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Project Summary

Characterization of Mine Leachates and the Development of a Ground-Water Monitoring Strategy for Mine Sites

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The total number of active and inactive mining sites in the United States has been estimated to be as high as 82,000. The 20,000 active mining sites currently process an estimated 1.5 billion tons of ore per year and the cumulative quantity of mine waste that has been produced has been estimated to be 50 billion tons. These wastes are usually discarded in waste piles, tailings basins, and depleted heap leaching pads. Although the adverse environmental impacts of mine waste leachates and acid mine drainage on surface waters have been widely documented, the impact of mine leachates on ground water is poorly understood. One of the factors that contributes to this situation is the fact that the United States does not have a national strategy for monitoring of mining sites.

When the Resource, Conservation, and Recovery Act (RCRA) program was initially developed, seventeen industries were classified as generators of non-hazardous wastes and exempted from the ground-water monitoring requirements. One of these industries was mining because the wastes were considered to have a low toxicity despite their large volume. It was subsequently determined that mining wastes may pose an unacceptable environmental risk if they are not properly managed. However, several issues limited the development of an effective ground-water monitoring strategy:

1. The composition and environmental behavior of mine waste leachates is poorly understood.

2. The problem of how to effectively sample the large areas covered by tailings ponds, that range in size from several acres to several thousand acres, has never been addressed.

3. The parameters that should be monitored in ground water adjacent to mine waste disposal sites to detect fugitive mine waste leachate have not been selected and evaluated.

The objective of this research project was to develop a better understanding of the composition of mine waste leachates and to identify cost effective ground-water monitoring parameters that could be incorporated into a monitoring strategy to reliably detect the migration of contaminants from hard rock mining operations.

Approach

Information used in this study was obtained from reports and data submitted to state regulatory agencies as part of routine, ongoing monitoring programs at mining facilities in the southwest United States. This effort focused on gold mines in Nevada that utilize cyanide heap leaching technology and copper mines in Arizona. These operations were selected because (1) cyanide heap leaching is the fastest growing sector in the mining industry and the high concentrations of cyanide used in this process are a potential environmental concern and (2) approximately 80 percent of the mining activity in the country is associated with gold and copper mining. This approach to data collection produced a larger project database that was more representative of the hard rock mining industry than a detailed investigation at a single site.

The data collection effort produced monitoring records, ranging from 1 to 15 years in length, for 30 heap leaching facilities in Nevada and five copper mines in Arizona. Monitoring locations varied between sites but usually included several locations in the recirculating heap leaching systems (barren ponds and pregnant ponds), tailings disposal ponds, and ground-water monitoring wells upgradient and downgradient of each mine. More than 300 quarterly surveys of mine leachates and 500 quarterly surveys of ground water in the vicinity of mining operations have been compiled and evaluated in this study. Each of the surveys generally included complete geochemical cation analyses, complete geochemical anion analyses, a trace metal scan, and cyanide (heap leaching sites only).

Results

The compiled monitoring data illustrated several properties of mine leachates. First, the individual constituent concentrations are highly variable and frequently display a non-normal distribution. Second, as many as 31 mine leachate constituents (8 geochemical parameters, 19 trace metals, phosphate, pH, total dissolved solids, and cyanide) may be present at concentrations above environmental screening levels. Third, a small set of geochemical parameters are always the most abundant ions in the leachates and usually represent 90 to 95 percent of the total dissolved solids concentration.

Since the leachate constituents are all naturally occurring substances that are not uniquely characteristic of mine waste, the project focused on the use of multiple ion chemical signatures to uniquely characterize the mine leachates. The parameters chosen for this purpose were the common geochemical ions of calcium, magnesium, sodium, potassium, chloride, sulfate, and alkalinity. These ions were selected because (1) they were repeatedly present in mine leachates at high concentration, (2) they represented more than 90 percent of the total dissolved solids concentration of mine leachates, and (3) they had previously been used to successfully characterize ground water and other waste leachates. An example of the graphical fingerprint pattern developed for the tailings leachate at the Cortez Gold Mine is shown in Figure 1. Despite the variable concentrations that had been reported, the normalized results (actual concentration divided by total dissolved solids concentration) from the pregnant pond, barren pond, tailings solution, and tailings reclaim water at this site produced a consistent sulfate-rich, alkalinity-poor fingerprint for these leachates. The reproducibility of this fingerprint was estimated by regression analysis to be 98 percent. Another property of the mine leachate fingerprint illustrated in Figure 1 is that it is distinctly different from the regional ground water fingerprint. Based on these properties, it was postulated that the geochemical fingerprint would provide a mechanism to uniquely characterize mine leachates at their source and monitor their migration into the environment.

The monitoring data from each selected mine site were used as a series of case studies to evaluate the feasibility of fingerprinting mine leachates with geochemical parameters. The results demonstrated that the leachates at each mine had a distinctive geochemical composition that displayed the following properties:

1. The shape of the fingerprint varied from mine to mine but the same small set of geochemical parameters defined a consistent pattern in 26 case studies.

2. Monitoring results from multiple locations at the same mine produced identical geochemical fingerprint patterns.

3. The reproducibility of individual geochemical fingerprint patterns ranged from 70 percent to 99 percent with an average of 91 percent across all case studies.

4. The mine leachate fingerprint was consistently and distinctly different from the geochemical fingerprint of ground water upgradient of each mining operation.

