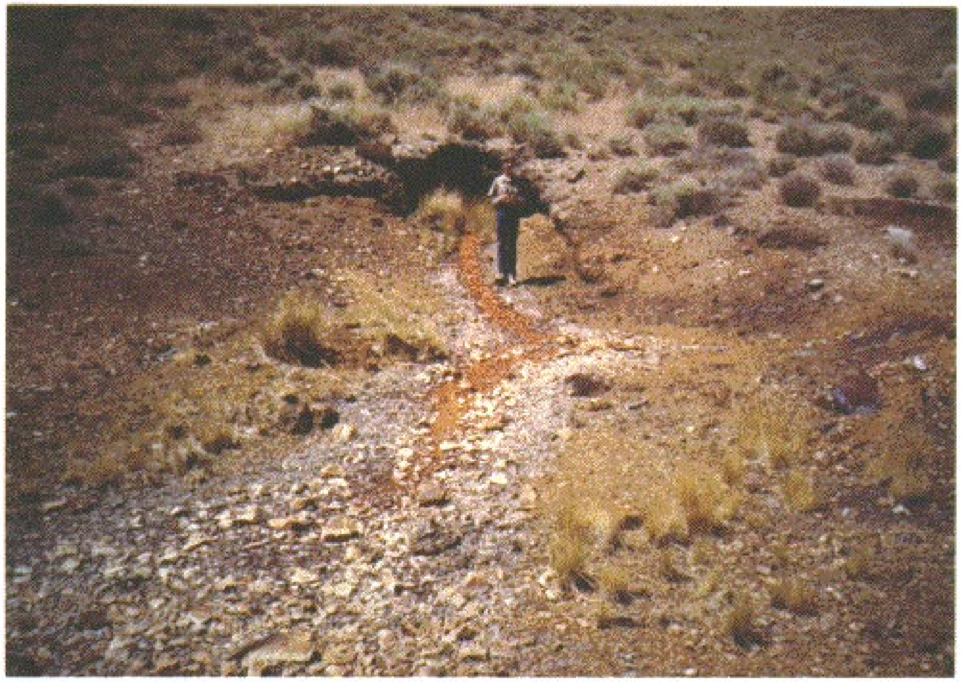
Water Quality at Inactive and Abandoned Mines in Nevada



Nevada Bureau of Mines and Geology Open-File Report 95-4

Nevada Bureau of Mines and Geology
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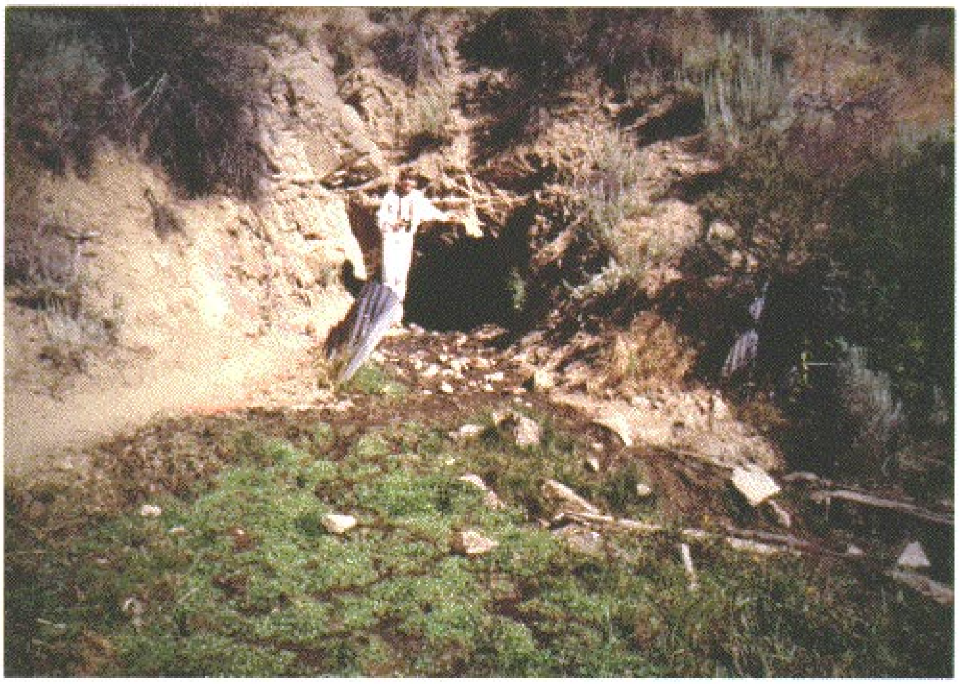

The upper photograph is locality PE-419, on the east side of Majuba Hill in Pershing County. Here a small amount of water flows from an adit and then disappears into the ground a few meters away. Iron-oxide cemented rock, which attracted the miners to dig this adit, is evidence of naturally occurring acid-rock drainage. The lower photograph is locality EL-13, near Mountain City in Elko County. Water flowing from this adit meets drinking water standards, supports the growth of watercress, and is drunk by wildlife and livestock.

Water Quality at Inactive and Abandoned Mines in Nevada

Report of a Cooperative Project among State Agencies

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Nevada Bureau of Mines and Geology Open-File Report 95-4

for the Western Governors' Association

written by

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The Nevada Bureau of Mines and Geology (NBMG) is a research and public service unit of the University of Nevada and is the State Geological Survey. NBMG is part of the Mackay School of Mines at the University of Nevada, Reno. NBMG scientists conduct research and publish reports on mineral and energy resources, engineering geology, environmental geology, earthquakes and other hazards, groundwater, and geologic mapping in Nevada. In addition, NBMG provides special services in the areas of analytical geochemistry and assay standards, mineral and rock identification, sample curation, earth-science education and in-service teacher training, continuing education for professional geoscientists, geologic and geotechnical information, mineral and energy resource information, historical information, geographic information systems, and electronic databases.

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The Nevada Division of Minerals, a unit of the Department of Business and Industry, is responsible for administering programs and activities to promote, advance, and protect mining and the development and production of petroleum and geothermal resources in Nevada. The division's mission is to administer programs and activities to further the responsible development and production of the state's mineral resources to benefit and promote the welfare of the people of the state. The Commission on Mineral Resources establishes mineral-related policy for the Nevada Division of Minerals. The division's Bureau of Industrial Relations, Public Affairs and Administration compiles annual data on all active mines, maintains the state's mine registry, produces educational documents and materials concerning many aspects of the minerals industry, and participates in governmental activities affecting policies and laws concerning the minerals industry and resource development. The Bureau of Regulation is responsible for permitting, inspecting, and monitoring all oil, gas, and geothermal drilling activities on both public and private lands in Nevada and for monitoring production of oil, gas, and geothermal resources to insure proper management and conservation. The Bureau of Abandoned Mine Lands provides for public safety through programs to identify and rank dangerous conditions, which resulted from past mining practices, to secure dangerous orphaned sites, and to educate the public to recognize and avoid those hazards. The Bureau also administers the state's reclamation bond-pool program.

The Nevada Bureau of Mines and Geology and the Nevada Division of Minerals thank reviewers of this report: Debra Struhsacker (Environmental Permitting Consultant), Tom Leshendok (U.S. Bureau of Land Management), David Gaskin (Nevada Division of Environmental Protection), and Joe Tingley, Hal Bonham, and Dick Meeuwig (Nevada Bureau of Mines and Geology).

CONTENTS

EXECUTIVE SUMMARY

This report presents new data and the compilation of existing data on water quality at inactive and abandoned mines in Nevada. Evaluation of these data helps assess the need for additional investigations of inactive and abandoned mines. In addition, this report presents data on water quality at open pits that began filling with water within the last two decades.

This report focuses largely on water-quality issues, such as acid-mine drainage, that are the direct result of groundwater and surface water interacting with rocks exposed during mining. At the sites visited in Nevada, few localities where water flows from inactive or abandoned mines have acid-mine drainage problems, and of these, few have high flow rates.

Water quality generally is predictable from geological knowledge about ore-deposit type and mineralogy of ore and associated wall rocks. Acidic, metal-laden waters occur predictably at mineral deposits that contain significant quantities of pyrite (iron disulfide) and at which most of the acid-buffering capacity of the wall rocks had been destroyed by the natural ore-forming process. Wall rocks at many pits at which waters have been sampled contain substantial amounts of calcite, which tends to buffer the pH at slightly basic conditions.

Evidence of the occurrence of natural springs of acidic, arsenic-rich, metal-bearing waters, which flowed prior to any mining activity, is found locally in surface rocks cemented by iron oxide.

On the basis of counting adits and shafts shown on all 7.5-minute, 1:24,000-scale topographic maps covering the state, field-based estimates of the numbers of adits and shafts that do not appear on topographic maps, field measurements of rates of water flow from adits, and new chemical data in this report, we estimate that the number of inactive and abandoned mine sites that may be of concern regarding acid-mine drainage is likely to be fewer than 100, or less than 0.05% of the total number of inactive and abandoned mine sites in the state (estimated to be 225,000 to 310,000). The number is low largely because the climate in most of Nevada is arid.

The impacts on groundwater and surface water from ore processing, such as use of mercury and cyanide, and from other industrial activity at mining and milling sites, such as waste disposal, are not considered in this report but deserve further study.

Numerous sites, estimated to be approximately 50,000, present varying degrees of physical safety hazards to Nevada residents and visitors. The Division of Minerals operates programs to identify and rank those sites and secure them to avoid accidental harm to passers by.

To begin to set priorities for water-quality remediation, investigations are needed at sites not visited during this study. Follow-up measurements of flow rates and dilution downstream from sites identified in this study as having potential problems also are warranted, as are investigations of contamination from ore processing and other industrial activities at the sites. Knowledge of mineral-deposit type will be helpful in setting priorities for follow-up investigations and for possible cleanup. In particular, those deposits with high concentrations of iron disulfide and low concentrations of acid-buffering minerals are more likely to be problems than others. In Nevada, the deposits of greatest concern are quartz-alunite (high sulfidation) precious metal deposits in volcanic rocks and porphyry copper and porphyry copper-molybdenum deposits in plutonic rocks. Massive sulfide deposits, which meet these criteria as well, are uncommon in Nevada.

INTRODUCTION AND BACKGROUND

This report presents the results of a cooperative project among state agencies to characterize potential water-quality and related environmental concerns about inactive and abandoned mines in Nevada. The work has been supported in part by a grant from the U.S. Environmental Protection Agency, through the Western Governors' Association.

Three State agencies have primary responsibilities for issues concerning mine wastes. The Nevada Division of Minerals within the Department of Business and Industry helps to protect the public against physical hazards of abandoned mines. The Bureau of Mining Regulation and Reclamation within the Department of Conservation and Natural Resources is the regulatory agency responsible for mine reclamation and environmental compliance at existing mines. The Nevada Bureau of Mines and Geology, which is the State Geological Survey and a research and public service unit of the University of Nevada, collects and evaluates data and information on geology, hydrology, resources, and natural hazards of the State.

The Nevada Division of Minerals has operated the State's abandoned mine lands program since legislation was adopted in 1987 to identify, rank the degree of hazard, and secure mine sites that are no longer operating. Since the inception of the program, over 2,400 sites have been secured from threat of physical hazard. It is estimated that some 50,000 sites in Nevada pose varying degrees of physical safety hazard to the public. Field investigations have also yielded information that will be useful in determining the possibility of sites contributing to surface and groundwater contamination, such as acid mine drainage or excessive arsenic. Mines in Nevada have produced a variety of metals, including gold, silver, copper, iron, lead, tungsten, and zinc. Many mine openings were developed to explore for metals, but were never operating mines. Arsenic and mercury, potentially toxic elements which are often found with deposits of gold and silver, were also produced locally. Other potentially toxic elements of local concern include boron, cadmium, selenium, and thallium. There are over 500 historic mining districts scattered throughout the State (Tingley, 1992; Tingley and others, 1993), and sites within the Division of Minerals and Nevada Bureau of Mines and Geology databases are located within most of these mining districts.

Because Nevada is the most arid state in the United States, few abandoned mines appear to pose a significant threat to streams, rivers, lakes, or local groundwaters. From the total of approximately 6,600 abandoned mines that have been investigated through the summer of 1995, the Division of Minerals has identified 72 sites (1.1%) at which water was present in or near the mines.

We have used various data sets, including the U.S. Geological Survey's Mineral Resource Data System and the Nevada Bureau of Mines and Geology's chemical data sets on ores (from over 4,000 mines throughout the State) and country rocks, to determine which deposits, among the 72 identified by the Division of Minerals, are known to contain, or are likely to contain, potentially toxic elements and are likely to result in acid mine drainage.

Additional field examinations and sampling of rocks and waters have been undertaken as part of this project to fill in gaps in current knowledge. Because the winter-spring rainy season of 1994-1995 was one of the wettest on record in the State of Nevada, the summer of 1995 was an ideal time for sampling waters at inactive and abandoned mines.

Inactive and abandoned mines are not the only environmental concern regarding mining. Nevada is in the midst of the largest gold mining boom in the history of the United States (Dobra and Thomas, 1995). Nevada's output in 1994 (6.8 million troy ounces valued at $2.6 billion) was 64% of U.S. production and 10% of the total world gold production (Nevada Division of Minerals, 1994; Price and others, 1995). Sound reclamation plans are in place to deal with the huge volumes of overburden and mine wastes that are being generated and with the fate of surface water that will collect in pits after mining ceases. Research is ongoing to help predict the eventual chemical compositions of waters in the pits (e.g. Shevenell and others, 1995). Water-chemistry data collected as part of this project and contributed to the Nevada Division of Environmental Protection, Nevada Division of Minerals, and Nevada Bureau of Mines and Geology by operating companies can be used to help calibrate modeled pit water compositions. These new data will allow for better prediction of chemical interactions at mine sites throughout the Basin and Range.

This project consists of three tasks. The first task addresses water-quality issues at inactive and abandoned mines. The second task involves collection of preliminary data on water quality in pit lakes, which likely will change over time. The third task uses geographic information systems (GIS) to begin to evaluate the magnitude of possible environmental problems associated with inactive and abandoned mines.

TASK 1: Collect and analyze data that will help to set priorities for environmental cleanup of abandoned mines.

During the last eight years the Nevada Division of Minerals has inspected over 6,600 abandoned mine sites throughout Nevada, focusing on areas near population centers. Of these, 72 (listed in Table 1 and located on Figure 1) were identified as containing water, either in shafts and adits or flowing from adits. Staff of the Nevada Bureau of Mines and Geology and the Nevada Division of Minerals reviewed photographs and data sheets on these sites and selected a subset of sites for possible water sampling.

Of the 72 sites, 20 were eliminated because the geology was similar at nearby, sampled sites. For example, we sampled only two of the nine shallow brine wells in the Leete district. Because the geology is similar throughout the district, the two samples that we did take, from two ends of the district, should be representative. During our examinations in July and August 1995, we found 18 sites without water. Because the winter of 1994-95 and the spring of 1995 were exceptionally wet in Nevada, it is unlikely that surface water flows regularly from natural or man-made springs at any of these sites. Reasons for not sampling certain sites are listed in Table 1.

Information was accumulated from available geologic literature and databases on mineralogy and ore-deposit types (probable mobilization of trace elements and acid-generating potential), country rocks (acid-buffering capacity), past production (for information on the scale of operations and metals produced), and known chemical compositions of samples previously collected from mine dumps and mine exposures. Some of this information is compiled in Table 1. In addition, we used topographic maps to determine which surface water would receive any drainage from the listed sites.

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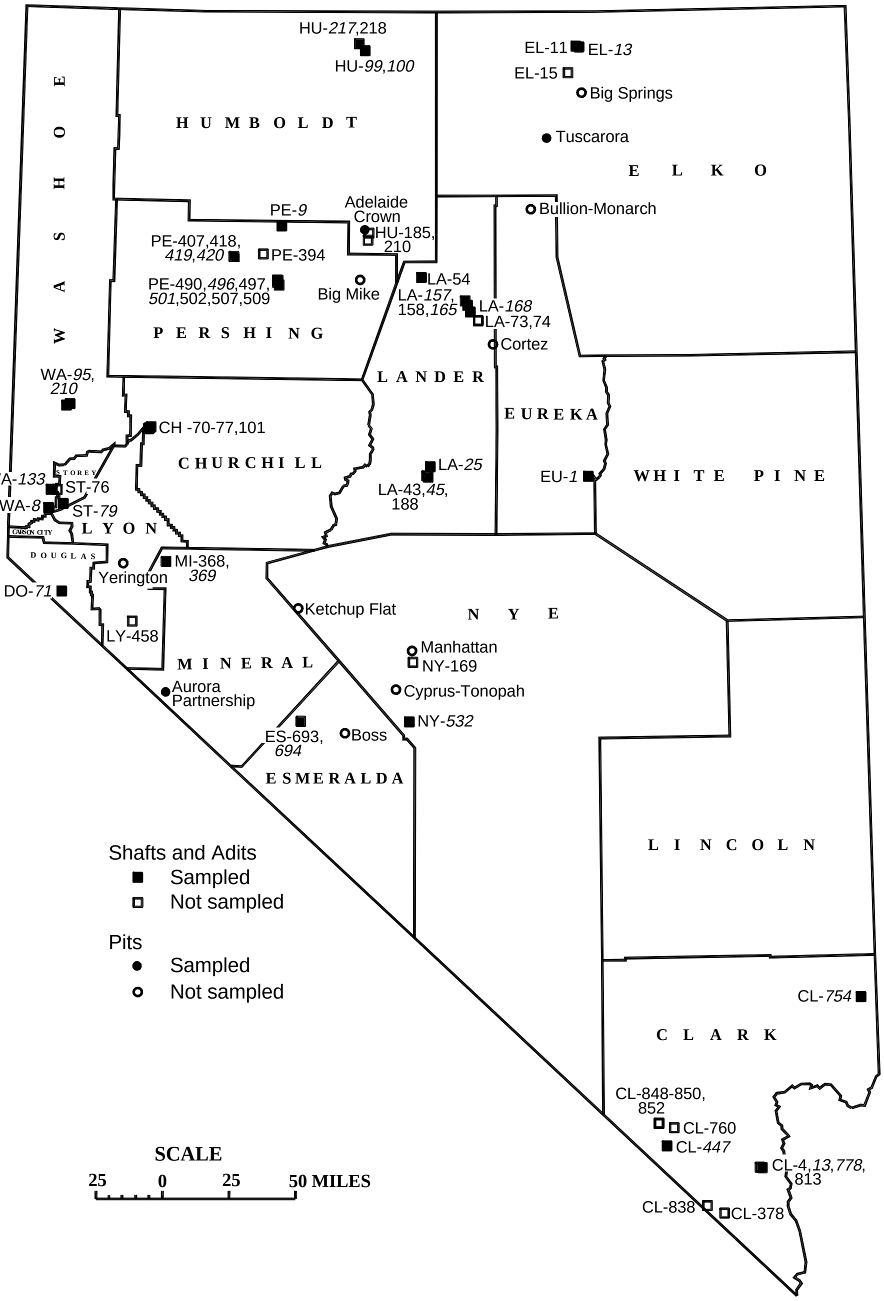

Figure 1. Locations of 12 pits (circles) and 72 abandoned mines (squares) investigated as part of this project. Filled symbols indicate locations where water samples were collected. Some sites overlap at this map scale.

Table 1. Geological characteristics of abandoned mines investigated as part of this project. Samples for which new data were collected as part of this project are listed in bold italics.

Location	Mineral-deposit type and features specifically relevant to water quality
Leete district ***CH-71 & 76,*** 70, 72, 73, 74, 75, 77, 161 Churchill County	Saline minerals: salt (NaCl) and minor borate. Sites consist of nine shallow wells (5 to 6 feet to water) dug to produce salt from brine at the edge of a playa (the Fernley sink). The two wells sampled are at both ends of the area of salt production. Wild burros drink from a former salt well next to well CH-71. The district was active from 1871 to 1913. Reference: Willden and Speed (1974).
Crescent district CL-378, 838 Clark County	Polymetallic vein with Au, Ag, Cu, and Pb. Gneiss and quartz monzonite wall rocks are affected by argillic, sericitic, and propylitic alteration. Tetrahedrite occurs in veins. Possible porphyry Cu-Mo target at depth. CL-378 is on private property and has a locked door on the adit. Water is reported from a winze in the adit. No water flows from the adit or in the stream nearby. Production was minor (less than 1,000 tons of ore, judging from the size of the dumps) from both mines. CL-838 was dry when visited in August 1995. Surface water near CL-378 would flow ultimately into the Colorado River; surface water near CL-838 would flow into Ivanpah Valley. Reference: Longwell and others (1965).
Eldorado district ***CL-***4, ***13, 778,*** 813 Clark County	Polymetallic vein with Au, Ag, Cu, Pb, and Zn. Low sulfide, quartz-calcite veins. Quartz monzonite porphyry wall rocks are affected by argillic and propylitic alteration. Production from the two shafts that were sampled was minor (<200 tons each), but overall the mines in this part of the district produced well over $2,000,000 in metals (Au, Ag, Cu, and Pb) from 1857 to approximately 1942. Exploration drilling was in progress in August 1995. Surface water in this area would flow into the Colorado River. Reference: Longwell and others (1965).
Goodsprings district ***CL-447,*** 760, 848, 849, 850, 852 Clark County	Base metal replacement. Zn, Pb, Cu, Ag, and Au. Limestone wall rocks should buffer any acid generated by oxidation of sulfides. Some Au veins occur in quartz-feldspar porphyry intrusions and may contain sufficient pyrite to be an acid-mine drainage problem. In most of the ore, however, low pyrite content would suggest little acid generating capacity. CL-760 appears to be a spring dug out with a tunnel. CL-848 through 852 contained no water when visited in August 1995. Water was sampled from a shaft of the Iron Gold mine. Production from this mine was likely on the order of 1,000 tons of ore, but overall production in the district was substantial, more than 150,000 tons of Zn, Pb, and Cu ore from 1855 to approximately 1964, plus some Au from 1990 to 91. Surface water near CL-447 would flow into Ivanpah Valley. Reference: Longwell and others (1965).
Bunkerville district ***CL-754*** Clark County	Mafic intrusive Ni-Cu-Pt-group elements (PGE). Pyrrhotite is abundant in the host rocks (hornblende gneiss and hornblendite), which are metamorphosed ultramafic rocks. Water from the lower adit of the Great Eastern mine was sampled. Underground workings include approximately 2,200 feet of drifts and crosscuts, but occurrence of ore was erratic. Cu and Ni were produced from the district from the 1890s to 1942, and this mine was active from 1915 to 1942. Surface water in this area would flow into the Virgin River. Reference: Longwell and others (1965).

