total dissolved solids, and conductivity. "Prior to the spring of 1990, sulfide, oxide, and calcareous waste rock were disposed of together. On May 8, 1990, acid drainage was observed flowing from the base of the waste rock dump and into the unnamed drainage. Monitoring showed pH values ranging from 2.37 to 3.21 near the base of the waste rock at the discharge point" (USEPA, 1994b). "[The company's] assessment of the acid drainage problem noted that it occurred during the snowmelt period of 1990 and cites two contributing factors for the occurrence of discharge. First, snow accumulation removed from other areas of the facility was disposed of on a localized area of the dump. Second, the pre-mining topography of the dump area collects and concentrated surface drainage from a watershed of about .15 square km. As the snow melted, it infiltrated the waste rock pile, oxidizing sulfur-bearing minerals and generating acid. The solution migrated along pre-mining topography and discharged at the toe of the dump" (USEPA, 1994b). The company immediately notified the State and USEPA and took appropriate measures to address the acid drainage and to change its waste rock and snow disposal practices. Sulfidic waste rock is now being encapsulated within oxidized and/or calcareous waste rock that has either no net acid-generating potential or some acid-neutralizing potential (USEPA, 1994b) (Newmont, 2003)

Summitville Mine

Summitville is the classic example in the United States where the water balance and precipitation calculations were based on data from the nearest town, Alamosa 75 km distance and over two km lower in elevation. Very cold temperatures were unanticipated when the liner for the CN heap leach was laid in place. Failure of the liner occurred almost immediately releasing ARD and cyanide (Pendleton et al, 1995). "The polluted water was supposed to be contained in a heap-leach pond, but the state's oversight of the operation was lax. Unusually heavy snow and runoff overwhelmed the pond's critical systems, sending cyanide-laced liquid into tributaries of the Rio Grande River, killing all fish downstream for 17 miles" (CMA, 2003). In addition, no one expected to have snow depths of over 8 meters the first winter the government took over the site. The unknown effects of the water balance and weather were factors contributing to the mine's failure (King, ed., 1995).

Ten-Mile Watershed

The Upper Ten Mile Creek Watershed is located in the Rimini Mining District, southwest of Helena, Montana. This area is unique because of the need to combine efforts to address ARD. Mining began in the Rimini Mining District before 1870 and continued through the 1920s. Little mining has been performed in the Rimini Mining District since the early 1930s. The site boundary includes the drainage basin of Ten Mile Creek upstream of the Helena Water Treatment Plant and includes tributaries that supply water to the plant's five intake pipelines. The USEPA identified 150 individual mine sites within the watershed boundary, of which 70 have been prioritized for clean-up. Many of these mine features are above the five City of Helena drinking water intakes which supply over 70 percent of the city's water. It was important to move wastes to an area that could be controlled and monitored to limit impacts to the water supply. Because the wastes were on mixed ownership sites, a unique agreement was made to dispose of wastes in the joint Luttrell Repository engineered to address agency and local community concerns. In particular, decisions were made to minimize operation and maintenance costs that the State will need to assume; and to provide a secure repository for wastes removed from the watershed (USEPA, 2002f).

UraVan Mining District

The 1.8 square km (450-acre) Uravan U site began as a Ra-recovery plant in 1912. Its owners later converted it for V extraction. From the 1940s to 1984, the plant utilized H_2SO_4 in the U and V processing facility, thus the origin of the town's name, Ura-Van. Operations at the site left a large volume of both acidic and alkaline wastes, contaminating air, soil and ground water near the plant and the San Miguel River. Contaminants included radioactive products such as raffinates, raffinate crystals, and mill tailings containing U and Ra. Other chemicals in the tailings and ground water were heavy metals, such as Pb, As, Cd and V. The most difficult aspect of remediation of this mining waste and ARD site was the fact that the town of Ura-van was in the middle of the site. The final cleanup required moving everyone from the town permanently (USEPA, 2002g).