This set of observations suggests that the set of geochemical parameters can be used in a monitoring program to uniquely characterize mine leachates at their source and differentiate them from regional ground water.

Attempts were also made to fingerprint mine leachates with trace metals because of concern regarding these contaminants. However, it was not possible to define a consistent trace metal fingerprint in the leachates. The reproducibility of trace metals distributions was usually less than 30 percent which is considerably lower than the 90 percent repeatedly observed for geochemical parameters. These results suggest that trace metals would not be useful for uniquely characterizing mine waste leachates.

The information compiled during the study also provided insight into the behavior of mine leachate geochemical fingerprints. One particularly useful study was a column study performed with Twin Butte tailings leachate. The data from this laboratory study demonstrated that the geochemical fingerprints for mine leachates will retain their unique chemical identity as they migrate through the subsurface. In addition, the geochemical parameters that define the fingerprint migrated faster than the trace metals present in mine leachate. The case study field monitoring data provided additional corroboration of this observation. The tailings leachate fingerprint was identified downgradient of four copper mines and the heap leaching process solution fingerprint was identified downgradient of eight gold mining facilities included in this study. These results suggest that the geochemical fingerprint acts as an internal tracer and can be used to monitor the migration of mine leachates in the environment.

Proposed Mine Site Monitoring Strategy

The assessment of routine monitoring data from 26 gold mines in Nevada and 4 copper mines in Arizona demonstrates that mine leachates have a characteristic geochemical fingerprint. Furthermore, the geochemical fingerprint was shown to migrate faster than the trace metals present in mine leachates and to maintain its identity as the leachates migrates under both controlled laboratory and field conditions. These results suggest the possibility of using a multi-phased ground-water monitoring strategy for mine sites:

1. In the first phase, mine leachates can be characterized at their source with a short list of geochemical parameters (calcium, magnesium, sodium, potassium, sulfate, chloride, alkalinity, and total dissolved solids). These data will be sufficient to define the fingerprint of the leachate.

2. In the second phase of the strategy, it is suggested that the set of geochemical parameters used to define the source fingerprint can function as effective detection monitoring parameters. As long as the more mobile, characteristic fingerprint of the leachate is not detected, there is no need to monitor for the less mobile and less abundant constituents of the leachate. The site would remain in a low level detection monitoring mode.

3. In the third phase, when the more mobile, more abundant, and characteristic geochemical ions have been detected, there is a reason to believe that a leakage event or spill has occurred. At that time, the program would be expanded to monitor for the less abundant and less mobile constituents of mine leachates (trace metals).

This phased approach to monitoring is functionally similar to that developed for use at RCRA sites. Based on properties illustrated in the case studies, it would provide characterization of the mine leachates at their source and early detection of their migration into the environment. This approach should also provide more effective identification of leakage events and lower monitoring costs.

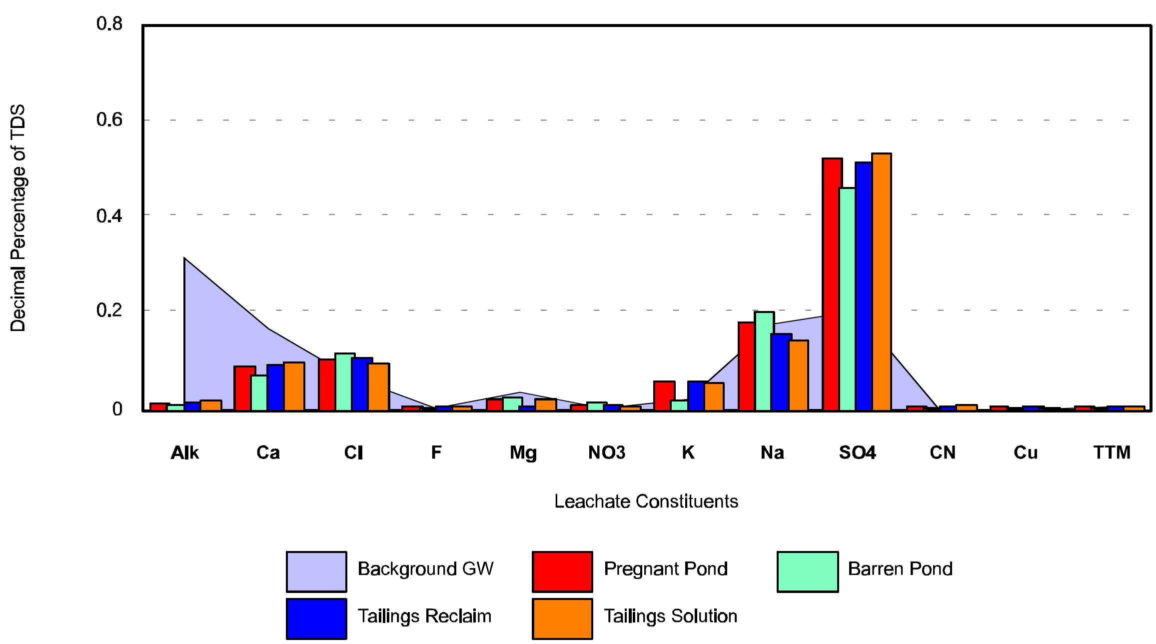

Figure 1. Comparison of the geochemical fingerprint for mine leachates at the Cortez Gold Mine with the regional ground-water fingerprint.