Table 1. (continued)

Location	Mineral-deposit type and features specifically relevant to water quality
Veta Grande mine ***DO-71*** Douglas County	Variation on quartz-adularia precious metal. Quartz vein with low sulfur content, hosted in interbedded metavolcanic and metasedimentary rocks; minor Au and Ag production. Surface water in this area would flow into the Carson River. The Bureau of Land Management is investigating contamination from ore processing at this site. Reference: Moore (1969).
Rio Tinto mine ***Tailings*** EL-11 Elko County	Massive sulfide. Shale-hosted. Abundant pyrite. Primary ore minerals include chalcopyrite, sphalerite, and minor galena. Water from Mill Creek was sampled after flowing over and along the tailings piles. Limonite is abundant in the streambed. Water was not sampled from the shaft at EL-11 because no water was detected in this shaft. Water does occur in a two-inch vertical pipe down hill from EL-11 in the dry creek bed, but no equipment was available to sample from such a small-diameter well. Surface water in this area flows into the Owyhee River. Cu, Ag, and Au were the major metals mined from 1869 to the 1950s; most production was from 1931 to 1947. Reference: LaPointe and others (1991).
Mountain City ***EL-13***	Polymetallic vein(?). Calcite-veined phyllite occurs on the dump at this adit. No ore minerals are visible, although limonite does occur in some calcite veins. The dump contains less than 200 tons of rock, indicating that this mine probably was unproductive. Surface water in this area flows into the Owyhee River. Au and Ag were presumably the metals sought at this mine, although neither these nor typically associated trace elements are enriched in the sample collected from this site (see Table 5). Reference: LaPointe and others (1991).
Aura district EL-15 Elko County	Skarn, possibly with Cu, Pb, Zn, Au, and Ag. Shaft has been backfilled, and no water is visible at the site. The dump contains only a few tons of rock. No samples were collected from this site. Reference: LaPointe and others (1991).
Divide district ES-504, 505 Esmeralda County	Quartz-adularia precious metal (Au and Ag). Volcanic-hosted. Wall rocks are affected by sericitic and propylitic alteration. No flowing streams occur nearby. Reference: Albers and Stewart (1972).
Rock Hill district ***ES***-693, ***694*** Esmeralda County	Tungsten quartz vein. Contains pyrite, chalcopyrite, and scheelite. Host rocks include slate, siltstone, quartzite, and limestone. ES-693 is a tungsten placer that has been expanded into a borrow pit. Tungsten was produced from this district between approximately 1958 and 1979. Surface water in this area would flow into Columbus Salt Marsh. References: Albers and Stewart (1972), Stager and Tingley (1988).
Eureka district ***EU-1*** Eureka County	Base-metal replacement. Ag, Au, Pb, Zn, and Cu were produced in the district between 1864 and approximately 1988. Limestone wall rocks should buffer any acid generated. The adit is a small cut into conglomerate; little ore production could have come from this mine. Surface water in this area would flow into Diamond Valley. Reference: Roberts and others (1967).

Table 1. (continued)

Location	Mineral-deposit type and features specifically relevant to water quality
Buckskin-National ***HU-99, 100*** Humboldt County	Variation on quartz-adularia precious metal. Volcanic-hosted. Au and Ag were produced from this district between 1907 and 1941. This orebody has a higher than usual sulfosalt content for this type of deposit and has an overprint of near-surface acid leaching related to a former boiling water table. Wall rocks locally have little capacity for buffering acid. At HU-100, however, the volcanic host rock at the adit portal contains magnetite and has not been as thoroughly attacked by hypogene acid waters as have some other rocks in the district. Quartz pseudomorphs after calcite indicate that the hypogene system was not strongly acid. Surface water in this area flows into the Little Humboldt Valley and ultimately into the Humboldt River. References: Willden (1964), Vikre (1985, 1987).
National mine ***HU-217,*** 218 Humboldt County	Variation on quartz-adularia precious metal. Volcanic-hosted. Au and Ag were produced from this district between 1907 and 1941. Higher than usual sulfosalt content. Abundance of kaolinite implies conditions more acid than are typical of quartz-adularia systems. Some stibnite occurs in quartz-pyrite veins. A bulldozer had been used to shut the shaft at HU-218. Stream water appears to seep into a depression made or left by the bulldozer; this site was not sampled. At HU-217, which was sampled, the adit has been covered, but water seeps from the muck used to cover the adit. Limonite coats rocks for hundreds of meters downstream from this adit. Surface water in this area flows into the Quinn River. References: Willden (1964), Vikre (1985, 1987).
Gold Run district 210 Humboldt County	Base metal skarn and replacement. Au, Ag, Cu, Pb, and Zn. Limestone HU-185, wall rocks should buffer acid. HU-210 has apparently been backfilled by the land owner, and access through the Hot Springs Ranch has been cut off. HU-185, one of the declines at Adelaide, was dry in August 1995. Surface water in this area would flow into Pumpernickel Valley. The district was discovered in 1866. Reference: Willden (1964).
Reese River district ***LA-25,*** 43, ***45,*** 188 Lander County	Polymetallic vein with Au, Ag, minor Cu and Pb. Low sulfide content in ore. Wall rock is granodiorite. Iron precipitates occur in the stream channel at LA-25. Surface water in this area would flow into the Reese River. Au, with minor Ag, Cu, and Pb were produced at LA-25. Ag and minor Au were produced at LA-45. The district was active from 1862 to approximately 1903. Reference: Stewart and others (1977).
Battle Mountain ***LA-54*** Lander County	Polymetallic vein(?). Samples from dump include quartzite with calcite veinlets, pyrite-rich phyllite, and quartzite(?) altered to an assemblage of quartz, sericite, and pyrite. Surface water in this area would flow into the Reese River. Ag, Au, Pb, Zn, and Cu have been produced in this district from 1866 to the present. Reference: Stewart and others (1977).
Bullion district LA-73, 74 Lander County	Polymetallic vein. No water issues from adits at these locations. Surface water in this area would flow into Crescent Valley and the Humboldt River. Reference: Stewart and others (1977).

Table 1. (continued)

Location	Mineral-deposit type and features specifically relevant to water quality
Hilltop district ***LA-157,*** 158, ***165*** Lander County	Polymetallic vein. Au, Ag, Cu. Abundant arsenopyrite is reported from the district. At LA-165 wall rock is a sericitized, calcite-bearing feldspar porphyry cut by a quartz-limonite vein. At LA-157 the adit starts at the contact between Paleozoic chert and overlying gravel. Twenty meters downstream from where acid water from LA-157 enters the stream, the pH of the stream is 6.5 (measured with pH paper). At LA-158, pH is approximately 6 to 6.5. Surface water in this area flows into the Reese River. Although the district was active from 1882 to approximately 1934, peak years of Au and Ag production were from 1912 to 1920. Reference: Stewart and others (1977).
Gray Eagle mine Bullion district ***LA-168*** Lander County	Polymetallic vein. Au, Ag, Cu, Pb, and Zn. Dump contains samples of quartz-galena-sphalerite-pyrite-arsenopyrite(?) vein. Adit has been bulldozed closed. Water is seeping from the muck closing the adit into ponds in a storage shed. Limonite staining occurs in the seepage. Drums of cyanide compounds, which were previously reported from this site, have been removed. Surface water in this area flows into Crescent Valley and the Humboldt River. Production occurred from 1869 to the 1940s. Reference: Stewart and others (1977).
Wilson district (Pine Grove) LY-458 Lyon County	Polymetallic vein. Au, Ag, and Cu. The adit was dry in August 1995. Surface water in this area would flow into the Walker River. The district has been intermittently active since discovery in 1865. Reference: Moore (1969).
Mountain View ***MI-*** 368, ***369*** Mineral County	Polymetallic vein. Au, Ag, and Cu. Wall rock is limestone. Surface water in this area would flow into the Walker River. The district was discovered in 1908. Reference: Ross (1961).
Willow Springs NY-169 Nye County	Mafic intrusive Ni. Serpentinite with garnierite. Shaft appears to have been backfilled. Surface water in this area would flow into Big Smoky Valley. Reference: Kleinhampl and Ziony (1984).
Tonopah area ***NY-532*** Nye County	Polymetallic vein with Au, Ag, and Cu. Surface water in this area would flow into Big Smoky Valley. Peak years of Ag and Au production in the district were 1910 to 1914, although production is known from 1900 to 1948. Reference: Kleinhampl and Ziony (1984).
Keystone mine Mill City district ***PE-9*** Pershing County	Polymetallic vein. Ag, Pb, Zn, Cu, and Au were produced in the district from 1856 to 1966. Quartz veins occur in shale that contains abundant pyrite. Surface water in this area would flow into the Humboldt River. Reference: Johnson (1977).
56 Copper mine PE-394 Pershing County	Porphyry copper. No surface water is present at this location. The adit was dry for the first 20 meters in August 1995. Surface water in this area would flow into the Humboldt River. A small leach operation produced Cu in the 1970s. References: Johnson (1977); J. V. Tingley (personal communication, 1995).

Table 1. (continued)

Location	Mineral-deposit type and features specifically relevant to water quality
Majuba Canyon or Last Chance mine ***PE-407*** Pershing County	Polymetallic vein. Pb, Ag, Au. Galena occurs with calcite. Massive pyrrhotite-galena ore occurs on the dump. Andesite dike samples from the dump are weakly propylitized, indicating limited acid in the hypogene fluids. Ag, Pb, and Au were produced from 1905 to approximately 1943. Surface water in this area would flow into the Humboldt River. Reference: Johnson (1977).
Majuba Hill ***PE-***418, ***419, 420*** Pershing County	Porphyry Cu-Mo. Cu-arsenate minerals are abundant in the district and at PE-418, but PE-418 has been backfilled and is now dry. At PE-420 water from the adit is dammed by the dump into a 5 x 10 m pond, but no water flows in the streambed below. Similarly, uphill at PE-419, water from the adit leaves a trail of limonite staining for 15 m, then sinks into the dump but does not discharge below the dump. Site PE-419 was a spring, which ormed ferricrete (limonite-cemented colluvium). Ferricrete is approximately 1 m thick and rests on the dip slope on top of steeply dipping phyllite. Miners may have started the adit at the outcrop of the ferricrete, thinking it was gossan produced from the oxidation of massive concentrations of sulfide ore. Chips from obsidian arrowheads are present at PE-419; this natural spring of acid, limonite-depositing water was probably a source of water for Native Americans. Quartz-porphyry rhyolite from the intrusive complex at Majuba Hill occurs on the dump. Limonite, after pyrite, occurs in the rhyolite, along with small amounts of molybdenite(?). No copper minerals were found on the dumps at PE-419 or 420. The rhyolite is altered to an assemblage of quartz, sericite, and pyrite. Surface water in this area would flow into the Humboldt River. Mining was active, mostly on the western side of the hill, from 1875 to 1945. References: Johnson (1977), MacKenzie and Bookstrom (1976).
Star district ***PE-***490, ***496,*** 497, ***501,*** 502 Pershing County	Polymetallic vein. Ag, Pb, Sb, Au, Cu, and Zn. Arsenopyrite is present in the district. Host rocks from the dumps and portals are varied and include rhyolite and sedimentary rocks. The host rock at the portal of the DeSoto mine (PE-501) is limestone, whereas that at the portal of the nearby adit (PE-496) is a quartz-feldspar porphyry. Vein samples from the dump at PE-501 contain quartz, galena, sphalerite, and traces of oxide Cu minerals. Vein samples from the dump at PE-496 contain quartz, calcite, galena, and stibnite. Ag and Pb were produced from this area from 1861 into the 1940s. Surface water in this area would flow into Buena Vista Valley. References: Lawrence (1963), Johnson (1977).
Bloody Canyon mine ***PE-***507, ***509*** Pershing County	Variation on polymetallic vein. Sb occurs in quartz-stibnite veins in rhyolite. Surface water in this area would flow into Buena Vista Valley. The mine produced Ag and Sb from 1907 to 1942. Reference: Johnson (1977).
Castle Peak district ST-76 Storey County	Quartz-alunite precious metal or volcanic-hosted mercury (?). Shaft has been filled in. No streams flow in this area. Deposits in this district produced Hg. Reference: Bonham (1969).

Table 1. (continued)

Location	Mineral-deposit type and features specifically relevant to water quality
Flowery district ***ST-79*** Storey County	This site appears to have been a rock-lined water well rather than a mine shaft. No ore occurs in the flat area near the well; this flat area may have been a home site, rather than a mine dump. Approximately 300 m to the south, small adits and shafts worked veins of the quartz-adularia precious metal type in volcanic host rocks. Surface water in this area flows into the Carson River. The Ag-Au district has been intermittently active since the 1860s. Reference: Bonham (1969).
Jumbo district ***WA-8*** Washoe County	Quartz-adularia precious metal, volcanic-hosted. Calcite veins occur in propylitically altered volcanic rock in samples on dump. Pyrite content of unweathered rock on dump is minor (< 2%). Surface water in this area flows into Washoe Lake. The Ag-Au district was active intermittently from 1859 to 1948. Reference: Bonham (1969).
Geiger Grade ***WA-133***	Quartz-alunite precious metal. Volcanic-hosted. Limonite stains the streambed for 300+ m downstream. Wall rocks have little acid-buffering capacity. Ferricrete (sample WA-133-R3) occurs in the drainage 200 m to the southwest of this site. Surface water in this area flows into the Truckee River, but water flow stops (disappears into the streambed) 100 m downstream from the adit. Au and Ag were sought in this area from 1875 to perhaps the 1940s. Reference: Bonham (1969).
Pyramid district ***WA-95*** Washoe County	Quartz-alunite precious metal. Volcanic-hosted. As minerals are abundant (enargite, Cu-arsenates) at the Jones-Kincaid mine. This adit apparently was driven to intersect the vein at the Jones-Kincaid mine. The mine-drainage water plates Cu onto steel. Wall rocks have little acid-buffering capacity. Copiapite (hydrated iron sulfate) occurs as a precipitate on pebbles in the streambed 0 to 10 mm above water level. Surface water in this area flows into Pyramid Lake. Water from the adit flows into the stream in Perry Canyon. Au and Ag were produced from the district from 1863 to 1952, with peak years being 1876 to 1889. References: Bonham (1969), Nielsen (1981).
Pyramid district ***WA-210*** Washoe County	Polymetallic vein with Pb, Zn, Cu. Enargite is reported from this property. This may actually be a variation on a quartz-alunite precious metal deposit, but wall rocks are propylitically altered and contain calcite. Production was minor, judging from less than 150 tons of material present on the dump. Surface water in this area flows into Pyramid Lake. References: Bonham (1969), Nielsen (1981).

Field investigations were conducted in July and August 1995. Samples of waters, ores, and country rocks were collected from 34 of the 72 sites. Sampling and analytical procedures are covered in detail in the appendix of this report. Water samples were filtered and acidified in the field for cation analyses in the laboratory; separate samples were filtered for anion analyses. Several sites were dry at this time, a few shafts had been reclaimed or filled since last inspected, and one was locked and posted as private property. Results of field measurements of pH and water flow rate are listed in Table 2.

Samples are categorized on the basis of mineral-deposit type. This same classification of mineral deposits is used in other work by the Nevada Bureau of Mines and Geology for abandoned mines on lands managed by the U.S. Bureau of Land Management. Categorizing mineral deposits by type raises debates about both individual deposits and deposit types in general. Our classification is similar to that of Cox and Singer (1986). The terminology for epithermal precious metal deposits, of which there are many in Nevada, has evolved as more deposits are examined and compared with one another. Two major types have emerged. Most recently White and Hedenquist (1995) have labeled these low-sulfidation (what we call quartz-adularia) and high-sulfidation (what we call quartz-alunite) deposits. The quartz-adularia type includes the hot-spring gold-silver, Creede epithermal veins, and Comstock epithermal veins of Cox and Singer (1986).

As might be predicted from knowledge of the amount of acid-generating and acid-buffering capacities of different types of mineral deposits, samples can be grouped into geologically similar categories (Table 2 and Figure 2). Note that the two water samples collected from quartz-alunite precious metal deposits have low pH. Because the buffering capacity of the country rocks characteristically is destroyed in this type of deposit, low pH and significant metal transport are expected when water is present.

Results of chemical analyses of water samples collected from adits and shafts, as well as new data that we collected on open pits, are listed in Table 3. Waters have been analyzed by inductively coupled plasma-atomic emission spectrometry for most cations (Ca, Mg, Na, K, Fe, Mn, Cu, Pb, Zn, Cd, Cr, Co), by flame atomic absorption for Sr, by atomic emission for Cs, by cold-vapor atomic absorption spectrometry for Hg, by graphite furnace atomic absorption for Tl, by hydride generation-atomic absorption spectrometry for As, and by ion chromatography for anions (F^-, Cl^-, Br^-, NO_2^-, NO_3^-, PO_4^{3-}, and SO_4^{2-}). Selected rock samples, which supplement existing knowledge from published reports, past production, and geochemical databases, also have been analyzed for metals and selected, potentially toxic elements (Hg by cold-vapor atomic absorption spectrometry; As, Sb, Cu, Mo, Pb, and Zn by x-ray fluorescence; and Ag and Au by atomic absorption spectrometry). Because of budgetary limitations, only two samples (WA-8 and WA-133) were analyzed for Hg, Tl, and Cs.

With the exception of the stream water at the Rio Tinto mine, the analyzed waters are essentially groundwaters that either emerge as springs from adits or occur in shafts, the equivalent of hand-dug wells.

Our investigation focuses largely on water-quality issues, such as acid-mine drainage, that are the direct result of groundwater and surface water interacting with rocks exposed during mining. The impacts on groundwater and surface water from ore processing, such as use of mercury and cyanide, and from other industrial activity at mining and milling sites, such as waste disposal, are not considered in this report but deserve further study.

Relative concentrations of selected cations and anions are plotted in Figures 3 through 8.

(continued on page 24)

Table 2. Mine sites for which new data were collected on the chemistry of waters in pits, shafts, and adits.

Mineral-deposit type and water sample number		Field measurements		
		pH	Flow rate (L/min)	Depth to water (m)
Variation on Carlin-type gold deposits				
1.	Adelaide Crown north pit	7.0		0
Base-metal replacement deposits				
2.	CL-447 (Goodsprings district) shaft	7.5		10
3.	EU-1 (Eureka district) adit	6.5	0.0	
Polymetallic veins				
4.	CL-13 (Nelson district) shaft	6.7		1
5.	CL-778 (Nelson district) shaft	6.5		7
6.	EL-13 (Mountain City district) adit	6.9	70	
7.	LA-25 (Reese River district) adit	6.3	15	
8.	LA-45 (Reese River district) inclined shaft	7.6		4
9.	LA-54 (Battle Mountain district) adit	6.8	3	
10.	LA-157 (Hilltop district) adit	4.5	0.6	
11.	LA-165 (Hilltop district) adit	6.8	2	
12.	LA-168 (Gray Eagle mine) closed adit	6.6	1	
13.	MI-369 (Mountain View district) shaft	7.5		12
14.	NY-532 (Tonopah area) shaft	6.9		7
15.	PE-9 (Keystone mine) adit	6.8	0.0	
16.	PE-407 (Last Chance mine) inclined shaft	6.9		11
17.	PE-496 (Star district) adit	7.0	15	
18.	PE-501 (Star district) adit	7.5	0.5	
19.	PE-509 (Bloody Canyon mine) adit	6.8	15	
20.	WA-210 (Pyramid district) winze in shaft	5.4		4
Tungsten quartz veins				
21.	ES-694 (Rock Hill district) shaft	7.2		
Mafic intrusive nickel-copper-platinum-group-element (PGE) deposits				
22.	CL-754 (Bunkerville district) adit	7.8	3	
Saline mineral deposits				
23.	CH-71 (Leete district) salt well	8.0		2
24.	CH-76 (Leete district) salt well	7.8		2
Quartz-adularia precious metal deposits				
25.	Tuscarora pit - deep water	7.5		12
26.	Tuscarora pit - shallow water	7.5		0
27.	AP-1 (Aurora Partnership pit - shallow water)	6.2		2
28.	AP-2 (Aurora Partnership pit - deep water)	6.3		15
29.	DO-71 (Veta Grande mine) adit	6.8	35	
30.	ST-79 (Flowery district) water well, not a mine	6.7		2
31.	WA-8 (Jumbo district) adit	6.6	44	

Table 2. (continued)

Mineral-deposit type and water sample number		Field measurements		
		pH	Flow rate (L/min)	Depth to water (m)
Quartz-adularia precious metal deposits with high sulfide				
32.	HU-99 (Buckskin-National mine) adit	2.5	30	
33.	HU-100 (Buckskin-National mine) adit	3.3	30	
34.	HU-217 (National mine) closed adit	2.6	40	
Quartz-alunite precious metal deposits				
35.	WA-95 (Pyramid district) adit	2.1	1.5	
36.	WA-133 (Geiger Grade) adit	3.0	2	
Porphyry copper-molybdenum deposits				
37.	PE-419 (Majuba Hill) adit	4.4	4	
38.	PE-420 (Majuba Hill) adit	6.0	4	
Massive sulfide deposits				
39.	Rio Tinto tailings - stream next to tailings	6.2	120	

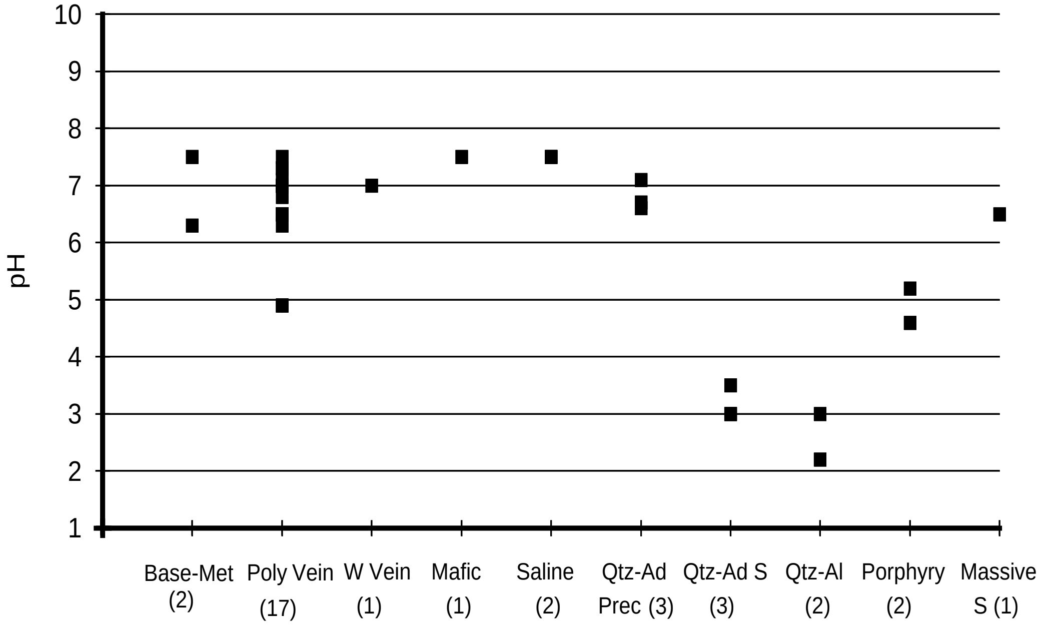

Figure 2. Deposit-type groupings of pH of waters collected from adits and shafts. Numbers in parentheses are numbers of water samples from each deposit type. Some symbols overlap.

Table 3. Chemical analyses of waters collected for this study.

Project: WGA Mine Waters
Date: 29Nov95
Notes: Data analyzed in the NBMG Laboratories. Data are reported in mg/L (except pH)
No Hg (>0.001), Tl (>0.005), or Cs (>20) were detected in samples WA-8 and WA-133. No other samples were analyzed for these elements.
No F (>0.5), Br (>0.5), or PO4 (>1.0) were detected in any of the samples.