Wellington –Oro

Beginning high in the Rocky Mountains, French Gulch flows near the ski resort of Breckenridge, Colorado. Sampling studies determined that the Wellington-Oro Mine was the primary source of metals loading in the watershed (USEPA, 1995a). Probably the most important lesson learned from cleanup efforts at this site is that evaluations of water balance in historic mines are very complex. Within the mine complex were several potential sources. It was decided to remediate the simple problems first then re-evaluate what was known about the water. First, the area had been placer mined by dredging. Therefore, no stream channel flowed on the surface. Tailings materials from the mill were deposited in the low spots in the dredged spoils. The conceptual model of this source was the water level in the tailings fluctuated on a seasonal basis. To verify this assumption, the stream channel was re-established at a level lower than the bottom of the tailings and the site was re-evaluated. The second phase was to evaluate the water level in the mine pool which extended into the mountain over 6 km. Wells were drilled and levels mapped over a one-year time frame. In the spring some of the wells had artesian flow yet none of the mine openings were flowing. Therefore, the USEPA surmised that the water must be flowing directly from the mine into the alluvium. Further investigation revealed numerous hydraulic connections via fractures in the bedrock. A tracer study was initiated and a major fault discovered (USEPA, 1995a). Attempts were made to seal the fault through injections into the mine pool. As a last resort, a treatment plant will be constructed and water from the mine pool will be treated and discharged (USEPA, 2002h). The major lesson here is that an iterative cycle of assessment and remediation was the most efficient process at this site. In addition, given the constraints of current technologies and tight budgets, only so much can be done.

<u>X Mine</u>

References to this example were removed because of extreme political sensitivity at this time.

<u>Yak Tunnel</u>

The Yak Tunnel is the primary source of ARD in the mining town of Leadville, Colorado. Mining in the area began in 1859 with the discovery of placer Au in California Gulch followed by Ag and Pb discoveries in the 1870's. Area mines produced significant quantities of Zn, Pb, and Cu through World War II, but mining activity has virtually ceased since then. However, over 120 years of mining, ore processing, and smelting, have resulted in approximately 2,000 waste rock piles at the California Gulch site. The history of the Yak Tunnel and the town of Leadville is rich with stories of various characters such as Meyer Guggenheim who combined many smelter operations in the area into the American Smelting & Refining Co (ASARCO). A second historic character, Horace Tabor, became one of the richest men in the world yet died penny-less. Another character was the unsinkable Molly Brown, named so after her voyage on the Titanic. Doc Holliday also had a few exciting moments in town. Thus as you can see, the history of mining and the Yak Tunnel/Leadville are intertwined. Conducting mine cleanup and building new ARD treatment plants was a challenge. Respect for the history turned the attitude of the local citizens from being averse to supporting ARD cleanup (USEPA, 2002i).

<u>Zortman/Landusky</u>

The Zortman and Landusky gold mines in north-central Montana became the responsibility of the US Bureau of Land Management (BLM) and the State of Montana after the parent company went bankrupt in 1999. Two critical issues had to be faced. First, the original chemical composition had changed over the life of the recent mine. In 1979 the ore was primarily an oxide: by the time of financial collapse the ore was much more sulfidic. Second, the bond was nowhere near sufficient to cover costs of reclamation. As part of the 1994 Environmental Impact Statement (EIS) for mine expansion, extensive static and kinetic tests of drill cores were analyzed (Miller and Hertel, 1997). In part due to the results of these tests, the mine expansion never went forward.

A field reconnaissance program was undertaken to determine if there was any material in the general area that could be used as non-acid generating cover material and to identify and characterize the sources of acid generating material. The program consisted of field observations with paste pH and with laboratory confirmation. The results for the leach pads showed that a very small number of samples would be considered non-acid generating with greater neutralizing potential than acid potential. “The added alkalinity in the leach pads is very soluble and therefore readily ‘available’ to neutralize any acid produced. Once consumed however, it is anticipated that the leach pads will become acidic as some on site already have” (Shaw, 2000).

Orville Kiehn, recent EPA retiree, warned regulators that insufficient money was being set aside for water treatment at this site. "This spring, Montana's legislature created a special fund for water treatment to make up for it, for the next 120 years, at a cost of more than $19 million" (Johnson, 2005).

