

## SECTION C

# Research on Hard-Rock Mining in Arid Southwest Alluvial Basins

Hard-rock mining for copper, gold, silver, and other minerals has been an important part of the economy of the southwestern United States for more than a century. Unfortunately, historical mining practices have contaminated ground water and surface water at many abandoned and active mine sites. Leakage and runoff from unlined wastewater ponds, heap-leach areas, tailings, and other contaminant sources can migrate from areas of hard-rock mining into regional alluvial aquifers that provide the sole source of drinking water to many local communities. Contaminants may also discharge to limited surface-water supplies, either by direct runoff or by ground-water discharge to streams. The Globe-Miami Mining District in Arizona has been a major copper-producing area since the late 19<sup>th</sup> century. Past mining practices there have contaminated the regional alluvial aquifer and a perennial stream in the area with acidic, metal-laden mine wastes. The U.S. Geological Survey (USGS), in collaboration with researchers at the University of Arizona and Arizona State University, is studying this contamination with the overall objective of increasing scientific understanding of the controls on transport of metals and other inorganic contaminants. This knowledge, and new methods and models developed as part of these investigations should have considerable transfer value to other similarly contaminated sites.

Since 1984, the USGS has monitored the distribution of contaminants in the Globe area by sampling and analyzing ground water, surface water, aquifer materials, and streambed sediments. The chemical and physical processes that control contaminant movement and fate are being examined using laboratory experiments, ground-water flow models, inverse- and forward- geochemical models, stream-tracer experiments, and stream-transport modeling.

A plume of acidic, contaminated ground water is moving northward through the alluvium beneath the major stream in the basin, Pinal Creek. Acidic ground water is neutralized mainly through the dissolution of carbonate minerals. As the pH of ground water increases, the dissolved concentrations of trace metals, such as copper, cobalt, nickel, and zinc, decrease through the pH-dependent sorption to iron hydroxide (Stollenwerk, 1994). The oxidation and precipitation of iron hydroxide in the aquifer are coupled, at least in part, to the reductive dissolution of manganese oxide. Recharge to the basin is quite low in most years. Intense rainfall and (or) snowmelt in some years do result in significant recharge that contributes to substantial dilution of contaminants. Other factors that contributed to remediation of contamination was the removal in the early 1980's of the wastewater pond that was a significant source of contamination, and pumping of contaminated ground water that began in the mid 1980's. All of those factors contributed to a significant decrease in the concentrations of many of the metals; however, the pH in the acidic part of the plume remains near 4. Contaminated ground water is not in a state of geochemical equilibrium with selected solid phases in the aquifer (Stollenwerk, 1994; Brown and others, 1998). Because of this, knowledge of reaction rates is necessary to better understand the movement and fate of contaminants in the basin. One goal of laboratory and field activities is to determine appropriate site-specific rates for carbonate and manganese-oxide dissolution reactions. Preliminary results indicate that field dissolution rates of calcite were considerably lower than rates measured in laboratory experiments by other investigators. A three-dimensional ground-water flow model of the aquifer system is being developed to better understand ground-water flow patterns and interaction of ground water and surface water. The use of chlorofluorocarbon-derived ground-water ages to constrain simulated travel times and velocities should increase the accuracy and reliability of model parameter estimates. Sampling for a variety of other isotopes and dissolved gases should help to better define recharge areas and mixing of contaminated and uncontaminated ground water.

Slug tests and field investigations of ground-water and surface-water interactions should provide information on the hydraulic characteristics of discrete layers of stream alluvium and further improve the estimates of model parameters.

In the northern part of the basin, contaminated ground water discharges to Pinal Creek in the 6-km perennial reach near the downstream end of the basin (where the aquifer is truncated by impermeable rock formations). Carbon dioxide degassing to the atmosphere in the perennial reach causes the pH of surface water to rise from about 6 near the beginning of the perennial flow to about 8 near the basin outlet (Choi and others, 1998). Movement of stream water into shallow ground water beneath the channel (hyporheic zone) increases the pH and dissolved oxygen in shallow ground water, resulting in the enhancement of the precipitation of manganese oxide coatings onto streambed gravels. Enhanced precipitation of manganese oxides in the hyporheic zone cumulatively removes approximately 20 percent of the load of dissolved manganese in the stream (Harvey and Fuller, 1998). Trace metals such as nickel, cobalt, and zinc are also removed in the hyporheic zone by co-precipitation or sorption onto manganese oxides. Laboratory experiments confirmed that precipitation of manganese oxides in the hyporheic zone is microbially mediated, that microbial activity increases with increasing pH, and that higher amounts of pre-existing manganese-oxide solids increase the rate of manganese precipitation.

One goal of ongoing research is to improve the design of stream-tracer experiments to increase the reliability of those experiments as a tool to characterize rates of metal removal at various sites (Wagner and Harvey, 1997). Another goal is to use our detailed understanding of processes at Pinal Creek to develop and test improved models of surface- and ground-water interactions and chemical transport that are transferable to other areas with different physical and chemical characteristics.

## References

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