		Carlin-type	Base-metal replacements		Polymetallic Veins				
	Drinking Water Standard	Adelaide	CL-447	EU-1	CL-13	CL-778	EL-13	LA-25	LA-45
Ca	--	76	263	82	78	151	90	94	137
Mg	150	17	579	17	135	99	6	36	67
Na	--	46	502	10	7	46	12	12	47
K	--	7	45	1	1	2	2	2	8
Fe	0.6	<0.05	<0.05	3.7	0.19	<0.05	<0.05	<0.05	0.07
Mn	0.1	0.027	0.54	0.014	1.9	0.022	0.011	2.0	0.65
Si	--	--	--	--	--	--	--	--	--
Cu	1.3	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Pb	0.015	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Zn	5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	1.0	<0.05
Cd	0.005	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Cr	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Co	--	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
As	0.05	0.010	<0.005	22	<0.005	<0.005	<0.005	<0.005	<0.005
Sr	--	--	--	--	--	--	--	--	--
Cl	400	24	1680	3.2	53	65	3.5	3.6	40
NO3	10	<0.5	<0.5	<0.5	<0.5	1.4	0.7	<0.5	<0.5
SO4	500	65	5340	166	2090	1990	22	388	273
Alkalinity	--	176	100	176	202	166	186	60	474
pH	6.5-8.5	7.80	7.36	7.17	7.14	7.25	7.47	6.77	7.69

Table 3, continued

	Polymetallic Veins (cont'd)											
	LA-54	LA-157	LA-165	LA-168	MI-369	NY-532	PE-09	PE-407	PE-496	PE-501	PE-509	WA-210
Ca	98	109	151	107	37	50	83	104	107	138	128	171
Mg	40	45	30	30	6	6	81	16	25	32	44	26
Na	47	47	78	34	108	29	276	58	15	19	26	44
K	3	9	1	6	2	1	2	5	<1.0	<1.0	3	12
Fe	<0.05	4.9	<0.05	0.13	0.07	<0.05	<0.05	<0.05	<0.05	<0.05	0.84	21
Mn	0.88	1.6	0.008	2.4	0.43	2.1	0.45	1.1	<0.002	<0.002	0.13	12
Si	--	--	--	--	--	--	--	--	--	--	--	--
Cu	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.1
Pb	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Zn	<0.05	3	<0.05	1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	36
Cd	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.1
Cr	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Co	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
As	<0.005	<0.005	<0.005	0.54	13	<0.005	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sr	--	--	--	--	--	--	--	--	--	--	--	--
Cl	28	44	71	21	32	10	127	52	4.8	2.7	17	8.7
NO3	<0.5	<0.5	0.9	<0.5	1.2	<0.5	0.5	2.0	0.5	1.7	<0.5	<0.5
SO4	162	500	324	241	73	29	412	118	144	118	294	588
Alkalinity	272	<10	207	202	232	262	252	237	171	227	207	<10
pH	7.04	3.77	7.21	7.18	7.41	7.55	7.45	7.39	7.68	7.83	7.38	4.05

Table 3, continued

	Tungsten Veins	Mafic Ni-Cu-PGE	Saline Mineral Deposits		Quartz-Adularia Precious Metal Deposits					
	ES-694	CL-754	CH-71	CH-76	Tuscarora Deep	Tuscarora Shallow	AP-1	AP-2	DO-71	ST-79
Ca	87	47	184	152	41	30	66	85	55	126
Mg	10	35	20	46	10	7	17	21	7	48
Na	830	20	3200	3300	23	17	37	37	18	49
K	34	3	330	324	2	1	5	4	1	7
Fe	0.56	0.07	<0.05	<0.05	0.05	0.05	<0.05	<0.05	<0.05	0.13
Mn	0.45	0.033	0.32	0.23	0.021	0.002	0.022	0.091	0.02	1.6
Si	--	--	--	--	--	--	--	--	--	--
Cu	<0.005	0.2	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Pb	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Zn	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Cd	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Cr	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Co	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
As	<0.005	<0.005	0.011	0.018	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sr	--	--	--	--	--	--	--	--	--	--
Cl	1130	10	3520	3350	5.5	4.7	7.9	5.4	2.1	38
NO3	<0.5	3.8	<0.5	<0.5	<0.5	<0.5	16	17	1.9	<0.5
SO4	525	84	125	127	61	51	265	36	65	338
Alkalinity	141	333	176	272	79	67	76	102	156	277
pH	7.50	7.88	7.49	7.27	7.09	7.86	7.31	7.42	7.32	7.03

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Table 3, continued

	Quartz-Adularia Precious Metal	Quartz-Adulari/High Sulfur			Quartz-Alunite		Porphyry Cu-Mo		Massive Sulfide
	WA-8(1.6u) acidified	HU-99	HU-100	HU-217	WA-95	WA-133(1.6u) acidified	PE-419	PE-420	Rio Tinto Tailings
Ca	59	2	2	189	234	219	30	55	97
Mg	10	<0.02	<0.02	73	174	46	4	7	13
Na	28	3	3	16	47	127	31	32	7
K	<1.0	1	2	2	6	2	5	6	2
Fe	<0.05	107	0.96	342	1380	191	5.3	0.62	1.4
Mn	<0.002	0.12	0.2	27	19	4.4	2.4	4.6	1.5
Si	<0.5	--	--	--	--	0.7	--	--	--
Cu	<0.005	0.2	<0.005	0.4	451	0.7	0.1	<0.005	<0.005
Pb	<0.5	<0.5	<0.5	<0.5	3.1	<0.5	<0.5	<0.5	<0.5
Zn	<0.05	<0.05	<0.05	9	34	1	6	9	<0.05
Cd	<0.05	<0.05	<0.05	0.1	0.9	0.1	<0.05	<0.05	<0.05
Cr	<0.1	<0.1	<0.1	<0.1	0.4	0.07	<0.1	<0.1	<0.1
Co	<0.05	<0.05	<0.05	2	6	1	<0.05	<0.05	<0.05
As	<0.005	0.83	<0.005	0.15	16.0	0.010	<0.005	<0.005	<0.005
Sr	<2	--	--	--	--	12	--	--	--
Cl	2.2	0.5	1.1	1.8	3.0	2.8	42	35	1.3
NO3	5.8	0.6	1.0	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
SO4	30	510	45	1460	4620	2206	96	147	318
Alkalinity	173	<10	<10	<10	<10	<10	<10	15	21
pH	7.56	2.80	3.76	2.77	2.41	2.95	3.94	6.24	6.30

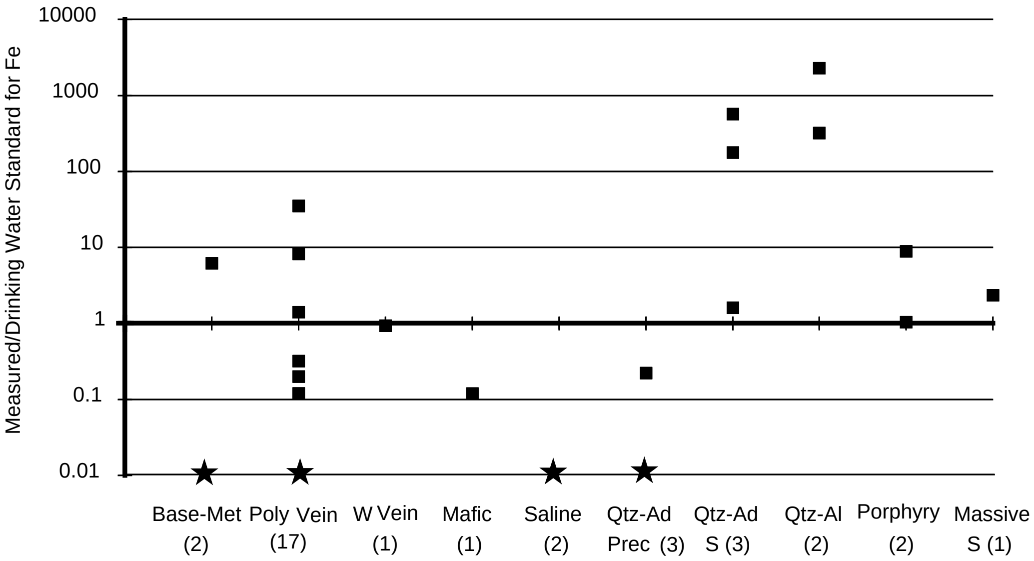

Figure 3. Relative concentrations of iron in waters from adits and shafts, grouped by deposit types. Concentrations are relative to Nevada drinking-water standards. Values greater than 1 exceed the drinking-water standard. A value of 10 is 10 times greater than the drinking-water standard. Stars in this and other figures indicate samples for which actual values are lower than indicated values (generally below the analytical detection limit).

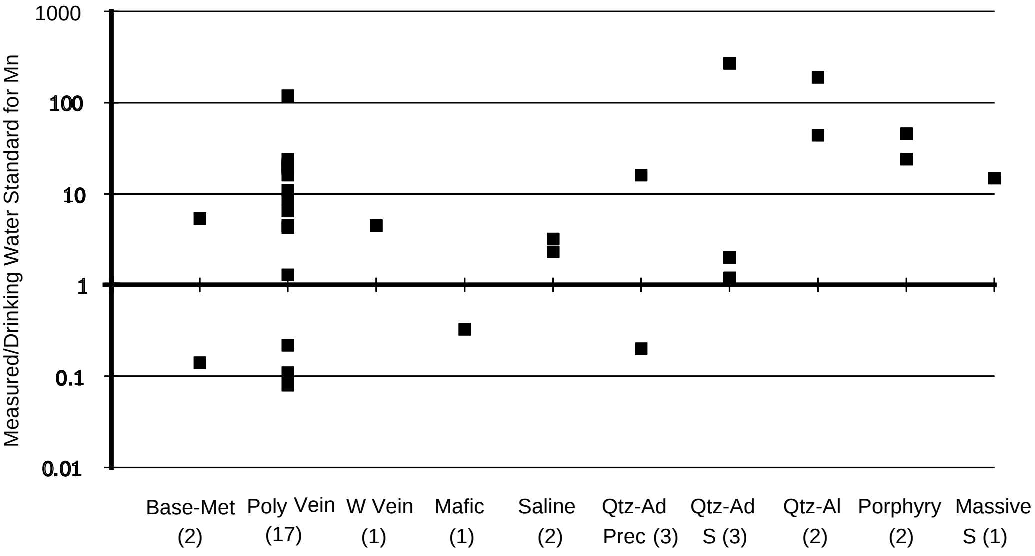

Figure 4. Relative concentrations of manganese in waters from adits and shafts, grouped by deposit type.

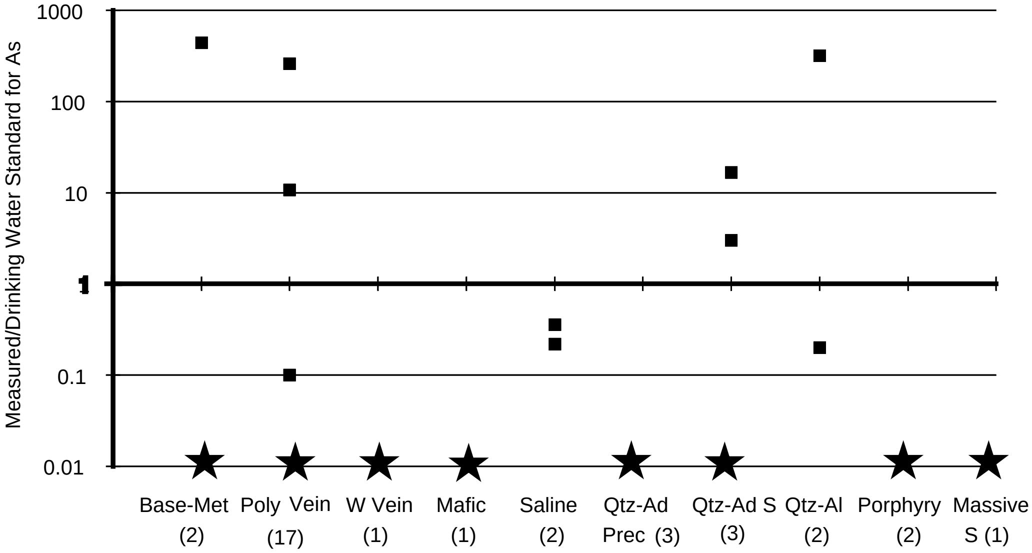

Figure 5. Relative concentrations of arsenic in waters from adits and shafts, grouped by deposit type.

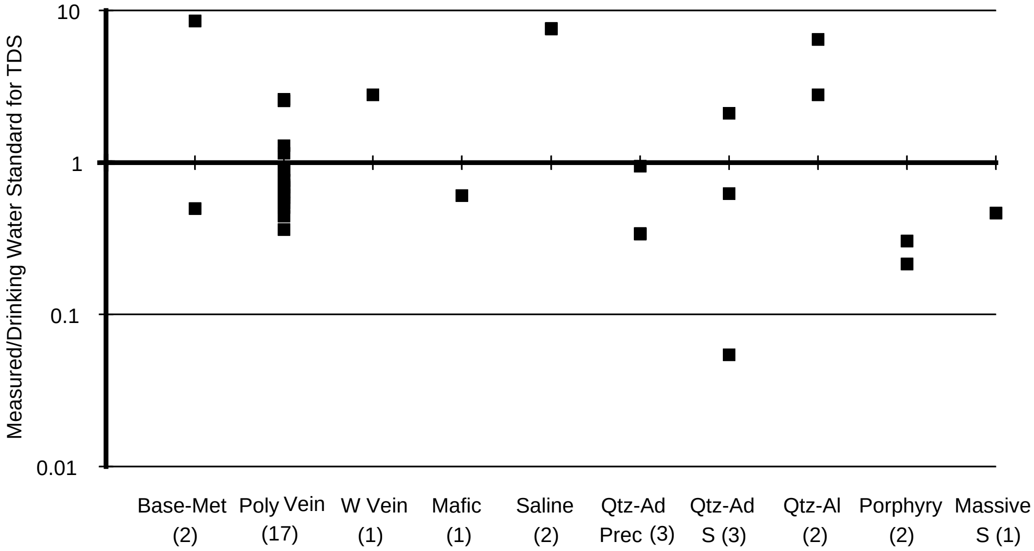

Figure 6. Relative concentrations of calculated total dissolved solids (TDS) in waters from adits and shafts, grouped by deposit type.

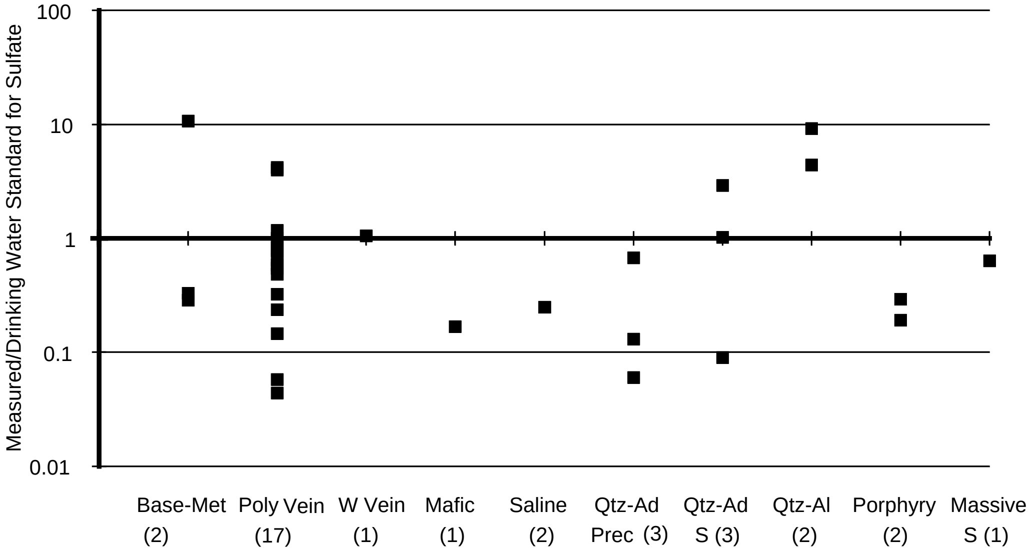

Figure 7. Relative concentrations of sulfate in waters from adits and shafts, grouped by deposit type.

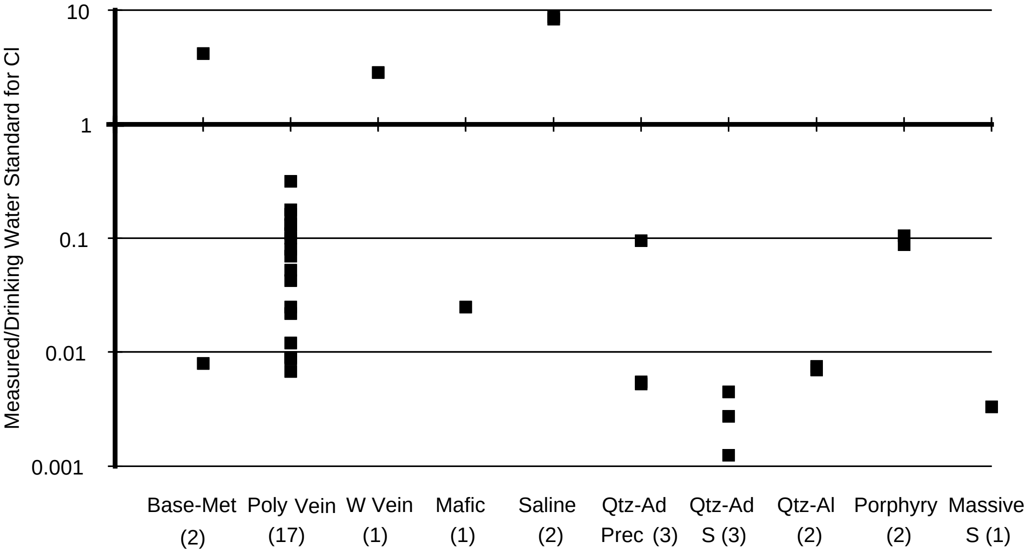

Figure 8. Relative concentrations of chloride in waters from adits and shafts, grouped by deposit type.

Concentrations are plotted relative to Nevada drinking-water standards. Values greater than one in these graphs exceed the drinking-water standard; a value of 10 is 10 times greater than the drinking water standard. Stars in this and other figures indicate samples for which actual values are lower than indicated values (generally below the analytical detection limit). Iron, manganese, and arsenic locally exceed drinking water standards by factors of greater than 10. Chloride, sulfate, and total dissolved solids generally are below drinking water standards.

At several sites samples of ores and wall rocks were collected to determine the contents of metals and potentially toxic trace elements, which may, through natural or mining-induced processes, contaminate surface and ground waters. Geochemical data on these samples are listed in Table 4. Additional data, from site CL-754, are listed in Table 5. Many of the samples contain high concentrations of arsenic, relative to typical rocks.

Table 4. Geochemical data on ore and rock samples from adits and shafts.

Sample number	PE-419-R1	PE-419-R2	WA-133-R2	WA-133-R3
Rock type	sericitized rhyolite	ferricrete with rhyolite fragments	quartz-limonite vein	ferricrete with andesite fragments
Major oxides (%)				
SiO_2	77.2	47.7	9.39	48.3
TiO_2	0.03	0.14	0.05	0.53
Al_2O_3	13.3	8.39	2.78	12.1
Fe_2O_3	2.02	32.1	61.5	25.9
MnO	0.025	0.050	0.002	0.007
MgO	0.14	0.23	0.16	0.26
CaO	0.05	0.16	0.03	0.09
Na_2O	0.32	0.39	0.46	0.51
K_2O	3.86	2.47	2.70	0.94
P_2O_5	0.02	0.10	<0.02	0.70
LOI	2.54	8.21	23.2	10.7
Total oxides	99.5	99.9	100.3	100.0
Trace elements (ppm)				
Cu	300	49	33	44
Mo	6	13	<5	<5
Zn	1,400	3,800	43	36
Pb	1,500	110	21	11
Ag	4	<0.2	<0.2	<0.2
Au	0.015	0.012	<0.010	<0.010
Hg	0.050	0.013	0.011	0.035
As	720	1,000	13	26
Sb	<10	15	23	<10

Table 4. continued.

Sample number		EL-13-R1	HU-99-R1	HU-217-R1	LA-54-R1
Rock type	average granite*	calcite-veined	quartz vein phyllite	quartz vein	quartzite with calcite vein
Trace elements (ppm)					
Cu	12	29	<2	67	3
Mo	1.3	<5	5	<5	<5
Zn	51	63	12	98	750
Pb	18	5	11	69	1,500
Ag	0.037	<0.2	91	24	8
Au	0.0023	<0.010	0.56	0.056	0.016
Hg	0.04	<0.010	2.4	0.097	0.061
As	2.1	<10	150	88	310
Sb	0.2	<10	<10	120	<10

Sample number	LA-169-R1	PE-496-R2	PE-501-R1	PE-509-R1
Rock type	quartz vein with sulfides	quartz vein with sulfides	quartz vein with sulfides	quartz-stibnite vein
Trace elements (ppm)				
Cu	2,600	2,100	2,300	130
Mo	24	39	13	460
Zn	18,000	4,250	29,000	79
Pb	53,000	3,190	5,800	460
Ag	350	550	580	1
Au	0.47	0.43	0.46	<0.010
Hg	0.78	0.97	0.72	0.20
As	38,000	140	120	81
Sb	690	460	340	20,000

* Data for average granite are from Rose and others (1979).

Table 5. Comparison of analyses (in ppm) of ore from the Great Eastern mine, Bunkerville district, Clark County with typical ultramafic rocks.

	Mafic ore, Great Eastern mine (site CL-754) (Lechler, 1995)	Typical ultramafic rocks (Rose and others, 1979)
Pt	1.7	0.032
Pd	0.36	0.013
Cu	8,400	42
Pb	8	1
Zn	76	58
Mo	4	0.3
As	25	1
Sb	46	0.1
Se	4	0.13
Sn	19	0.5
W	2	0.1
Ba	28	0.4

Ferricrete as Evidence of Natural Acid-Rock Drainage Before Mining

The precipitates of naturally occurring acid-rock drainage can be compared with water coming from nearby adits at two locations (PE-419 in a quartz-sericite-pyrite altered intrusive rhyolite in a porphyry-copper-molybdenum system and WA-133 in argillically altered andesite in a quartz-alunite system. Ferricrete (surficial material, such as sand, gravel, or rock fragments on the land's surface, which has been cemented by iron oxide to form a rock) occurs at these two sites. Iron oxide in the ferricrete presumably precipitated from a water similar to the water now emerging from the adits.

As might be expected, the metals and trace elements that are concentrated in these waters are, for the most part, also concentrated in the associated ferricretes (Table 6). Specifically, iron, copper, and zinc are concentrated in both rock and water samples at locality PE-419; and iron, copper, zinc, and arsenic are concentrated in both rock and water samples at locality WA-133.

Interestingly, arsenic is not enriched in the PE-419 water but is enriched in the associated ferricrete. Iron (in the iron oxide of ferricrete) is a scavenger of arsenic and is used in modern mining operations to reduce arsenic concentrations in discharge waters. Because the PE-419 water has a pH near 4, and iron oxide is precipitating from this water, as seen in orange-colored, filtered colloidal particles, it is likely that the analyzed PE-419 water has lost much of its arsenic through co-precipitation with or adsorption on iron oxide. In contrast, the WA-133 water, with a pH of 3, has not lost its arsenic.

Ferricretes are the products of natural acid-rock drainage, unrelated to mining activity. Native Americans probably used the pre-mining spring at locality PE-419; they left behind chips of obsidian, a rock that was used to make arrowheads but is not found nearby. On occasion, prospectors have opened adits or dug shafts on ferricrete, hoping that is was a weathered outcrop of a sulfide deposit, which is mineralogically similar to ferricrete. This appears to be the case at locality PE-419. The dump at this adit contains abundant pyrite, but there is no indication of quartz veins that might be associated with ore, and the rock from the dump (sample PE-419-R1 in Table 4) is not an ore-grade sample. At this locality prospecting may have reestablished or accentuated the ancient spring.