Summary

In summary, the information provided in this paper is for the purpose of identifying both successes and failures in ARD in the United States. The problems extend far beyond that of the purely scientific into the realms of policy and politics. As was stated, my observations are mine alone and I am very open to corrections or updates. In conclusion, science, engineering and the environment in general is better served by open discussion of perspectives and working together on an international scale to deal with ARD issues.

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Table 1 Mining Sites from A to Z

Mine	Challenge	Lessons learned	More information
Argo Tunnel, CO	Inaccurate flow measurements	Plant retrofits are very	www.epa.gov/region08/superfund/sites/co/clrck www.cdphe.state.co.us/hm/ClearCreek/
Beal Mountain, MT	Discharge of cyanate phytotoxic	A new method for analyzing cyanate is needed	http://www.mpi.org.au/campaigns/cyanide/observations_cyanide
Chalk Creek, CO	Remote draining abandoned mine	In-mountain diversions reduce load	www.epa.gov/region08/community_resources/steward/ cbepnews/new9-98.html#tool
Ducktown /Copper Basin, TN	Quality, quantity and flow paths of all waters	Characterize the flow before agreements	http://www.epa.gov/region4/waste/copper/index.htm
Elizabeth, VT	Historic mine from 1700's - 1900's		www.epa.gov/superfund/accomp/factsheets05/elizabeth.htm
Ferris-Haggerty, WY	Neutral pH drainage inaccessible in winter	Place the bioreactor underground	
Gilt Edge, SD	What water treatment	Lime treatment is cost-effective	http://www.epa.gov/region8/superfund/sd/giltedge/
Henderson, CO	Threatened species thrived in tailings pond	Adopt the Boreal toad as a mine mascot	http://www.climaxmolybdenum.com/WorldwideLocations/USA_Colorado_Henderson.htm
Iron Mountain, CA	Negative pH drainage	Multiple financial mechanisms	http://yosemite.epa.gov/r9/sfund/overview.nsf/0/7a8166ef298804808825660b007ee658?OpenDocument
Jerrit Canyon, NV	Mercury emissions from refractory ore	Voluntary controls can work	
Kennecott, UT	Selenium in groundwater	In situ biological treatment	www.epa.gov/region08/superfund/sites/ut/kennes.html
Leviathan, CA	Treatment at a remote location	Store winter drainage for summer treatment	http://yosemite.epa.gov/r9/r9press.nsf/ffd3527d09daec14882568b70065a5cd/8f46dac10f78fadc8825699f006142ae!OpenDocument
Mogul, CO	Plugging lower mine increased load		www.co.blm.gov/mines/upperanimas/upperanimas.htm
New World, MT	Mine adjacent to National Park	Purchase the proposed mine	http://www2.nature.nps.gov/YearInReview/yr_rvw96/chapter6/newworld.htm
Ophir, CO	Drinking water impacts	Source water protection	http://www.restorationtrust.org/ARDI_sum.pdf
Pinto Creek, AZ	Overload tailings w/waste rock stability issues	Good designs are better than good remediation	http://www.pinalcreekgroup.com/
Questa, NM	Waste rock stability		http://www.epa.gov/Arkansas/6sf/pdffiles/molycorp.pdf
Rain Mine, NV	Acid rock at only 15% possible NAP	Special handling of all NAP necessary	www.mining-technology.com/projects/index. http://imcg.wr.usgs.gov/usbmak/mt1.html
Summitville, CO	Recent cyanide heap failure	On-site water-balance	
Tintic District. (Eureka) ,UT	Lead carbonate very bioavailable	Moving a town can be more problematic than moving piles	http://www.epa.gov/region08/superfund/sites/Eureka_Fact_Sheet.pdf
UraVan, CO	Rafinate ponds in town	Move town	www.epa.gov/Region8/superfund/co/uravan/index.html
Wellington-Oro, CO	Fluctuating water levels underground	Design and construct in incremental steps	http://www.epa.gov/Region8/superfund/co/frenchgulch/
X Mine	Century old mine		
Yak Tunnel, CO	Historic town in the middle of 200 mines	Make the waste piles an historic asset	www.epa.gov/region08/superfund/sites/co/calgulch
Zortmann / Landusky, MT	Predicted no ARD Inadequate bond	Modify bonding procedures	www.robertsongeoconsultants.com/papers/publicationlist. asp