Ferricretes can locally extend for several kilometers as pediment skirts; these may have formed from acid runoff from the oxidized outcrops of large masses of pyrite-bearing rock (J. V. Tingley, personal communication, 1995).

Table 6. Relative enrichments of metals and trace elements in rocks formed from natural acidic waters (ferricrete) and associated waters.*

	Locality PE-419		Locality WA-133	
	Rock	Water	Rock	Water
Ca	0.11	0.08	0.06	0.5
Mg	0.6	0.003	0.7	0.03
Na	0.12	0.003	0.2	0.012
K	0.5	0.013	0.2	0.005
Fe	16	530	13	19,000
Mn	1.0	1,200	0.14	2,200
Cu	4	33	4	230
Zn	75	600	0.7	100
As	500	<2	12	3

* Values listed for rocks are measured concentrations (see Table 4) divided by average values for granites (from Rose and others, 1979). Values listed for waters are measured concentrations (see Table 3) divided by average values for seawater (from Mason, 1966). By calculating relative concentrations, rather than tabulating absolute concentrations, enrichments and depletions in both rocks and waters can be readily compared.

Some Limitations of the Data

The sampled waters were not analyzed for mercury (with the exceptions of WA-8 and WA-133), cyanide, or other contaminants that may have been introduced during ore processing or other industrial activities at the sites. We are therefore unable to evaluate the magnitude of this type of impact.

The only Superfund site in Nevada is a more than 50-mile-long stretch of the Carson River, which was contaminated with mercury from amalgamation processing of silver-gold ores on the Comstock Lode at Virginia City in the second half of the nineteenth century. The Nevada Bureau of Mines and Geology has been investigating mercury contamination in the Carson River as part of a National Institute of Environmental Health Sciences project at the University of Nevada (Lechler, 1992; Lechler and others, 1993, 1995; Miller and others, 1995). This mercury was introduced in the milling process and was not part of the ore itself. Mercury does occur naturally, however, in some of the mining districts throughout the state.

The Comstock Lode was the major producer of gold and silver in Nevada in the 1800s (Tingley and others, 1993) and the major user of mercury in ore processing. Cyanidation, first introduced in United States in the 1891, quickly replaced amalgamation as the main ore-processing technique, such that we do not expect mercury contamination similar in magnitude to the Carson River situation to exist elsewhere in the state. There may be, however, local problems in mining districts that were active primarily in the late 1800s.

TASK 2. Evaluate potential chemical hazards from open pits that have begun to fill with water as part of reclamation after recent large-scale mining.

Open pits from large-scale mining of copper began filling with water in approximately 1979. In more recent years, open pits at gold mines have begun to fill. The Bureau of Mining Regulation and Reclamation suggested that we investigate 11 mines at which pits have been filled, at least partially, with water since mining stopped (Table 7). On the basis of potential problems associated with pyrite-rich massive sulfide deposits, a twelfth pit, the Big Mike mine, was visited, but it was dry in August 1995. Of the 11 mines with water, existing data that were submitted to the Bureau of Mining Regulation and Reclamation, the Nevada Division of Minerals, or the Nevada Bureau of Mines and Geology have been compiled and are listed in Table 8. In addition, we collected samples from three pits (see geochemical data in Table 3). The new water samples have been analyzed for the same constituents as the samples from inactive and abandoned mines. Field measurements are reported in Table 2.

Table 7. Geological characteristics of open-pit mines investigated as part of this project. Pits for which new data were collected as part of this project are listed in bold italics. See Table 3 for analytical data on pit waters collected as part of this project. Other geochemical data on pit-lake waters are listed in Table 8.

Location	Mineral-deposit type and features specifically relevant to water quality
Adelaide Crown north pit, Humboldt County	Variation on Carlin-type gold. This deposit may actually be more like Manhattan, a sediment-hosted, quartz-adularia precious metal deposit. Some As sulfides are reported from this mine. Pit water was sampled from the shore. Production from this small pit was a few tens of thousands of tons of ore. Production in the district was from 1866 to 1991, but peaked between 1866 and 1920. This small pit was active from 1990 to 1991. Reference: Bonham and Hess (1995).
Big Springs, Elko County	Variation on Carlin-type gold. Host rocks include not only calcite-bearing sedimentary rocks but also igneous intrusions. Six pits produced approximately 460,000 ounces of Au from 1987 to 1994. Reference: Bonham and Hess (1995).
Boss, Esmeralda County	Variation on Carlin-type gold. Sediment-hosted. Oxide ore with high As content. As of 1987, announced reserves were 500,000 short tons containing 0.07 ounces of gold per ton. Reference: Bonham and Hess (1995).
Bullion-Monarch, Eureka County	Carlin-type gold. Reserves in 1987 were 1 million tons at 0.10 ounces of Au per ton. Reference: Bonham and Hess (1995).
Cortez, Lander County	Carlin-type gold. Calcite-bearing sedimentary host rocks. Oxide ore with little or no sulfide. Production from 1968 through 1982 was 1.0 million ounces of Au. Reference: Bonham and Hess (1995).
Manhattan, Nye County	Sediment-hosted, epithermal precious metal, quartz-adularia. Production from 1983 through 1989 was approximately 100,000 ounces of Au. Reference: Bonham and Hess (1995).

Table 7. continued.

Location	Mineral-deposit type and features specifically relevant to water quality
Tuscarora, Elko County	Quartz-adularia precious metal. Volcanic-hosted. Pit water was sampled at the surface and at depth from the middle of the pit lake. Production from 1986 through 1990 was approximately 64,000 ounces of Au and 213,000 ounces of silver. Au and Ag were produced from the district beginning in 1867. Reference: Bonham and Hess (1995).
Aurora Partnership, Mineral County	Quartz-adularia precious metal. Volcanic-hosted. Production from 1983 through 1994 was approximately 180,000 ounces of Au and 290,000 ounces of Ag. Au and Ag were produced from the district beginning in 1860. Reference: Bonham and Hess (1995).
Ketchup Flat, Nye County	Quartz-alunite precious metal. Volcanic-hosted. Reserves in 1989 were 300,000 ounces of Au and 3,100,000 ounces of Ag. Reference: Bonham and Hess (1995).
Big Mike, Pershing County	Massive sulfide. Volcanic hosted. Abundant pyrite. This pit had no water when visited in August 1995. Production from 1970 and 1971 was approximately $11.2 million in Cu. Ore minerals include chalcopyrite, bornite, digenite, tenorite, and cuprite. Reference: Johnson (1977).
Yerington, Lyon County	Porphyry copper. Production of Cu, from the 1950s to 1978 exceeded $300,000,000. Reference: Moore (1969).
Cyprus-Tonopah Nye County	Porphyry copper-molybdenum. Reserves in 1980 were 150 million tons of Mo-Cu ore. Reference: Kleinhampl and Ziony (1984).

Listed in Table 8 are the deposit type, name of mine, depth of water sampled (assumed to be at the surface unless otherwise noted), date sampled, pH, temperature, various chemical constituents, calculated charge balance, and references to sample numbers or data sheets supplied to us. An asterisk in Table 8 indicates that the sample is included in the plots of chemical data (Figures 9 through 16).

All pits sampled during this project have neutral to slightly basic waters (Figure 9). Relative concentrations of selected cations and anions are plotted in Figures 10 through 16. Iron locally exceeds drinking water standards, but by factors less than 10 (Figure 10). Manganese exceeds drinking water standards by factors greater than 10 in only one pit (Table 8 and Figure 11). Arsenic is of concern in some Carlin-type gold deposits (Figure 12). Fluoride, chloride, sulfate, and total dissolved solids generally are below drinking water standards. As in previous plots of chemical data, values greater than 1 exceed the drinking water standard.

Table 8. Geochemical data on waters from pit lakes, compiled from data submitted by operating companies.

Deposit	Carlin	Carlin	Carlin	Carlin	Carlin	Carlin	Carlin
Mine	**Boss Pit***	**Boss Pit**	**Boss**	**Boss Pit**	**Boss Pit***	**Boss Pit**	**Cortez Pit* East End**
Depth							
Date Sampled	**10/2/90**	**9/3/93**	**4/1/94**	**7/1/94**	**12/26/94**	**5/31/95**	**6/15/92**
pH	8	8.11	8.18	8.19	8.1	8.24	8.02
Temp (C)							
Ca	462	110	150	190	340	300	44.2
Mg	140	99	66	110	65	110	18
Na	2145	1900	3000	1900	3100	1800	72.8
K	16.2	20	21	21	18	<2.5	11.3
Fe	0.04	0.059	0.81	<0.05	3.2	<0.05	0.145
Ag	0.02	0.041	0.23	0.03	0.04	0.038	
Al							
As	0.91	0.97	3.1	0.92	1.2	1.2	0.038
Ba	<0.3	<0.25	<0.25	<0.25	<0.25	<0.25	0.061
Be							
Bi							
Cd	<0.01	<0.01	<0.01	<0.01	<0.01	0.016	<0.007
Co							
Cr	<0.02	<0.05	<0.05	<0.05	<0.05	<0.05	<0.01
Cs							
Cu	0.02	<0.05	0.19	<0.05	<0.05	<0.05	<0.007
Ga							
Hg	<0.001	<0.001	0.005	<0.001	<0.001	<0.001	<0.0005
Li							
Mn	<0.02	<0.5	<0.05	<0.05	<0.5	<0.5	0.005
Mo							
NH4							
Ni							
Pb	<0.05	<0.05	0.09	<0.05	<0.05	<0.05	<0.005
Sb							
Sc							
Se	0.009	0.046	0.42	0.039	0.056	0.064	<0.005
Si							
Sn							
Sr							
Ti							
Tl							
V							
Zn	<0.02	<0.05	<0.05	<0.05	<0.05	<0.05	<0.005
Cl	2000	2850	4310	2740	2580	2730	24.8
Br							
NO3	26.4	27	195	29	17	23	<1
PO4							
SO4	3270	4020	4860	4330	4040	4540	86.5
HCO3		123	154	124	122	124	275
F	3	5.3	4.3	4.3	4.5	4.6	1.78
CO3							
B							
Alkalinity		101	126	102	100	102	225
Free CN							
WAD CN	<0.005		0.53		<0.02	<0.04	<0.005
TDS calc	8060	9260	12890	9550	10390	9740	760
TDS meas	8513	11320	15660	11600	11600	11900	434
SC							
Cations	128.30	96.83	144.00	101.73	157.82	102.42	7.15
Anions	124.69	166.43	225.57	169.75	159.17	173.86	7.09
Balance	0.014	-0.264	-0.221	-0.251	-0.004	-0.259	0.004
TSS							
Pet HC							
Total PO4							
Turbidity							
Reference	Boss Closure	Boss Closure	Boss Reclam. Project	Boss Closure	Boss Closure	Boss Closure	EPA
Reference			HLR				

	Table 8, continued					
Deposit	Carlin	Carlin	Carlin	Carlin	Carlin	Carlin
Mine	**Cortez Pit* Middle**	**Cortez Pit* West End**	**Cortez Pit**	**Cortez Pit**	**Cortez Pit**	**Big Springs***
Depth						
Date Sampled	**6/15/92**	**6/15/92**	**10/18/92**	**10/19/92**	**10/20/92**	**4/13/95**
pH	8.07	8.13	7.55	8.03	7.59	7.73
Temp (C)			22.6	39.3	16.2	
Ca	43.1	43.1	57.8	59.3	72.1	68.7
Mg	17.7	17.7	25.3	20.4	14.4	57.1
Na	72.4	71.4	104	90.4	95.2	3.39
K	11.4	11.1	15.7	17.5	11.6	1
Fe	0.257	<0.05	<0.05	<0.05	<0.05	0.236
Ag			<0.01	<0.01	<0.01	<0.01
Al						0.225
As	0.037	0.04	0.007	0.019	0.011	0.028
Ba	0.06	0.06	0.051	0.052	0.039	0.015
Be						<0.005
Bi						
Cd	<0.007	<0.007	<0.005	<0.005	<0.005	<0.005
Co						
Cr	<0.01	<0.01	<0.01	<0.01	0.012	0.05
Cs						
Cu	<0.007	<0.007	<0.005	<0.005	<0.005	<0.005
Ga						
Hg	<0.0005	0.00138	0.0005	<0.0005	<0.0005	<0.0002
Li						
Mn	<0.003	<0.003	0.135	0.008	<0.005	0.081
Mo						
NH4						
Ni						
Pb	0.006	0.007	<0.005	<0.005	<0.005	<0.005
Sb						
Sc						
Se	<0.005	<0.005	<0.005	<0.005	<0.01	0.007
Si						
Sn						
Sr						
Ti						
Tl						
V						
Zn	<0.005	0.006	0.01	0.013	<0.005	0.027
Cl	27.9	26.9	25.3	46	67.9	<1.5
Br						
NO3	<1	<1	1.7	<1	<1	<0.06
PO4						<0.025
SO4	85.6	81.9	157	125	103	312
HCO3	278	275	338	327	242	123
F	1.76	1.76	2.94	3.21	0.806	0.305
CO3						
B						<0.1
Alkalinity	228	225	277	268	198	101
Free CN						
WAD CN	<0.005	<0.005	<0.005	<0.005	<0.005	
TDS calc	770	750	1005	960	810	670
TDS meas	438	425	553	534	510	534
SC			938	845	788	736
Cations	7.06	7.00	9.90	9.02	9.22	8.32
Anions	7.22	7.06	9.68	9.43	8.06	8.58
Balance	-0.011	-0.004	0.012	-0.022	0.067	-0.015
TSS						<5
Pet HC						
Total PO4						
Turbidity						3
Reference	EPA	EPA	EPA	EPA	EPA	Independence Mining
Reference			PL-49	BW-1	TB-5	SWX 95-A000694

	Table 8, continued				
Deposit	Carlin	Carlin	Carlin	Carlin	Carlin
Mine	**Big Springs***	**Big Springs***	**Big Springs**	**Big Springs***	**Big Springs**
Depth					
Date Sampled	**4/13/95**	**5/30/95**	**5/30/95**	**5/30/95**	**5/30/95**
pH	7.75	8.1		8.01	
Temp (C)					
Ca	72.9	107		136	
Mg	42.6	130		84.6	
Na	3.47	4.11		5.82	
K	<1	1.36		2.07	
Fe	<0.05	<0.05		1	<0.05
Ag	<0.01	<0.01		<0.01	
Al	<0.2	<0.2		<0.2	
As	0.024	0.012	0.013	0.017	0.012
Ba	0.022	0.015		0.016	
Be	<0.005	<0.005		<0.005	
Bi					
Cd	<0.005	<0.005		<0.005	
Co					
Cr	<0.01	<0.01		0.197	0.015
Cs					
Cu	<0.005	<0.005		<0.005	
Ga					
Hg	<0.0002	<0.0002		<0.0002	
Li					
Mn	0.063	0.243	0.239	0.115	
Mo					
NH4					
Ni					
Pb	<0.005	<0.005		<0.005	
Sb					
Sc					
Se	0.009	0.017	0.015	0.013	0.015
Si					
Sn					
Sr					
Ti					
Tl					
V					
Zn	0.006	0.076		0.02	
Cl	1.58	<1.5		1.58	
Br					
NO3	0.22	<0.3		0.24	
PO4	<0.025	<0.025		<0.025	
SO4	283	646		481	
HCO3	98	155		155	
F	0.152	0.437		0.269	
CO3					
B	<0.1	<0.2		<0.2	
Alkalinity	80.7	127		127	
Free CN					
WAD CN					
TDS calc	585	1170		995	
TDS meas	489	1060		892	
SC	656	1200		1050	
Cations	7.33	16.27	0.01	14.12	0.00
Anions	7.56	16.06	0.00	12.62	0.00
Balance	-0.016	0.006	1.000	0.056	1.000
TSS	<5	<5		6	
Pet HC					
Total PO4					
Turbidity	3.5	1.98		1.01	
Reference	Independence Mining	Independence Mining	Independence Mining	Independence Mining	Independence Mining
Reference	BS303 95-A000692	SWX 95-A001094	SWX Filtered 95-A001095	303 95-A001090	303 Filtered A001091

	Table 8, continued				
Deposit	Carlin	Porphyry Copper	Porphyry Copper	Porphyry Copper	Qtz-Adularia Prec
Mine	**Adelaide**	**Yerington Pit**	**Yerington Pit***	**Yerington Pit***	**Aurora Partnership**
Depth		**0 m**	**50 m**	**100 m**	**J146-01**
Date Sampled		**4/7/95**	**4/7/95**	**4/7/95**	**5/25/95**
pH	7.8	8.25	7.98	7.84	
Temp (C)	17				
Ca	76	84.5	87.5	88.7	
Mg	17	15.2	14.9	14.9	
Na	46	71.3	72	72	
K	7	5.3	5.36	5.3	
Fe	<0.05	<0.01	<0.01	<0.01	
Ag					
Al					
As	0.01	0.004	0.003	0.003	<0.025
Ba		0.032	0.031	0.031	
Be					
Bi					
Cd	<0.05				
Co	<0.05				
Cr	<0.1				
Cs					
Cu	<0.005	0.114	0.135	0.158	0.024
Ga					
Hg		<0.0002	<0.0002	<0.0002	
Li					
Mn	0.027	0.03	0.05	0.06	
Mo					
NH4					6.5
Ni		<0.01	<0.01	<0.01	
Pb	<0.5				<0.015
Sb					
Sc					
Se		0.11	0.11	0.11	
Si					
Sn					
Sr		0.72	0.735	0.732	
Ti					
Tl					
V					
Zn		<0.005	0.016	0.012	<0.015
Cl	24	33.3	33.3	32.9	11.7
Br	<0.1				
NO3	<0.5	0.4	0.35	0.53	8.46
PO4					
SO4	65	270	269	277	
HCO3	215	151	152	151	
F		1.4	1.4	1.4	
CO3					
B		0.43	0.43	0.42	
Alkalinity	176				
Free CN					<0.002
WAD CN					
TDS calc	450	630	640	645	
TDS meas	450				465
SC					
Cations	7.37	8.71	8.87	8.92	0.00
Anions	5.55	9.12	9.11	9.25	0.33
Balance	0.141	-0.023	-0.014	-0.018	-1.000
TSS					31.5
Pet HC					none detected
Total PO4					2.9
Turbidity					9.1
Reference	NBMG	Glenn Miller	Glenn Miller	Glenn Miller	Aurora Partnership
Reference		33444	33445	33446	J146-01

	Table 8, continued			
Deposit	Qtz-Adularia Prec	Qtz-Adularia Prec	Qtz-Adularia Prec	Qtz-Adularia Prec
Mine	**Aurora Partnership***	**Aurora Partnership***	**Tuscarora Pit**	**Tuscarora Pit Water**
Depth	**1.5 m**	**14.6 m**		
Date Sampled	**8/24/95**	**8/24/95**	**8/22/90**	**8/22/90**
pH	7.31	7.42	7.8	7.8
Temp (C)	18	15		
Ca	66	85	61.4	61.4
Mg	17	21	14.4	14.4
Na	37	37	36.7	36.7
K	5	4	3.5	3.5
Fe	<0.05	<0.05	0.07	0.07
Ag			0.02	0.02
Al				
As	<0.005	<0.005	0.005	0.005
Ba			<0.3	<0.3
Be				
Bi				
Cd	<0.05	<0.05	<0.01	<0.01
Co	<0.05	<0.05		
Cr	<0.1	<0.1	<0.02	<0.02
Cs				
Cu	<0.005	<0.005	<0.02	<0.02
Ga				
Hg			<0.0005	<0.0005
Li				
Mn	0.022	0.091	0.06	0.06
Mo				
NH4				
Ni				
Pb	<0.5	<0.5	<0.005	<0.005
Sb				
Sc				
Se			<0.001	<0.001
Si				
Sn				
Sr				
Ti				
Tl				
V				
Zn	<0.05	<0.05	0.01	0.01
Cl	7.9	5.4	26	26
Br	<0.5	<0.5		
NO3	16	17	4.1	4.1
PO4				
SO4	265	36	129	129
HCO3	93	124		
F			0.3	0.3
CO3				
B				
Alkalinity	76	102		
Free CN				
WAD CN			<0.005	<0.005
TDS calc	510	330		
TDS meas	491	313	406	406
SC				
Cations	6.46	7.72	5.95	5.95
Anions	7.26	2.94	3.44	3.44
Balance	-0.059	0.448	0.268	0.268
TSS				
Pet HC				
Total PO4				
Turbidity				
Reference	NBMG	NBMG	Horizon Gold-Tuscarora Gold	Horizon Gold-Tuscarora Gold
Reference	AP-1	AP-2	Invoice #5195 Pit	Invoice #4754 Pit Water

	Table 8, continued		
Deposit	Qtz-Adularia Prec	Qtz-Adularia Prec	Qtz-Adularia Prec
Mine	**Tuscarora***	**Tuscarora**	**Tuscarora**
	Pit Water	**Pit**	**Pit Water**
Depth			
Date Sampled	**8/22/90**	**1/2/91**	**1/2/91**
pH	7.8	7.2	7.2
Temp (C)			
Ca	61.4	69.2	69.2
Mg	14.4	19	19
Na	36.3	45.1	45.1
K	3.5	3.4	3.4
Fe	0.07	0.06	0.06
Ag	<0.02	0.01	
Al			
As	0.005	0.002	0.002
Ba	<0.3	<0.3	<0.3
Be			
Bi			
Cd	<0.01	0.0005	0.0005
Co			
Cr	<0.02	<0.02	<0.02
Cs			
Cu	<0.02	<0.02	<0.02
Ga			
Hg	<0.0005	<0.0005	<0.0005
Li			
Mn	0.06	<0.02	<0.02
Mo			
NH4			
Ni			
Pb	<0.05	<0.003	<0.003
Sb			
Sc			
Se	0.001	0.001	
Si			
Sn			
Sr			
Ti			
Tl			
V			
Zn	0.01	0.02	
Cl	26	21	21
Br			
NO3	4.1	5.8	5.8
PO4			
SO4	129	175	175
HCO3	132		
F	0.3	0.6	0.6
CO3			
B			
Alkalinity	108		
Free CN			
WAD CN	<0.005	<0.005	<0.005
TDS calc	515		
TDS meas	406	462	462
SC			
Cations	5.93	7.07	7.07
Anions	5.60	4.27	4.27
Balance	0.029	0.247	0.247
TSS			
Pet HC			
Total PO4			
Turbidity			
Reference	Horizon Gold-Tuscarora Gold	Horizon Gold-Tuscarora Gold	Horizon Gold-Tuscarora Gold
Reference	Invoice #3533 Pit Water	Invoice #5195 Pit	Invoice #4754 Pit Water

	Table 8, continued		
Deposit	Qtz-Adularia Prec	Qtz-Adularia Prec	Qtz-Adularia Prec
Mine	**Tuscarora***	**Tuscarora***	**Tuscarora***
	Pit/Mine Water	**Pit**	**Pit Water**
Depth			
Date Sampled	**1/2/91**	**7/2/91**	**7/2/91**
pH	7.2	7.4	7.4
Temp (C)			
Ca	69.2	59.6	59.6
Mg	19	16	16
Na	45.1	37.5	37.5
K	3.4	3.4	3.4
Fe	0.06	0.11	0.11
Ag		<0.001	<0.001
Al			
As	0.002	0.003	0.003
Ba	<0.3	<0.3	<0.3
Be			
Bi			
Cd	0.0005	<0.0005	<0.0005
Co			
Cr	<0.02	<0.02	<0.02
Cs			
Cu	<0.02	<0.02	<0.02
Ga			
Hg	<0.005	0.0021	0.0021
Li			
Mn	<0.02	<0.02	<0.02
Mo			
NH4			
Ni			
Pb	<0.003	<0.003	<0.003
Sb			
Sc			
Se	0.001	<0.001	<0.001
Si			
Sn			
Sr			
Ti			
Tl			
V			
Zn	0.02	<0.01	<0.01
Cl	21	21	21
Br			
NO3	5.8	1.8	1.8
PO4			
SO4	175	160	160
HCO3	159	112	112
F	0.6	0.4	0.4
CO3			
B			
Alkalinity	130	92	92
Free CN			
WAD CN	<0.005	<0.005	<0.005
TDS calc	630	500	500
TDS meas	462	388	388
SC			
Cations	7.07	6.02	6.02
Anions	6.87	5.79	5.79
Balance	0.015	0.020	0.020
TSS			
Pet HC			
Total PO4			
Turbidity			
Reference	Horizon Gold-Tuscarora Gold	Horizon Gold-Tuscarora Gold	Horizon Gold-Tuscarora Gold
Reference	Invoice #4002 Pit/Mine Water	Invoice #5195 Pit	Invoice #4754 Pit Water

	Table 8, continued				
Deposit	Qtz-Adularia Prec	Qtz-Adularia Prec	Qtz-Adularia Prec	Qtz-Adularia Prec	Qtz-Adularia Prec
Mine	**Tuscarora**	**Tuscarora**	**Tuscarora***	**Tuscarora***	**Tuscarora***
	Pit Water	**Pit Water**	**Pit**	**Pit**	**Pit**
Depth					
Date Sampled	**1/6/92**	**4/2/92**	**6/9/92**	**12/7/92**	**12/7/93**
pH	7.87		8.98	8.34	8.48
Temp (C)					
Ca			50.4	51.8	41.5
Mg			15.4	17.4	12.6
Na			37.6	36.8	28.2
K			2.5	2.66	2.3
Fe			0.006	<0.05	<0.005
Ag			<0.05	<0.01	0.003
Al					
As	0.011		0.08	0.008	<0.025
Ba			0.028	0.027	0.034
Be					
Bi					
Cd			<0.005	<0.01	<0.005
Co					
Cr			<0.01	<0.01	<0.01
Cs					
Cu			<0.01	<0.005	<0.01
Ga					
Hg	<0.0005		0.006	<0.0005	0.0002
Li					
Mn			0.01	0.009	<0.005
Mo					
NH4					
Ni					
Pb	0.016		<0.01	<0.005	<0.015
Sb					
Sc					
Se	0.006		<0.002	0.007	<0.002
Si					
Sn					
Sr					
Ti					
Tl					
V					
Zn			<0.015	0.026	<0.015
Cl	20.3		33.6	24.7	27
Br					
NO3	3.54		0.13	<1	0
PO4					
SO4	168		190	171	100
HCO3	93		68	97	112
F	0.38		0.46	0.457	0.46
CO3					
B					
Alkalinity	76.1		56	79.2	92.2
Free CN				<0.005	
WAD CN	<0.005	<0.005	<0.005		<0.02
TDS calc	360		455	480	417
TDS meas	317	408	403	112	324
SC					
Cations	0.00	0.00	5.48	5.69	4.39
Anions	5.61	0.00	6.05	5.87	4.71
Balance	-1.000	0.000	-0.049	-0.015	-0.035
TSS					
Pet HC					
Total PO4					
Turbidity					
Reference	Horizon Gold Shares	Horizon Gold Shares	Tuscarora Gold	Horizon Gold Corp.	Tuscarora Gold
Reference	Lab #4438 Pit Water	Lab #5355 Pit Water		Lab #92-A001509 Pit	

	Table 8, continued				
Deposit	Qtz-Adularia Prec	Qtz-Adularia Prec	Qtz-Adularia Prec	Qtz-Adularia Prec	Qtz-Adularia Prec
Mine	**Tuscarora**	**Tuscarora**	**Tuscarora***	**Tuscarora***	**Tuscarora**
	Pit	**Pit**	**Pit**	**Pit**	**Pit**
Depth					**12 m**
Date Sampled	**7/1/94**	**9/29/94**	**2/16/95**	**5/10/95**	**8/14/95**
pH	8.63	8.57	8.68	8.28	7.09
Temp (C)					21
Ca	36	44	37	26	41
Mg	14	13	12	7.7	10
Na	31	37	26	18	23
K	<2.5	<2.5	<2.5	<2.5	2
Fe	0.083	0.37	1.1	0.66	0.05
Ag	<0.02	<0.02	<0.02	<0.02	
Al					
As	0.005	0.013	0.011	0.005	<0.005
Ba	<0.25	<0.25	<0.25	<0.25	
Be					
Bi					
Cd	<0.01	<0.01	<0.01	<0.005	<0.05
Co					<0.05
Cr	<0.05	<0.05	<0.05	<0.05	<0.1
Cs					
Cu	<0.05	<0.05	<0.05	<0.05	<0.005
Ga					
Hg	<0.001	<0.001	<0.001	<0.001	
Li					
Mn	<0.5	<0.5	<0.5	<0.5	0.021
Mo					
NH4					
Ni					
Pb	<0.05	<0.05	<0.05	<0.05	<0.5
Sb					
Sc					
Se	<0.005	<0.005	<0.005	<0.005	
Si					
Sn					
Sr					
Ti					
Tl					
V					
Zn	<0.05	<0.05	<0.05	<0.05	<0.05
Cl	19	22	19	12	5.5
Br					<0.1
NO3	<0.5	<0.5	<0.5	<0.5	<0.5
PO4					
SO4	122	116	94	65	61
HCO3	88	94	85	88	96
F	0.38	0.47	0.41	0.28	
CO3					
B					
Alkalinity	72	77	70	72	79
Free CN					
WAD CN		<0.04	<0.04	0.15	
TDS calc	390	410	350	290	239
TDS meas	320	350	310	220	239
SC					
Cations	4.40	4.99	4.12	2.84	3.92
Anions	4.54	4.60	3.91	3.15	3.01
Balance	-0.016	0.041	0.025	-0.050	0.133
TSS					
Pet HC					
Total PO4					
Turbidity					
Reference	Tuscarora Gold	Tuscarora Gold	Tuscarora Gold	Tuscarora Gold	NBMG
Reference					Tuscarora Deep

	Table 8, continued			
Deposit	Qtz-Adularia Prec	Qtz-Adularia Prec	Qtz-Alunite	Sed-Hosted Epithermal
Mine	**Tuscarora**	**Tuscarora**	**Ketchup Flat***	**Manhattan Mine***
	Pit	**Pit Water**		
Depth	**Surface**			
Date Sampled	**8/14/95**	**4th Quarter 1991**	**5/11/95**	**8/12/92**
pH	7.86	7.87	8	7.6
Temp (C)	20			
Ca	30	59	110	660
Mg	7	17.5	23	240
Na	17	354	160	56
K	1	3.69	23	13
Fe	0.05	0.137	0.02	0.14
Ag		<0.02	<0.0005	<0.05
Al				0.12
As	<0.005	<0.18	<0.005	0.005
Ba		0.055	0.02	<0.1
Be				<0.05
Bi				<0.05
Cd	<0.05	<0.007	0.0002	<0.005
Co	<0.05		<0.02	<0.05
Cr	<0.1	<0.01	<0.05	<0.025
Cs				
Cu	<0.005	<0.007		<0.025
Ga				<0.5
Hg		<0.5	<0.0005	<0.001
Li				<0.5
Mn	0.002	0.003	0.39	3.3
Mo				<0.05
NH4				
Ni				<0.05
Pb	<0.5	<0.05	<0.002	<0.005
Sb				<0.1
Sc				<0.5
Se		<0.13	<0.001	<0.002
Si				
Sn				<0.05
Sr				2
Ti				<0.05
Tl				<0.25
V				1.1
Zn	<0.05	0.007	0.04	<0.05
Cl	4.7	20.3	31	165
Br	<0.1			
NO3	<0.5	3.54	<0.1	8.6
PO4				0.039
SO4	51	168	620	1840
HCO3	82	93	12	223
F		0.38	0.4	2.2
CO3				
B				
Alkalinity	67	76.1	10	183
Free CN				
WAD CN		<0.005	<0.005	<0.01
TDS calc	192	800	990	3400
TDS meas	193	317	1074	3380
SC				
Cations	2.84	19.89	14.95	55.72
Anions	2.53	5.61	14.01	46.75
Balance	0.057	0.560	0.033	0.088
TSS				
Pet HC				
Total PO4				
Turbidity				
Reference	NBMG	Horizon Gold Shares	FMC Gold Company	Round Mtn. Gold Corp.
Reference	Tuscarora Shallow	Lab #4438 Pit Water	Paradise Pk Corp. #90023	#8630

	Table 8, continued			
Deposit	Sed-Hosted Epithermal	Sed-Hosted Epithermal	Sed-Hosted Epithermal	Sed-Hosted Epithermal
Mine	**Manhattan Mine***	**Manhattan Mine***	**Manhattan Mine***	**Manhattan Mine***
	West Pit	**West Pit**	**West Pit North Water**	**West Pit South Water**
Depth				
Date Sampled	**9/28/92**	**6/10/94**	**8/30/94**	**8/30/94**
pH	7.69	7.39	8.02	7.68
Temp (C)				
Ca	590	420	460	510
Mg	220	140	180	200
Na	59	64	62	63
K	13	10	13	13
Fe	0.19	0.2	0.37	0.7
Ag	<0.025	<0.025	<0.025	<0.025
Al	<0.05	0.063	0.057	0.24
As	<0.005	<0.005	<0.005	<0.005
Ba	<0.1	<0.1	<0.1	<0.1
Be	<0.05		<0.05	<0.05
Bi	<0.05		<0.5	<0.5
Cd	<0.005	<0.0005	<0.0005	<0.0005
Co	<0.05		<0.5	<0.5
Cr	0.041	<0.025	<0.025	<0.025
Cs				
Cu	<0.025	<0.025	<0.025	<0.025
Ga	<0.5		<0.5	<0.5
Hg	<0.001	<0.001	<0.001	<0.001
Li	0.5		<0.5	<0.5
Mn	1.7	2.2	0.56	0.44
Mo	<0.05		<0.25	<0.25
NH4				
Ni	<0.05		<0.5	<0.5
Pb	<0.005	<0.005	<0.005	<0.005
Sb	<0.1		<0.5	<0.5
Sc	<0.5		<0.5	<0.5
Se	<0.005	<0.005	<0.005	<0.005
Si				
Sn	<0.05		<0.5	<0.5
Sr	2.1		1.5	2.1
Ti	<0.05		<0.1	<0.1
Tl	<0.25		<2.5	<2.5
V	<0.05		<0.15	<0.15
Zn	<0.05	<0.05	<0.05	<0.05
Cl	152	42	74	72
Br				
NO3	20	<1	<1	<1
PO4	0.022		<0.5	<0.5
SO4	1960	1400	1870	1740
HCO3	200	129	166	149
F	2	0.52	1.4	1.1
CO3				
B				
Alkalinity	164	106	136	122
Free CN				
WAD CN	<0.01	<0.01	<0.01	<0.01
TDS calc	3390	2320	2970	2880
TDS meas	3390	2400	3340	3000
SC				
Cations	50.62	35.65	40.92	45.12
Anions	48.49	32.48	43.82	40.76
Balance	0.022	0.047	-0.034	0.051
TSS				
Pet HC				
Total PO4				
Turbidity				
Reference	Round Mtn. Gold Corp.	Round Mtn. Gold Corp.	Round Mtn. Gold Corp.	Round Mtn. Gold Corp.
Reference	#8836	#11914	#12309	#12310

	Table 8, continued	
Deposit	Sed-Hosted Epithermal	Sed-Hosted Epithermal
Mine	**Manhattan Mine**	**Manhattan Mine**
Depth		
Date Sampled	**10/26/94**	**10/26/94**
pH	7.52	7.75
Temp (C)		
Ca	580	570
Mg	220	220
Na	65	68
K	13	13
Fe	<0.05	<0.05
Ag	<0.025	<0.025
Al	0.027	0.026
As	<0.005	<0.005
Ba	<0.05	<0.05
Be	<0.05	<0.05
Bi	<0.5	<0.5
Cd		<0.0005
Co	<0.5	<0.5
Cr	<0.025	<0.025
Cs		
Cu	<0.025	<0.025
Ga	<0.5	<0.5
Hg	<0.001	<0.001
Li	<0.5	<0.5
Mn	0.19	0.2
Mo	<0.25	<0.25
NH4		
Ni	<0.5	<0.5
Pb	<0.005	<0.005
Sb	<0.5	<0.5
Sc	<0.5	<0.5
Se	<0.005	<0.005
Si		
Sn	<0.5	<0.5
Sr	2.1	2.1
Ti	<0.1	<0.1
Tl	<2.5	<2.5
V	<0.15	<0.15
Zn	<0.05	<0.05
Cl	85	83
Br		
NO3	<1	<1
PO4	<0.5	<0.5
SO4	1960	1920
HCO3	177	171
F	1.6	1.5
CO3		
B		
Alkalinity	145	140
Free CN		
WAD CN		<0.01
TDS calc	3260	3200
TDS meas	3320	3570
SC		
Cations	50.29	49.93
Anions	46.19	45.20
Balance	0.042	0.050
TSS		
Pet HC		
Total PO4		
Turbidity		
Reference	Round Mtn. Gold Corp.	Round Mtn. Gold corp.
Reference	WP-30 #12455	WP-2 #12456

* Samples which are included in the plots of this report.

Note: The reported data are not qualified, and the compilers can not attest to the accuracy of the data.

All data not references as NBMG was submitted to the Division of Minerals by the individual companies listed.

The authors wish to thank the Aurora Partnership, Tuscarora and Adelaide Mines for allowing access to their property to sample their pit lakes.

WAD CN is Weak Acid Dissociable cyanide which is composed of complexes of Cu and Zn.
Free CN consists of free ions only.
Total CN = WAD CN + Free CN

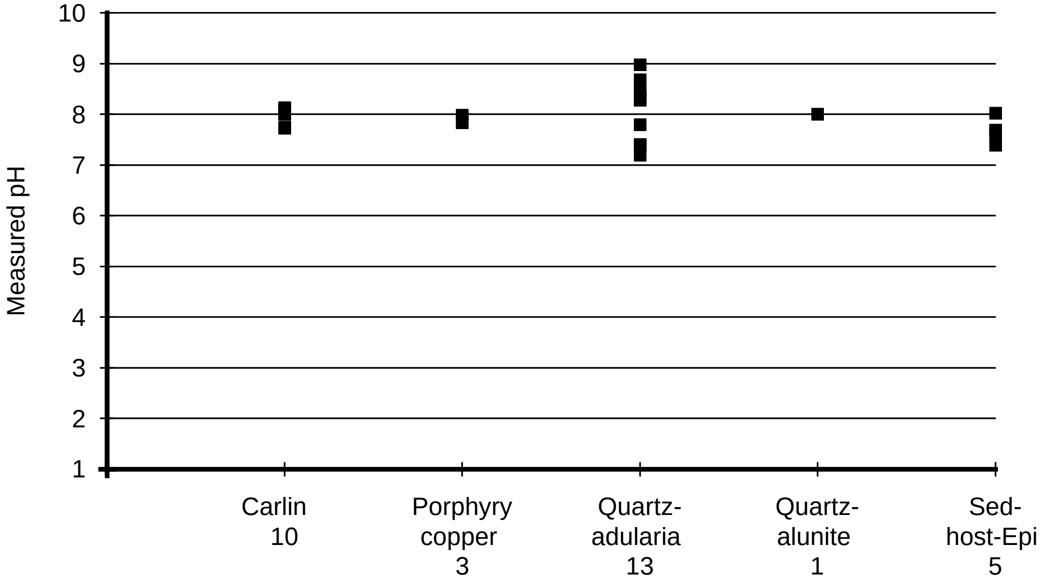

Figure 9. Deposit-type groupings of pH of waters from open pits. Numbers following the deposit type are numbers of pit-water samples for which data are presented in Tables 3 and 8.

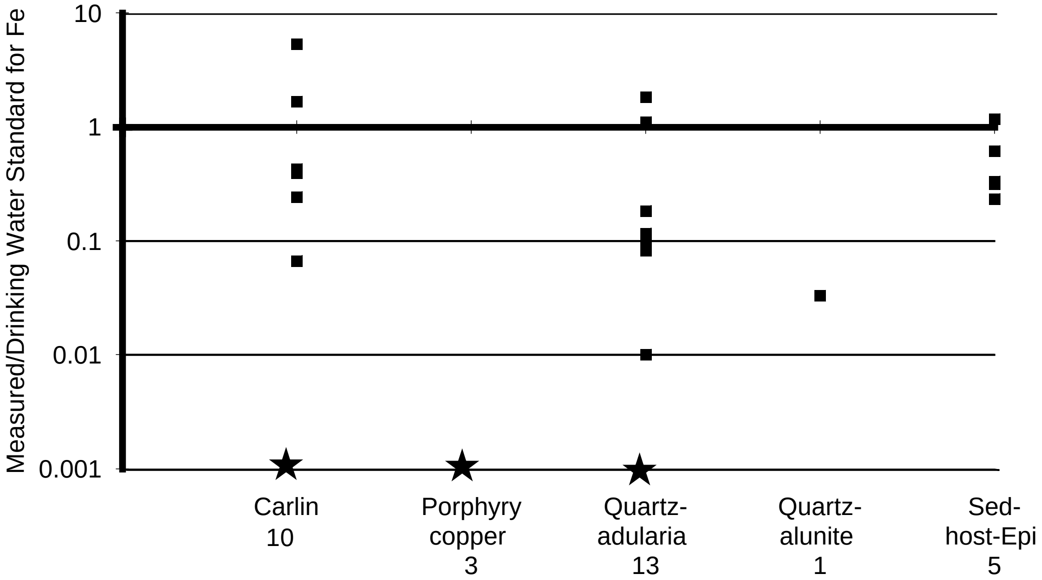

Figure 10. Relative concentrations of iron in waters from open pits, grouped by deposit type.

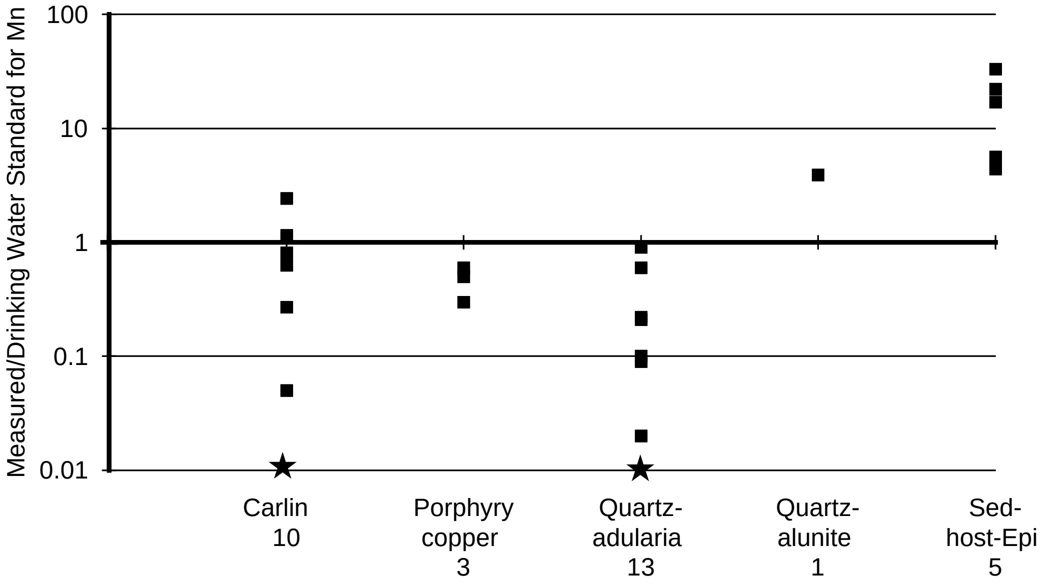

Figure 11. Relative concentrations of manganese in waters from open pits, grouped by deposit type.

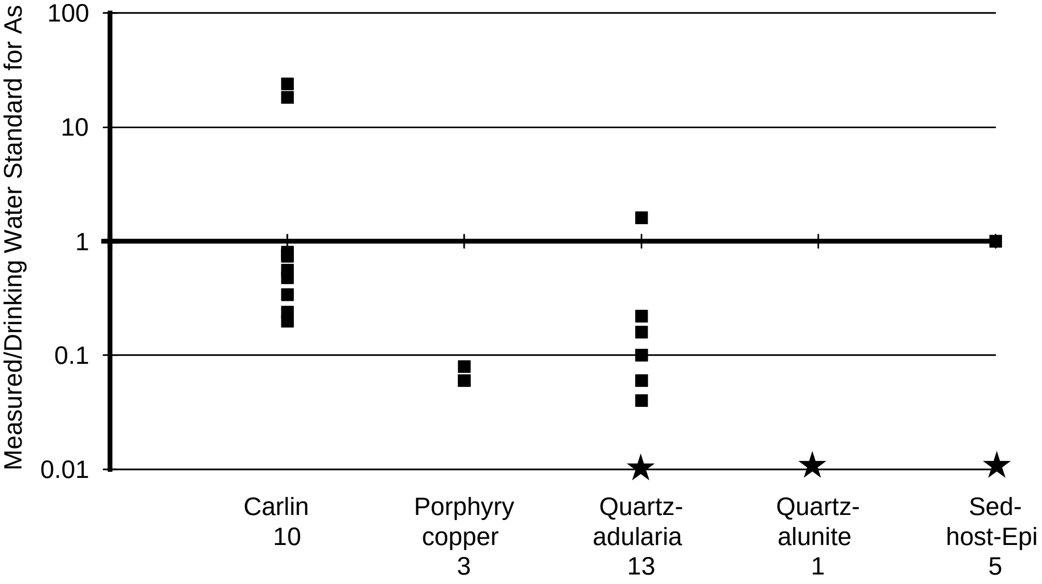

Figure 12. Relative concentrations of arsenic in waters from open pits, grouped by deposit type. The arsenic content of the one water sample from a quartz-alunite deposit falls off the graph, well below the drinking water standard.

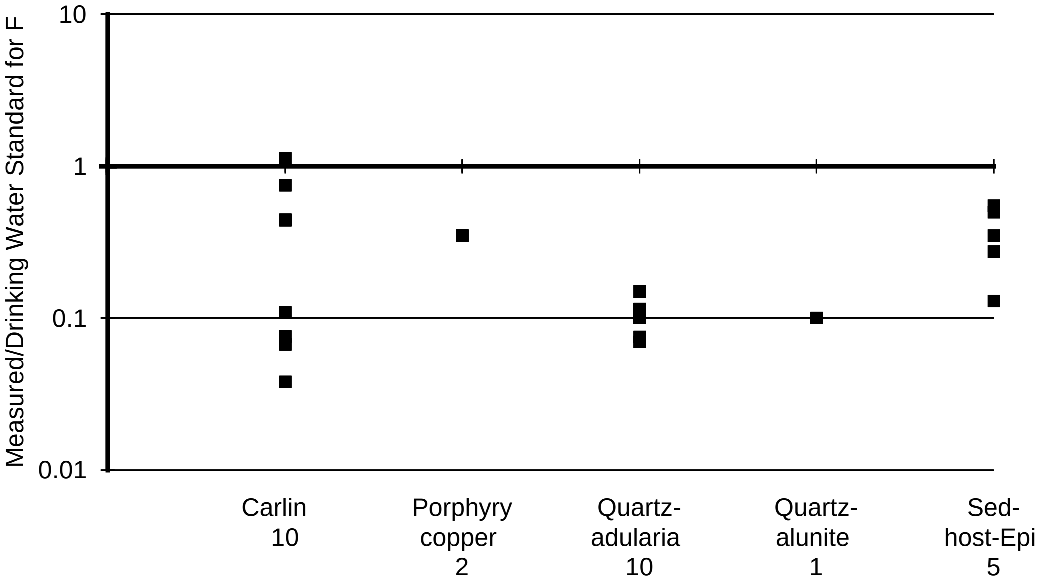

Figure 13. Relative concentrations of fluoride in waters from open pits, grouped by deposit type.

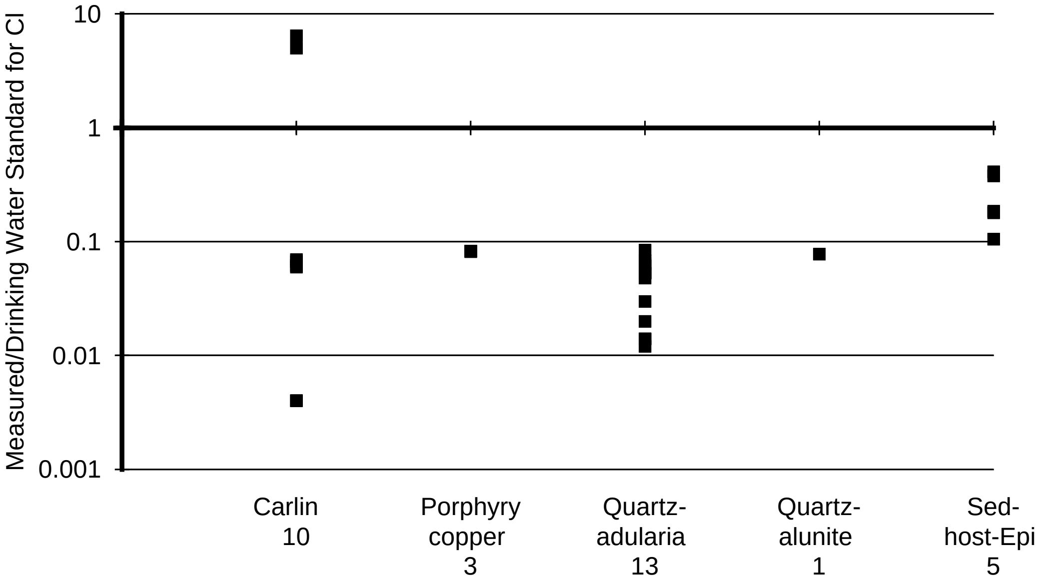

Figure 14. Relative concentrations of chloride in waters from open pits, grouped by deposit type

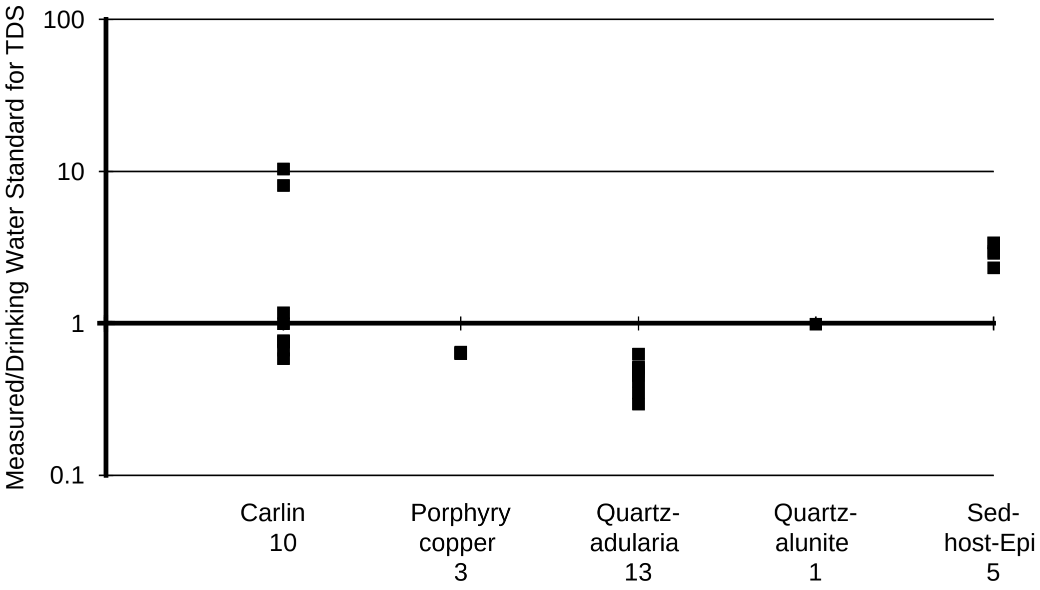

Figure 15. Relative concentrations of calculated total dissolved solids (TDS) in waters from open pits, grouped by deposit type.

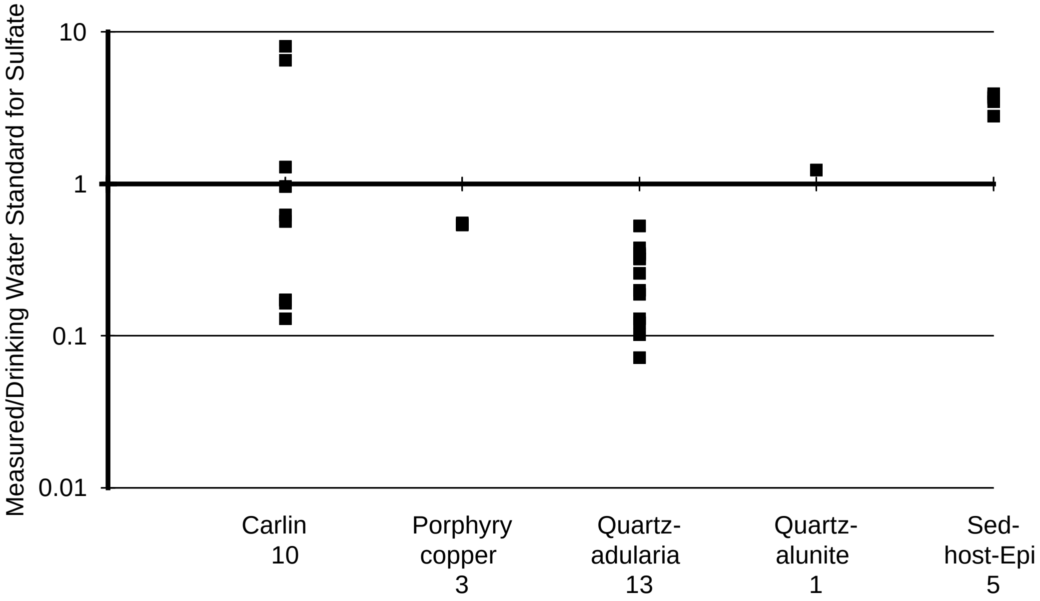

Figure 16. Relative concentrations of sulfate in waters from open pits, grouped by deposit type.

TASK 3. Complete and update a geographic information system (GIS) data layer on inactive and abandoned mines in Nevada.

At the outset of this project, a database on inactive and abandoned mines examined in the field by the Nevada Division of Minerals had only partially been incorporated into GIS. The Nevada Bureau of Mines and Geology completed the digitization of all Division of Minerals locations from 7.5-minute, 1:24,000-scale topographic maps. Additional data from the Nevada Division of Minerals database are incorporated as attributes in the GIS layer. The GIS layer is built in ARC/INFO, the copyrighted software used by most federal, state, and local government agencies with interests in abandoned mine issues in Nevada.

In addition to digitizing the 6,642 Division of Minerals locations of abandoned mine sites, the Nevada Bureau of Mines and Geology has also digitized locations of prospect pits, shafts, adits, glory holes, large open-pit mines, and other open cuts from all 7.5-minute topographic maps as part of a project with the Bureau of Land Management. The total number of inactive and abandoned mine sites on these maps, including the Division of Minerals locations, is approximately 102,000 (Table 9). Many of these mine sites are relatively shallow prospect pits, typically a few feet deep and a few feet across. These excavations were not deepened to make an actual mine and pose no likely environmental problem, although some may pose physical hazards to the public.

On the basis of field checks, the Nevada State Office of the Bureau of Land Management estimates that there are approximately 2.2 actual mine sites on the ground for every mine site that appears on the 7.5-minute topographic maps (Larry Steward, personal communication, 28 November 1995). This factor agrees well with the estimate of two to three made by the Nevada Division of Minerals, on the basis of their field checks. Therefore there are probably approximately 225,000 to perhaps as many as 310,000 actual mine or exploration sites in Nevada. Our data indicate that there are approximately 45,000 to 61,000 total adits and shafts (20,463 counted from topographic maps multiplied by factors of 2.2 and 3). Field checks by the Division of Minerals also indicate that many of the sites identified as prospect pits on 7.5-minute topographic maps are deep enough to be physical hazards. Whereas the topographic maps indicate 4,209 shafts and adits and 2,364 prospect pits visited by the Division of Minerals, the Division counts 5,760 as adits, shafts, and inclined shafts. That is, 1,551 of these prospect pits would more properly be labeled shafts or adits.

In beginning to assess the magnitude of acid-mine drainage concerns about inactive and abandoned mines, we can therefore estimate the number of sites with potential problems, ones requiring at least further investigation. Of the 4,209 adits and shafts visited over the years by the Division of Minerals (Table 9), only 72 had water present. From the new data listed in this report, only approximately seven of these sites have apparently serious water-quality problems (with field-measured pH less than 5 and with concentrations of arsenic, copper, cadmium, or other potentially toxic elements in excess of drinking water standards). As discussed on page 4, we did not sample all 72 sites, because some were dry and because some were geologically similar to other, nearby sites within the same district. Among the unsampled sites with water, only one (HU-218) has geological conditions similar to one of the sites with apparently serious water-quality problems. This raises the number of known serious sites from seven to eight. We therefore estimate that the total number of inactive and abandoned mine sites that may have serious water-quality problems in Nevada is less than 120 (61,000 x 8/4,209 = 116).

On the basis of our measured low rates of water flow coming from adits (Table 2) and given the arid climate throughout most of Nevada, we anticipate that many of the inactive and abandoned mine sites that may have water-quality problems will not be major environmental concerns because the amount of water involved is small, and because this water likely will not be a continuous source of contaminants to nearby surface or groundwaters due to the intermittent nature of precipitation. Specifically, only three of the seven acid (pH less than 5) waters that we analyzed had flow rates in excess of 10 liters per minute, and none were in excess of 50 liters per minute (Table 2). That is, the number of sites that may be of major concern regarding acid-mine drainage is likely to be fewer than 100.

In view of the large number of sites, however, it is clear that potential safety problems with abandoned mines are of concern in Nevada. Potential problems include injury and death from falling into shafts and down winzes in underground mines as well as cave-ins, asphyxia in poorly ventilated underground pockets, and dangers from wildlife (including rattlesnakes and rabid bats). The Nevada Division of Minerals estimates that there are approximately 50,000 sites which present varying degrees of physical safety hazards; most of these are shafts and adits (Table 9). By combining layers of data on population centers and nearness to highways and roads, GIS can be used to help set priorities for mitigating the physical hazards.

Once in GIS, the data on locations of inactive and abandoned mines can be used along with other data layers to help assess environmental issues related to these sites. The sites that fall outside established mining districts (compare Figures 17 and 18) are mostly borrow pits for sand and gravel. By combining the Nevada Bureau of Mines and Geology geochemical data from over 4,000 ore samples with the mining district boundaries, GIS can be used to illustrate that arsenic occurs in high concentrations in nearly all Nevada mining districts (Figure 19). Interestingly, arsenic in waters that we analyzed is of concern only locally. Although arsenic and other potentially toxic elements may be concentrated in the ores and wall rocks, they are not necessarily highly mobile and do not necessarily pose water-quality problems.

Table 9. Summary of inactive and abandoned mine sites in the NBMG database listed by county and comparing sites examined by the Division of Minerals to these plus other sites digitized from symbols shown on 7.5-minute, 1:24,000-scale U.S. Geological Survey topographic maps.

	Division of Minerals Sites	Total Digitized Sites
CARSON CITY		
Shafts	31	34
Adits	45	53
Open pits and glory holes	0	4
Shallow prospect pits	94	329
Sand, gravel, or borrow pits	0	23
SUBTOTALS FOR COUNTY	170	443
CHURCHILL COUNTY		
Shafts	73	536
Adits	21	465
Open pits and glory holes	0	49
Shallow prospect pits	33	4,103
Sand, gravel, or borrow pits	0	202
SUBTOTALS FOR COUNTY	127	5,355
CLARK COUNTY		
Shafts	436	772
Adits	377	823
Open pits and glory holes	20	99
Shallow prospect pits	624	2,844
Sand, gravel, or borrow pits	0	313
SUBTOTALS FOR COUNTY	1,457	4,851
DOUGLAS COUNTY		
Shafts	25	68
Adits	11	77
Open pits and glory holes	0	6
Shallow prospect pits	18	1,070
Sand, gravel, or borrow pits	0	40
SUBTOTALS FOR COUNTY	54	1,261
ELKO COUNTY		
Shafts	83	422
Adits	62	521
Open pits and glory holes	0	89
Shallow prospect pits	111	5,668
Sand, gravel, or borrow pits	0	535
SUBTOTALS FOR COUNTY	256	7,235

Table 9 (continued).

	Division of Minerals Sites	Total Digitized Sites
ESMERALDA COUNTY		
Shafts	62	1,790
Adits	9	888
Open pits and glory holes	0	158
Shallow prospect pits	359	13,309
Sand, gravel, or borrow pits	0	104
SUBTOTALS FOR COUNTY	430	16,249
EUREKA COUNTY		
Shafts	154	429
Adits	20	346
Open pits and glory holes	0	53
Shallow prospect pits	35	3,290
Sand, gravel, or borrow pits	0	136
SUBTOTALS FOR COUNTY	209	4,254
HUMBOLDT COUNTY		
Shafts	98	308
Adits	117	588
Open pits and glory holes	0	110
Shallow prospect pits	125	6,303
Sand, gravel, or borrow pits	0	367
SUBTOTALS FOR COUNTY	340	7,676
LANDER COUNTY		
Shafts	140	379
Adits	97	428
Open pits and glory holes	1	141
Shallow prospect pits	94	5,541
Sand, gravel, or borrow pits	0	239
SUBTOTALS FOR COUNTY	332	6,728
LINCOLN COUNTY		
Shafts	67	407
Adits	16	340
Open pits and glory holes	0	30
Shallow prospect pits	25	815
Sand, gravel, or borrow pits	0	115
SUBTOTALS FOR COUNTY	108	1,707
LYON COUNTY		
Shafts	328	491
Adits	255	450
Open pits and glory holes	1	18
Shallow prospect pits	258	4,446
Sand, gravel, or borrow pits	0	118
SUBTOTALS FOR COUNTY	842	5,523

Table 9 (continued).

	Division of Minerals Sites	Total Digitized Sites
MINERAL COUNTY		
Shafts	100	1,189
Adits	88	1,457
Open pits and glory holes	2	71
Shallow prospect pits	59	5,674
Sand, gravel, or borrow pits	0	90
Other	1	1
SUBTOTALS FOR COUNTY	250	8,482
NYE COUNTY		
Shafts	281	2,096
Adits	60	1,157
Open pits and glory holes	5	116
Shallow prospect pits	86	12,216
Sand, gravel, or borrow pits	0	395
Other	4	4
SUBTOTALS FOR COUNTY	436	15,984
PERSHING COUNTY		
Shafts	237	639
Adits	237	936
Open pits and glory holes	2	166
Shallow prospect pits	65	3,848
Sand, gravel, or borrow pits	0	171
Other	9	9
SUBTOTALS FOR COUNTY	550	5,769
STOREY COUNTY		
Shafts	82	169
Adits	35	72
Open pits and glory holes	3	24
Shallow prospect pits	48	551
Sand, gravel, or borrow pits	0	18
SUBTOTALS FOR COUNTY	168	834
WASHOE COUNTY		
Shafts	123	169
Adits	108	235
Open pits and glory holes	0	20
Shallow prospect pits	300	1,532
Sand, gravel, or borrow pits	0	231
Other	1	1
SUBTOTALS FOR COUNTY	532	2,188

Table 9 (continued).

	Division of Minerals Sites	Total Digitized Sites
WHITE PINE COUNTY		
Shafts	184	703
Adits	147	1,026
Open pits and glory holes	3	127
Shallow prospect pits	30	5,765
Sand, gravel, or borrow pits	0	287
Other	17	17
SUBTOTALS FOR COUNTY	381	7,925
STATE TOTALS		
Shafts	2,504	10,601
Adits	1,705	9,862
Open pits and glory holes	37	1,281
Shallow prospect pits	2,364	77,304
Sand, gravel, or borrow pits	0	3,384
Other	32	32
GRAND TOTAL	6,642	102,464

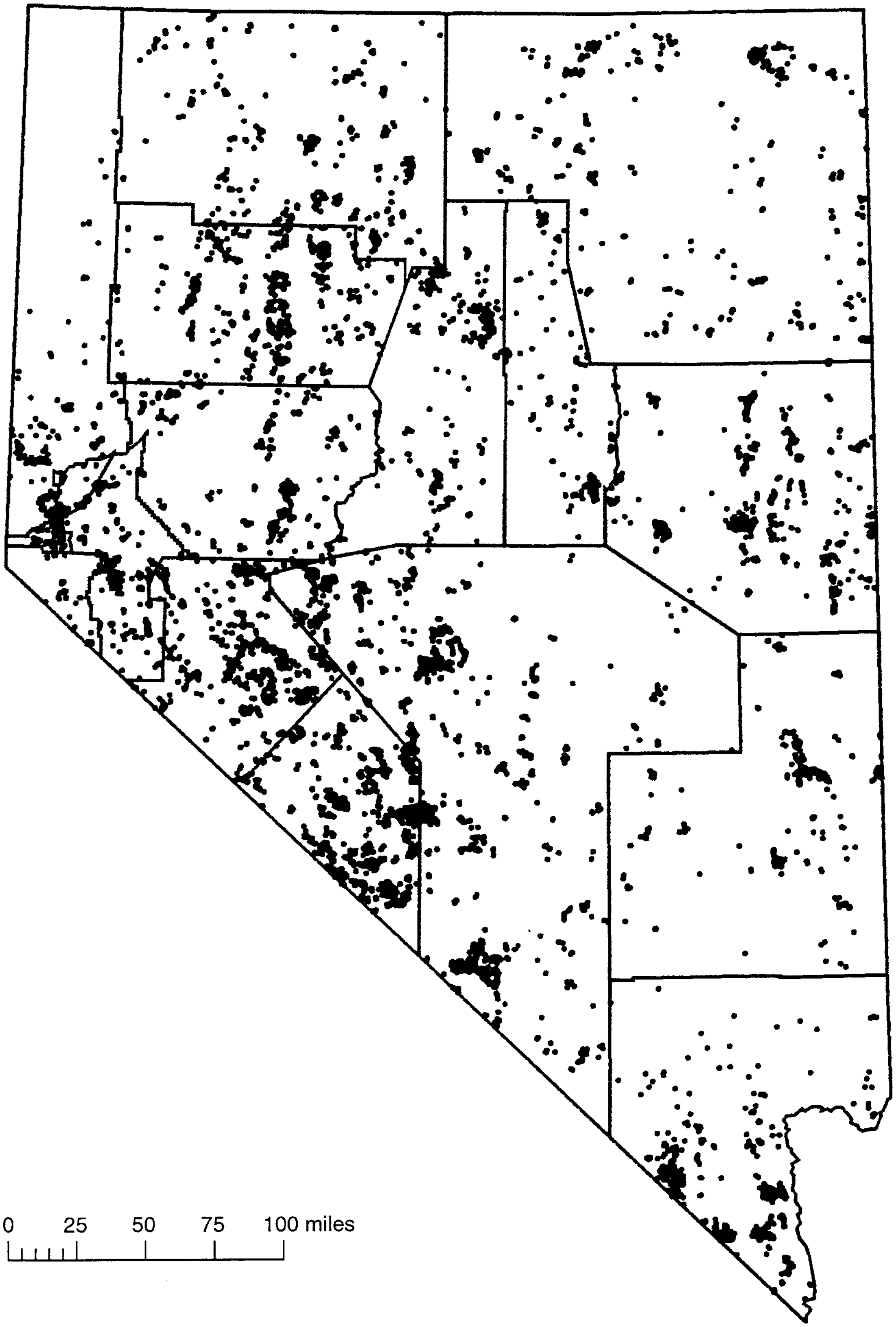

Figure 17. Locations of inactive and abandoned mines listed in the Nevada Bureau of Mines and Geology GIS database. Many sites overlap at this map scale.

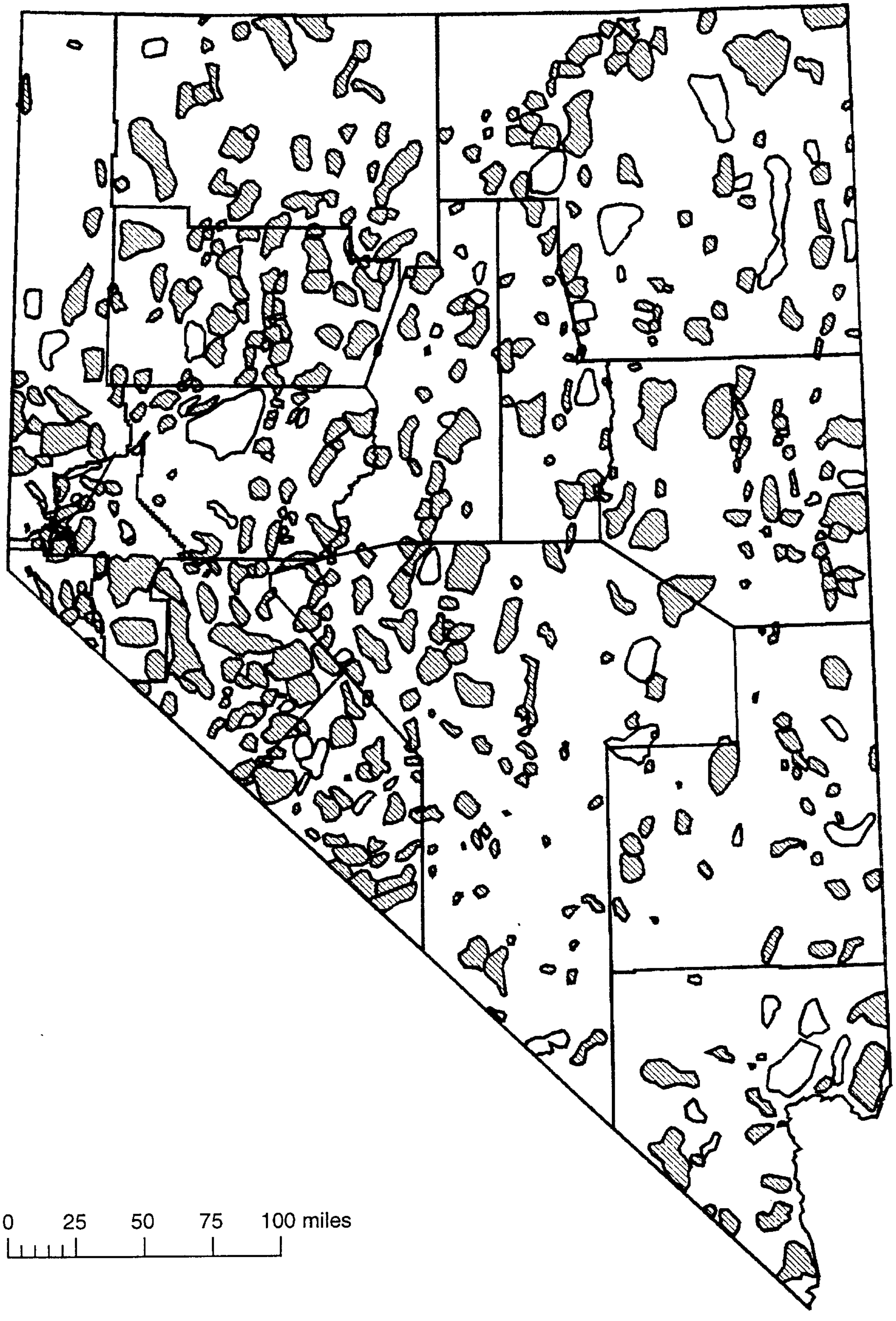

Figure 18. Locations of mining districts in Nevada (modified from Tingley, 1992). Shaded areas are metallic districts; outlined areas are nonmetallic districts.

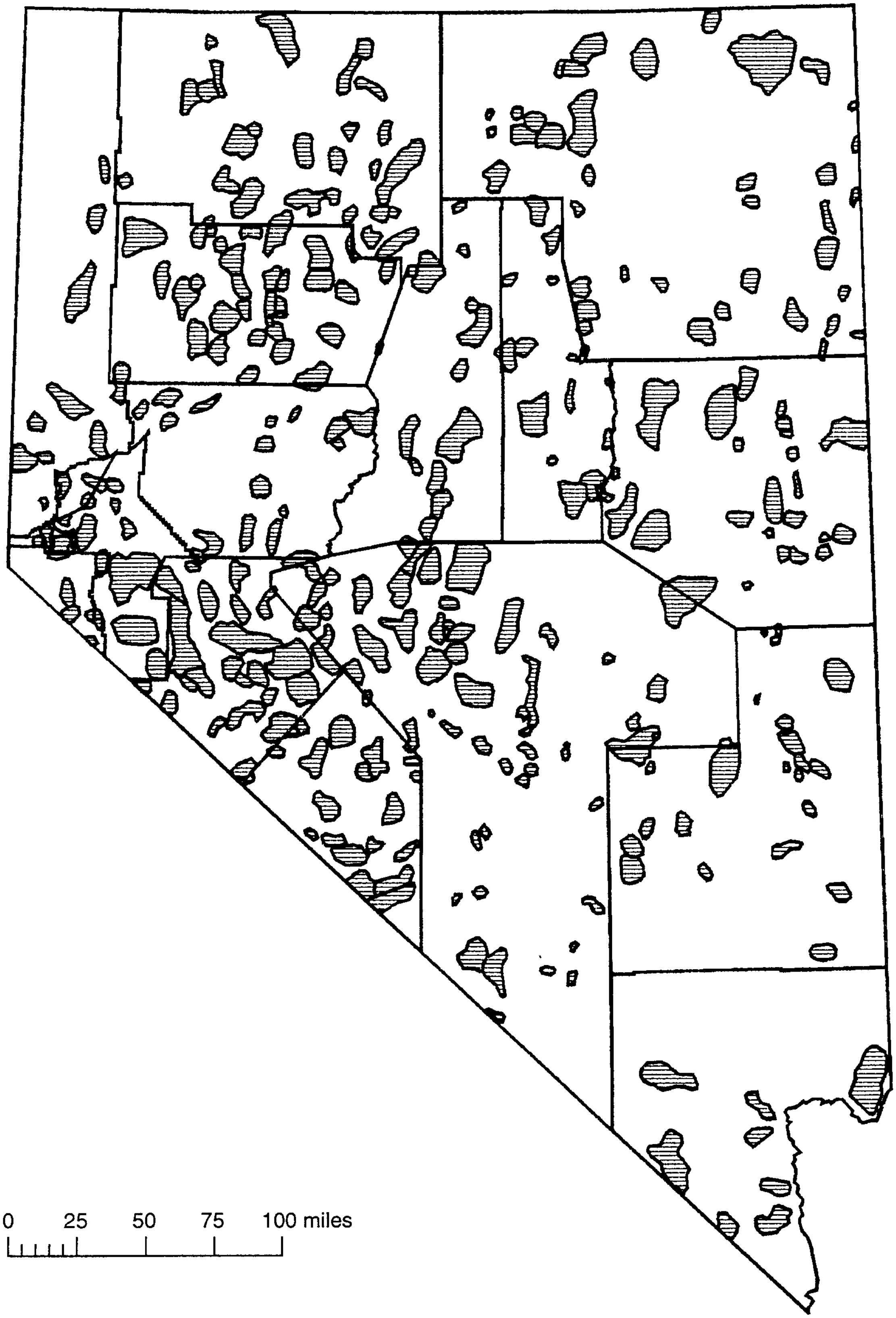

Figure 19. Locations of mining districts for which the Nevada Bureau of Mines and Geology geochemical database lists values of arsenic concentrations in ore samples in excess of 200 ppm.

DISCUSSION

Use of Geology to Predict Water Chemistry

As expected, water chemistry at inactive and abandoned mines can be closely linked to ore-deposit types, an observation made by Plumlee and others (1994) and King (1995). The point is well illustrated by plotting iron concentrations versus pH (Figure 20) or by plotting arsenic concentration versus pH (Figure 21). The worst quality water tends to be those waters with low pH (see also Table 3), and low pH develops in those deposits with little buffering capacity in the wall rocks (principally quartz-alunite precious metal deposits in Nevada).

Arsenic does not correlate with pH (Figure 21), because it is not transported in aqueous solution in the same types of complexes as most metals. Nonetheless, there are clear connections between arsenic concentrations and deposit types. Among the samples from adits and shafts, elevated arsenic concentrations are found in some, but not all, waters from quartz-adularia deposits with high sulfide contents, quartz-alunite deposits, base-metal replacement deposits, and polymetallic veins (Table 3). Arsenic concentration is below the drinking water standard in the pit-lake waters from three of the four Carlin-type deposits for which we have accumulated data (Table 8). In spite of the fact that arsenic is enriched in many ore deposits (Tables 4 and 5) and districts (Figure 19), arsenic does not appear to be a problem in waters from the sampled porphyry-copper, quartz-adularia precious metal, tungsten vein, mafic-intrusion-related nickel, salt brine, massive sulfide, or most polymetallic vein deposits.

In general, but not in every case, water quality is predictable from geological knowledge about ore-deposit type and mineralogy of ore and of associated wall rocks. The few places where acidic, metal-laden waters occur are predictably at mineral deposits that contain significant quantities of iron disulfide and for which most of the acid-buffering capacity of the wall rocks had been destroyed by the natural ore-forming process.

Quartz-alunite precious metal deposits, for which acid-buffering capacity of the wall rocks has been destroyed, have associated acidic waters that are concentrated in many elements (Figure 22). This is a combination of chemistry (at low temperatures metals tend to be more soluble in acidic than in neutral solutions) and geology (these types of deposits are known to be enriched in copper, arsenic, and many other trace elements).

In contrast, quartz-adularia precious metal deposits, which commonly contain calcite and whose waters are therefore buffered at higher pH values, understandably have few problems with water quality (Figure 23). Manganese, which has a wide geochemical dispersion halo around many types of ore deposits (geological evidence of its mobility in neutral as well as acidic solutions), appears to be the only metal that exceeds drinking-water standards in these deposits.

The quartz-adularia precious metal deposits of the National district are anomalous in containing higher than normal pyrite content in the wall rocks and in having a large area of argillic alteration formed by acid leaching related to condensation of hydrogen sulfide during the ore-forming process (Vikre, 1985, 1987). As a result of this geological condition, the waters coming from the adits in this district (Figure 24) are somewhat similar to those in the quartz-alunite deposits (Figure 22).

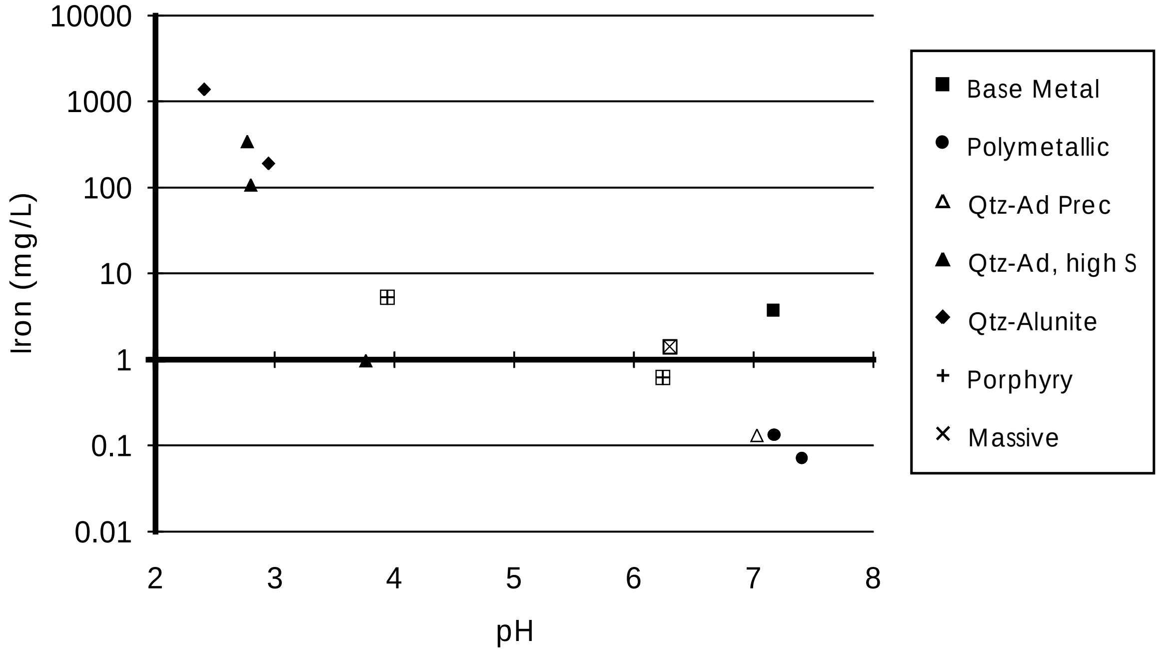

Figure 20. Iron concentration (in mg/L) versus pH of waters collected from adits and shafts.

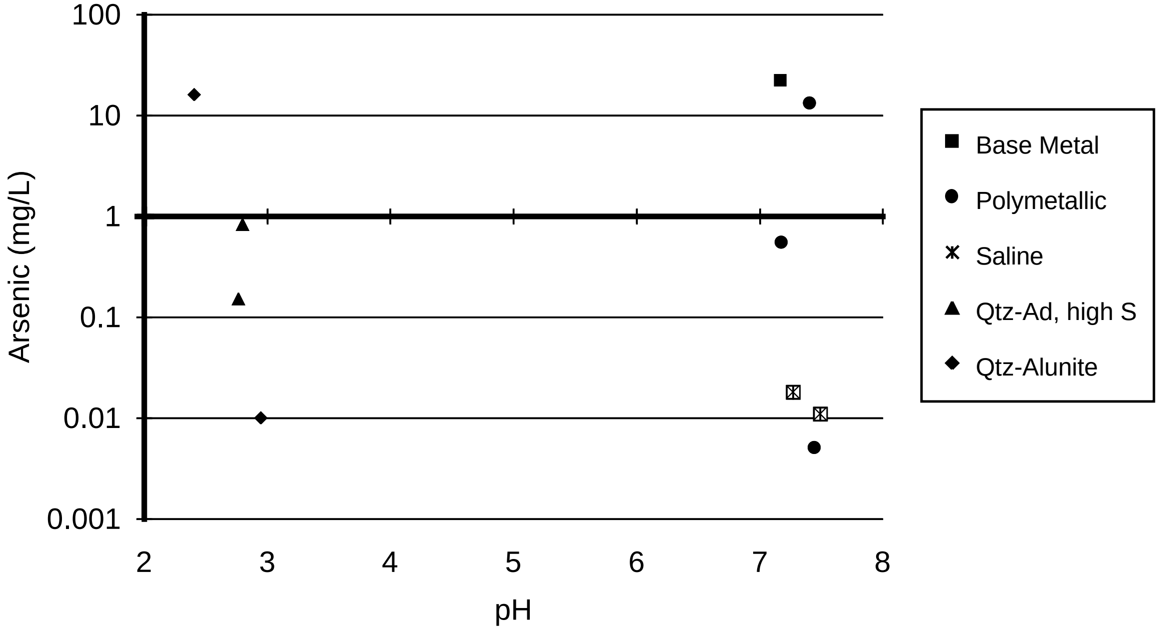

Figure 21. Arsenic concentration (in mg/L) versus pH of waters collected from adits and shafts.

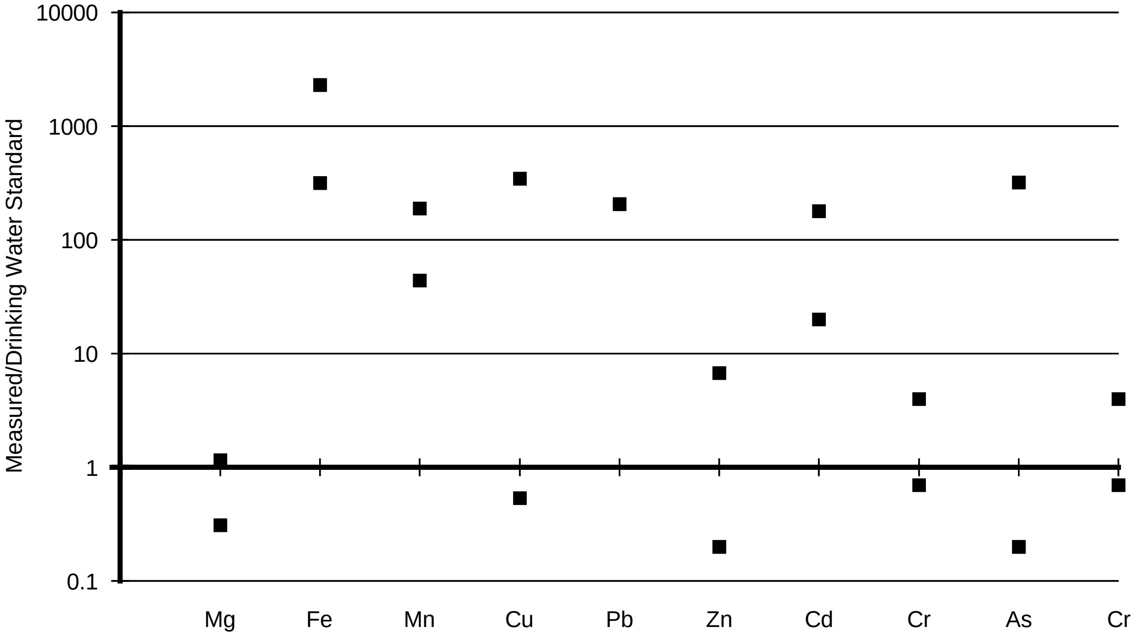

Figure 22. Anomalous elements in waters from two adits in quartz-alunite precious metal deposits. These deposits rarely contain calcite and are characterized by minerals that form in strongly acidic conditions. Therefore there is little buffering capacity in the wall rocks and high metal concentrations are expected wherever iron sulfide is oxidized to produce sulfuric acid.

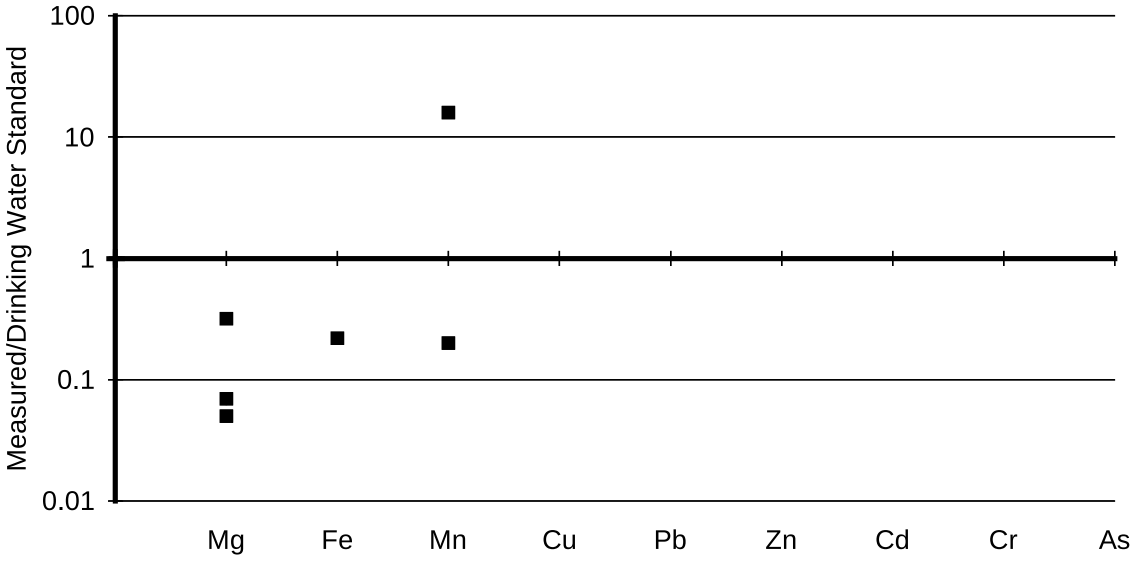

Figure 23. Anomalous elements in waters from typical quartz-adularia precious metal deposits. Three waters are represented on this graph; concentrations are below 1% of the drinking water standard for those elements with no data points. These deposits characteristically contain calcite, which buffers pH at levels too high for most metals to be carried in solution in high concentrations.

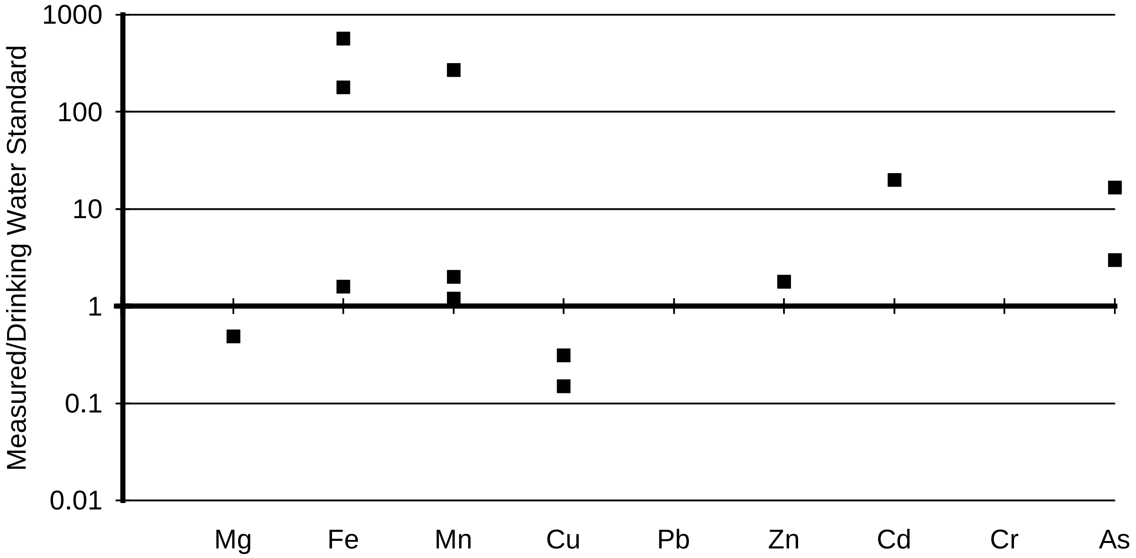

Figure 24. Anomalous elements in waters from three adits in the quartz-adularia precious metal deposits of the National district. These deposits have higher than normal sulfide contents and have had their calcite removed by naturally occurring acid waters (Vikre, 1985, 1987).

Wall rocks at many pits at which waters have been sampled contain substantial amounts of calcite, which tends to buffer the pH at neutral or slightly basic conditions (Figure 9).

Magnitude of Acid-Mine Drainage Problems from Abandoned Mines in Nevada

On the basis of counting adits and shafts shown on all 7.5-minute, 1:24,000-scale topographic maps covering the entire state, field-based estimates of the numbers of adits and shafts that do not appear on topographic maps, and new chemical data in this report, we estimate that the total number of inactive and abandoned mines sites that may (but not necessarily do) have significant acid-mine drainage in Nevada is less than 120. The number of sites that may be of major concern regarding acid-mine drainage is likely to be fewer than 100, largely because the climate in most of Nevada is arid and those few sites that do contain water generally have only small amounts of flow from the mine openings (Table 2). Of the 225,000 to 310,000 inactive and abandoned hardrock mine sites that we estimate to occur in Nevada, less than 0.05% are likely to require significant costs for cleanup.

We sampled seven acidic waters with elevated metal concentrations (sites with pH less than 5 in Table 2). All are waters flowing from adits, but of these, only three or four appear to be significant problems. The worst sites are in the National district (HU-99, 100, and 217), where flows are in the 30 to 40 liter-per-minute range, and in the Pyramid district (WA-95), where flow is only approximately 1.5 liters per minute. The water at site WA-133 flows downstream for only 100 meters before disappearing into the gravel of the streambed. Similarly, the water at site PE-419 flows only 15 meters from the adit before sinking into the dump; the water does not emerge below the dump, and water from the adit below (PE-420) is of considerably better quality. Water from site LA-157, flowing at only 0.6 liter per minute, is diluted by the stream into which it flows, such that 20 meters downstream the pH is 6.5. More study is needed to determine the downstream fate of the acidic waters. Such studies are required at few sites.

Lyon and others (1993) estimated that of approximately 557,650 abandoned hardrock mine sites throughout the United States, 14,950 or 2.7% have surface-water and groundwater contamination that may require remediation. Our estimate of the number of Nevada sites that may be of major concern regarding acid-mine drainage (fewer than 0.05%) are not directly comparable with those of Lyon and others (1993), because their report deals with various types of environmental and safety issues, not just acid-mine drainage. The impacts on groundwater and surface water from ore processing and from other industrial activity at mining and milling sites are not considered in our study, which focuses on acid-mine drainage.

SUGGESTIONS FOR FUTURE WORK

Identification of the Abandoned Mines that may be Environmental Problems

Our statistics on inactive and abandoned mines (Table 9) and our assumptions about the numbers of shafts and adits not shown on the topographic maps imply that we have visited perhaps only 7 to 9 percent of the existing sites. Using geological information, particularly deposit type, knowledge of the mineralogy and buffering capacity of the wall rocks, and information on precipitation and evapotranspiration, we should be able to narrow the group of unvisited adits and shafts to a tractable number.

Knowledge of mineral-deposit type will be helpful in setting priorities for follow-up investigations and for possible cleanup. In particular, those deposits with high concentrations of iron disulfide and low concentrations of acid-buffering minerals are more likely to be problematic than others. In Nevada, the most important types of deposits in terms of acid-mine drainage are quartz-alunite precious metal deposits in volcanic rocks and porphyry copper and porphyry copper-molybdenum deposits in plutonic rocks. Massive sulfide deposits, which meet these criteria as well, are uncommon in Nevada. The largest massive sulfide deposit known in Nevada, the Rio Tinto deposit, is a concern, because it is in one of the wettest parts of the state, and because water flows from the mine area into the Owyhee River, a tributary of the Snake River.

Some quartz-adularia precious metal deposits with higher than normal sulfide contents or with overprints of naturally occurring acid leaching, such as in the National district, are exceptions to the general rule that deposit type alone helps to determine acid-generating characteristics. Care must be taken to look closely at the geology, mineralogy, and alteration. Depending on the alteration zone in which a particular mine site is located, different characteristics can occur within the same overall deposit. In general, propylitic alteration zones, which commonly contain calcite, do not contain acidic waters (Geoff Plumlee, personal communication, 1995), although propylitic zones around some quartz-alunite deposits can contain enough pyrite that available calcite is destroyed during weathering (H. F. Bonham, Jr., personal communication, 1995). Propylitic zones are common in the periphery of many major igneous-hydrothermal ore deposits and, fortunately, tend to be of greater areal extent than the potential acid-generating argillic alteration zones at the centers of the deposits.

Additional sources of information to pursue to find the sites with flowing water include files and staff of the U.S. Bureau of Land Management, who have been accumulating data on abandoned mines on public land; geology professors and students at universities; Nevada Bureau of Mines and Geology staff, and staff of the U.S. Geological Survey, who have worked in mining districts scattered throughout the state; industry geologists; ranchers; and recreationists. Advertisement of the need for information on the Nevada Bureau of Mines and Geology World Wide Web home page on the Internet may attract valuable leads. Modeling, through GIS layers that incorporate information on precipitation, evapotranspiration, geology, and topography, along with locations of adits and shafts, may also help to identify sites with water.

Our study has not addressed environmental impacts from ore processing and from other industrial activity at mining and milling sites. The U.S. Bureau of Land Management is investigating the sites about which they are aware, and the U.S. Environmental Protection Agency includes some mining related sites on its list of possible concern for the Superfund Program (approximately 14 mines, mills, and processing plants, on the list of 62 sites in Nevada, as of 5 December 1995, according to Allen Biaggi, Nevada Division of Environmental Protection, written communication). Investigations are needed at these sites to determine the need for cleanup and the magnitude of environmental impacts.

Follow-up at Sites with Poor Quality Water

Follow-up is clearly needed at those sites with demonstrably poor water quality and potential for contamination of nearby streams and lakes. These include the Pyramid and National districts, the Geiger Grade area, Rio Tinto, and perhaps the Hilltop district. More work is also needed at some sites identified by others (U.S. Bureau of Mines, 1992). Follow-up investigations should focus on flow rates and dilution downstream, reaction with rocks in stream beds, temporal changes in flow rates and water chemistry, and natural biological mitigation by reeds, grasses, and other vegetation. Additional studies of potential impacts on ground-water supplies may be warranted locally. If follow-up investigations indicate the need, additional work on engineering approaches to remediation, such as addition of limestone to buffer acid waters, could be undertaken.

Elements of Concern and Scientific Questions

Several naturally occurring elements are of concern as being potentially toxic to humans and to wildlife. In particular, we lack data on selenium, mercury, and thallium. For this project we were strictly limited in funds available for geochemical analyses. Our analytical technique for selenium had too high a detection limit to provide meaningful data. Mercury, which occurs in many of the ore deposits in Nevada, was not analyzed in all our water samples, but is unlikely to be highly concentrated in them. Nonetheless, waters with mercury concentrations only slightly above background (10 ng/L or less) can produce bioaccumulations of mercury in fish, if local environments conducive to mercury methylation are present in the impacted surface waters. Thallium, which also occurs in trace amounts in many of the Nevada deposits and was not analyzed for most samples, is highly toxic to humans.

Future studies should evaluate not only water quality as it relates to drinking-water standards but also as it relates to other beneficial uses, such as agricultural and wildlife use.

The behavior of colloidal iron compounds and other colloidal particles should be investigated in detail at sites with low pH. In filtering water samples we noticed that colloidal iron is common. Concentrations of arsenic, which tends to co-precipitate with or be adsorbed by ferric iron compounds, may be controlled by the fate of ferric iron as pH is raised through reactions with rocks in the streambeds or through dilution.

Manganese concentrations in waters at inactive and abandoned mines are intriguing. We know from the common occurrence of manganese oxides in and peripheral to major ore deposits of many types that manganese is mobile in the weathering environment. The fact that it is concentrated (relative to drinking water standards) in waters associated with so many types of ore deposits is therefore understandable. Nonetheless, much still needs to be learned about the mobility of manganese, and although it does not appear to be a human-health concern, it may be a local concern for remediation.

Manganese concentrations in waters associated with mines should be put in context with other surface and groundwaters in the state. This can be accomplished by processing data available from the U.S. Geological Survey's databases to create a GIS coverage of dissolved manganese in surface and groundwaters of the state. With GIS one could then correlate high and low manganese concentrations with specific deposit types, and with the proximity of the deposits to regions of elevated manganese in waters. The same type of analysis could readily be done for iron and arsenic.

Further study of ferricretes is warranted. Our data indicate that these rocks can be used as indicators of past flow of water and tracers of past or pre-mining water chemistry. These might be of particular importance in districts where openings left from past activity preclude measurement of baseline concentrations of metals and other trace elements in waters.

Refinements of environmental ore-deposit models (as undertaken by Plumlee and others, 1994) will undoubtedly lead to better abilities to set priorities for remediation and may well help guide mitigation and remediation efforts.

Pit-Lake Geochemistry

This report does not attempt to draw conclusions from the data presented on pit-lake geochemistry, because of time and budget constraints. As noted wall rocks at many pits at which waters have been sampled contain substantial amounts of calcite, which tends to buffer the pH at slightly basic conditions. Nonetheless, pit-lake geochemistry should be monitored with time. The geochemistry and biogeochemistry of pit lakes is likely to change, because of evaporation, variable kinetics of water-rock interactions, changing influx of groundwater as pits fill to steady-state levels, and changing climate on seasonal and decadal timescales.

Predictions of the future of pit-lake geochemistry and biogeochemistry should be checked, and geochemical-hydrogeologic models should be perfected as more data become available. Data in this report allow geochemical models to be checked against the chemical compositions of pit waters.

A number of additional concerns regarding pit lakes, such as impacts on the quality of surrounding ground water, biochemical controls not factored into standard geochemical models, effects of pit backfilling, and risk-assessment methods for wildlife impacts (David Gaskin, written communication, 1995), should be addressed in future studies.

Related Studies

In the future, but not as part of this project, linkages will be established to allow State agencies to share not only this GIS layer but relevant GIS layers relating to geology, groundwater hydrology, streams, average precipitation, evapotranspiration, topography, population centers, and other information that will be useful in evaluating the impacts of abandoned and reclaimed mines on the environment and citizens of the State.

The Nevada Bureau of Mines and Geology is working with the U.S. Bureau of Land Management to develop procedures to analyze potential environmental hazards from abandoned mines on public lands (Shevenell and others, in preparation; Shevenell and Christensen, in preparation). The procedures being developed involve GIS technology that incorporates, among others, data on elevation- and slope-dependent rates of precipitation and evaporation, geological parameters, such as ore-deposit type as it relates to elevated levels of potentially toxic elements, and host rocks as they relate to acid buffering capacity. A ranking of abandoned mine sites in Clark County will be completed in January 1996, and similar ranking should be conducted for the remainder of the state as a tool in setting priorities for more detailed study.

In addition, the Nevada Bureau of Mines and Geology is cooperating with the Bureau of Land Management and other university researchers in long-term studies of the chemical compositions of waters that eventually will be filling open pits at active gold mines (Shevenell and others, 1995; Connors and others, 1994, 1995). The results of the study will provide information required to predict the extent of adverse environmental impacts to be expected at other active and abandoned mines with similar geology throughout the Basin and Range.

The Nevada Bureau of Mines and Geology is also cooperating with the U.S. Geological Survey in a study of arsenic in groundwater. Many otherwise potable supplies of groundwater in Nevada exceed the U.S. Environmental Protection Agency's guidelines for drinking water, but the source is natural, rather than being caused by mining activity. Setting priorities for cleanup requires the recognition of sources of natural contamination. That is, there are some places where attempts to clean up wastes from mining would be futile, because natural contamination would continue to be present after the cleanup.

The Division of Minerals will continue its program to inventory and work toward the securing of abandoned or inactive mines that pose a hazard to the safety of the public in Nevada. The presence or absence of water and related environmental issues associated with these sites will be noted and perhaps incorporated in future studies and remediation.

Applications to Other States

We hope that the results of this study will help other states address issues of inactive and abandoned mines as well as emerging issues of pit-lake geochemistry. We stress the importance of understanding the geological controls on water chemistry. Problems are more likely to occur in and around those ore deposits with high sulfide contents (capable of producing sulfuric acid, which in turn mobilizes metals) and little buffering capacity in the wall rocks (such as in centers of quartz-alunite precious metal deposits, massive sulfide deposits, and certain parts of porphyry copper deposits).

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APPENDIX - LABORATORY AND FIELD PROCEDURES

Laboratory Preparation

Prior to going into the field, 500 ml polypropylene sample bottles, which were to be used to collect waters for cation analyses, were filled with nitric acid (50%) and allowed to sit in the lab for a minimum of 2 days. These bottles were then rinsed a minimum of three times with deionized (DI) water. The bottles were subsequently filled with DI water for transport into the field. The 250 ml bottles to be used for collection of waters for anion analyses were cleaned in the lab by rinsing them with DI water three times. These bottles were also filled with DI water for transport into the field. Each bottle was double-bagged with clean zip-lock plastic bags to minimize the possibility of bottle contamination from dust and dirt.

Dropper bottles were soaked in 50% nitric acid for a minimum of 2 days. These droppers were then filled with reagent grade nitric acid for use in acidifying the cation samples in the field. Dropper bottles were placed inside of larger jars to minimize leakage of acid from the bottles and to keep them clean in the field.

Site Description

At each sampling site, a map of the site was sketched on an enlarged topographic base map noting locations of waters, shafts, pits, adits, drainages, and other distinguishing features. Site locations were described based on distances and directions from landmarks and roads. Photographs of the site were taken in duplicate (one for Nevada Bureau of Mines and Geology files and one for Division of Minerals files), and the numbers of the photos on the roll of film were noted on the field sheets. An example of the field sheet appears at the end of this appendix.

Several factors associated with the site sampled were also noted on field sheets. Any precipitates associated with the water (i.e., Fe oxy-hydroxides) were noted, as was the presence of any odor, algae, or gas discharges. The presence or absence of plants, animals (bats, snakes, deer, etc.), and insects and their larvae (dead or alive) were also noted.

The local geology and alteration of the rocks was also recorded on the field sheets, particularly if this information was not already available from the office database. If water was flowing out of an adit, flow rates were estimated in L/min using a bucket and stop watch. Sample numbers were assigned based on the Division of Minerals site numbers in their field sheets. For instance, the bottles were labeled with LA-101-C (to indicate a water chemistry sample has been collected at site LA-101) or LA-101-R (to indicate a rock sample was collected at the site).

Sampling Shafts and Inclines

When a shaft or incline was to be sampled, it was investigated to determine if there were too many obstacles to sample the water. Care was exercised to avoid losing equipment in these features. A Solinst electronic water level indicator was used to determine the depth to water, and this information was recorded on the field sheet. A Teflon bailer or polypropylene bucket (sampler) was attached to rope to retrieve samples. The bucket was used when it was felt that there was a significant possibility of the sampler becoming lodged and lost in the debris in the sampled feature (because the bailer is significantly more costly than the bucket). The bailer used has two balls, one at the top and one at the bottom, which seat in order that water is collected only at the depth of interest.

The sampler was lowered to collect water, and this first water was used to rinse the sampler. The sampler was then lowered several more times to collect additional water samples. Temperature (T), pH, specific conductance (SC), total dissolved solids (TDS) and ReDox (Eh in mV) were measured in a rinsed beaker filled with the sample water. A Corning Check-Mate field meter was used to measure all of these parameters. The pH and Eh were measured first, and then the water was discarded, and the beaker filled with new water before TDS and SC were measured. Next, enough water to rinse the filter flasks was filtered into the filter flask. This water was then discarded. Additional water was then filtered and used to rinse the polypropylene sample bottles. Care was taken to assure that the bottles and threads were kept clear of dirt. The water used to rinse the sample bottles was then discarded. To keep dirt out of the bottle caps were replaced immediately after bottles were rinsed. Additional sample was retrieved as necessary and filtered (see filtration section below). The 250 ml rinsed bottles were filled brim full, and capped with polyseal caps which displaced a small amount of water and air. A small amount of head space was reserved in the rinsed 500 ml bottle for the addition of acid.

After completion of sample collection, the inside and outside of the bailer or bucket were cleaned with DI water from a 5 gallon carboy. About 200 ml were placed in the bailer and it was shaken. The outside was cleaned with a steady stream of the DI water and then the outside of the bailer was wiped with clean rags or Kimwipes.

The ultimate goal of the sampling from each site was to have a 500 ml acidified bottle filtered through 1.6 µm, a 500 ml acidified bottle filtered through 0.1 µm, a 250 ml unacidified bottle filtered through 1.6 µm, and a 250 ml unacidified bottle filtered through 0.1 µm filters. In most cases it was too time consuming to filter through the 0.1 µm filter, and hence, this type of sample is not available at most of the sites.

Adits

Water was collected in a Teflon beaker or using a Teflon dipper, being careful not to stir up any sediment. If water was very shallow, the ground was dug out, and the sediment was allowed to settle. The same general procedure noted for shafts and inclines was used to collect the samples from adits.

Pits

Water from pit lakes was collected with the bailer or bucket, or, at the small Adelaide pit, with the long-handled dipper. An inflatable rubber boat allowed us to collect samples from the centers of the pits.

pH and Specific Conductance Meter

The meter was kept out of the sun when at all possible because direct sun appeared to result in irregular readings on the meter. The meter was calibrated at least once daily for pH. The meter was always checked for calibration before sample collection, and when the calibration was not correct, it was recalibrated, sometimes resulting in the meter having been calibrated two times within a particular day. The pH probe was routinely checked to assure that the KCl fill solution was no more than 1 inch below the fill hole. If it was lower, KCl solution was added through the fill hole and the probe was tapped to remove air bubbles. Before use, the wetting cap was removed from the probe, rinsed with DI water, and blotted dry with Kimwipes. The probe was also shaken to remove any excess water. The rubber sleeve was slid down so the fill hole was exposed and the probe was gently tapped to remove any air bubbles in the ceramic junction.

To calibrate the digital meter for pH, the probe was placed in pH = 7 buffer and calibrated (the pH value is automatically compensated for temperature). The probe was removed, rinsed and dried and then placed in pH = 4 solution for the second point of calibration. If the sample was between pH = 7 and 10, the meter was recalibrated using a pH = 10 buffer instead of the pH = 4 buffer. Caps on pH buffers were replaced immediately after use. The date, time, temperature and pH readings during the calibration process were recorded on the field sheet. To measure water, the cleaned probe was placed into the water sample with the water being below the fill hole on the probe so that the KCl solution did not become contaminated. The probe was left in the water until the readings had stabilized (generally 30 to 45 seconds). Using the same probe, Eh was measured in mV. The fill hole was covered and the end cap was replaced on the probe. (The end cap always contained a couple of drops of KCl.)

The specific conductance probe was then rinsed, blotted dry with Kimwipes, and shaken to remove any excess water. To calibrate for SC, the probe was placed in the air (reading = 0). Next the probe was placed in 1413 μS conductivity standard for the second point calibration. The date, time, temperature and SC readings during the calibration process were recorded on the field sheets. This calibration was generally done once per day. The SC of the sample was measured, letting the probe sit for $\geq$ 30 seconds. Using the same probe, TDS was measured and recorded on the field sheets. Following use, probes were cleaned using the DI water.

All calibration was done before water was collected for a sample. The sample pH was always measured with pH papers, and the temperature was measured with a thermometer to check the meter readings, and all information was recorded on field sheets.

Filtering

Ideally, two separate samples were collected at each site: one for total water quality, and a second filtered water to be preserved for later analysis if it was deemed necessary. The total water sample (filtered through 1.6 μm paper) and the filtered water (filtered through 0.1 μm paper) each were placed in a 500 ml acidified bottle for cations, and a 250 ml unacidified bottle for anions. A hand-operated vacuum pump was used to draw sample water through the filter papers into the filter flask, being careful not to put excessive vacuum on the pump to avoid boiling/degassing of the water.

Total Water Analyses (1.6 μ filter)

This sample was collected to obtain the total concentration of both dissolved constituents and colloidal particles. The water samples were filtered through stacked filter papers with a 25 μm filter paper on the top, a 5 μ paper in the middle and a 1.6 μ paper on the bottom. This procedure was done because colloids <1.6 μ could become trapped on the 1.6 μ filter paper as debris builds on the paper. By removing larger particles on the larger filter papers before filtration through the 1.6μ paper, this possibility was significantly reduced. Following sample collection, the bottles were returned to their double zip-lock bags and placed in a cooler for transport.

Dissolved Water Concentrations

The water was filtered through a 0.1 μm filter paper to remove colloidal material and microbes. Because these fine filters clog rapidly, pre-filtration through 25, 5, 1.6 and 0.45 μ filter paper was always required. Even with pre-filtrations, the 0.1 μm filter paper clogged rapidly, thus significantly slowing down the filtration process. Hence, due to time constraints, this sample could not be collected at the majority of the sampled sites, and a second set of 1.6 μ samples was often collected at the sites. Following sample collection, the bottles were returned to their double zip-lock bags and placed in a cooler for transport.

Acidification of the Samples

Acid was added to each filtered sample for cation analysis so that the pH of the sample dropped below 2 to keep cations in solution. The pH of the final filtered sample water was not measured in the field as this could have contaminated the sample. The following guidelines were adhered to in the addition of acid. A total of 20 drops of reagent-grade HNO_3 were added to the 500 ml sample if the

If the pH was 7.5 to 8.5, 25 drops were added, and if it was >8.5, 30 drops were added. In some cases, excess acid may have been added to the sample, yet this would not adversely affect analyses.

Sample and Bottle Handling

Disturbance to the water at its source was minimized at all times. Contact of sample water with air was also minimized. Caps were always kept on bottles when they were not being filled or rinsed, and bottles were kept in zip lock bags when the sample was not being poured into the bottles. When the sampling was complete, the cap was placed on the bottle, and taped to the bottle in a clockwise direction. Then the bottle was returned to the zip lock bags.

All sampling equipment was rinsed with DI water before moving to the next sampling site. The equipment was also wiped clean with large Kimwipes. The equipment was always rinsed with the next water to be sampled.

Rock Samples

Samples of ore and wall rocks with potentially interesting alterations were collected at several sites. The sample number and rock descriptions were recorded on the field sheet.

Field Sheets

After a field sheet was filled out for a site, it was placed in a file folder in a safe location in the field vehicle so that it did not become lost or blown away. Photocopies of the sheets were made as soon as they were returned from the field, and two people retained copies.

Analytical Procedures

Water samples were generally analyzed in the laboratory within one week of returning from each field trip. Sample pH was measured with a Corning model 240 pH meter. Acidic samples were measured after calibration with pH 4.0 and 7.0 buffers and alkaline samples were measured after calibration with pH 7.0 and 10.0 buffers.

Most anion concentrations were quantified with a Dionex model 2000i/SP ion chromatograph. Calibration was performed with a synthetic mixed-anion standard. Accuracy can be tied to a round-robin inter-laboratory exercise managed by Chevron and the Northern California Ion Chromatographers Association. Total HCO_3^- was determined in the laboratory by titration. Major and trace cations (Ca, Mg, Na, K, Fe, Mn, Si, Cu, Pb, Zn, Cd, Cr, Co, Se) were determined using a Perkin Elmer Plasma II Inductively-Coupled Plasma-Atomic Emission Spectrometer (ICP). The spectrometer was calibrated with a SPEX multi-element Plasma Shot A standard solution. Strontium and Cs were determined by flame atomic absorption (Sr) and atomic emission (Cs) on a Perkin Elmer model 2380 atomic absorption spectrometer. Calibration was performed with synthetic standards. Arsenic was determined by hydride atomic absorption spectrometry on the Perkin Elmer 2380 spectrometer. Calibration was performed with synthetic standards. Mercury (Hg) was determined by cold-vapor atomic absorption spectrometry on the Perkin Elmer 2380 spectrometer. Calibration was performed with synthetic standards. Thallium was determined by graphite furnace atomic absorption spectrometry after extraction into methyl iso-butyl ketone (MIBK). A Perkin Elmer 2380 spectrometer and HGA 400 graphite furnace were used to perform the analysis. Calibration was performed with synthetic standards.

Following initial evaluation of the data results, the Mn data generated by ICP were checked and verified by atomic absorption. Good agreement was found between the two techniques. Several other cations which might influence a charge balance (Ca, Mg, Na, K, and Fe) were also reanalyzed to verify the initial results. Checking the validity of these analyses was done by (1) verifying that the commercial multi-element ICP calibration standards used to produce the data are themselves accurate (this was done by comparing the standards with a different set of commercial standards); and 2) calibrating with both a blank and a standard of moderate concentration (i.e., from 1.5 to 20 mg/L, depending on the element). Concentrations of some elements in some samples greatly exceeded this range. It was deemed acceptable if this range was exceeded because of the linear nature of ICP calibration lines. However, the accuracy of the high numbers was verified by cross checking with 1000 mg/L standards for the above-mentioned elements. In addition, inter-element interferences were checked on the above-mentioned elements by comparing multi-element standards (which might show inter-element effects) with single element standards. No interferences were observed. Analyses for several anions were also checked (Cl^-, NO_3^-, and SO_4^{2-}) by preparing new calibration standards and rerunning most of the samples.

AML Field Sheet for Sites Containing Water.

Site ID ______________________ Date: ___________ Time: ___________

Weather: ____

Recent rain? ____

Investigator: ______________________

Location:

County: ______________________ Township: ___________ Range: ___________

Topo Sheet: ______________________ Section: ___________ 1/4 Section: ___________

Type of Feature: shaft adit decline ___________° pit

Water Information:

Meter Calibration: Time: not done

Readings: pH = 7 ___________ pH = 4 ___________ pH = 10 ___________ @°C

SC of air: ___________ SC of1413 uS: ___________ ___________ @°C

Temperature: ___________ °C

pH: ___________ @ ___________ °C pH with papers: ___________

Eh ___________ mV @ ___________ °C T with thermometer: ___________

Specific Cond. ___________ umhos/cm @ ___________ °C

TDS ___________ mg/L @ ___________ °C

Alkalinity ______________________ mg/L CaCO3

Flow Rate: ______________________ How Estimated: ______________________

Water Depth: ____

Samples Collected:

1.6 um filtered/acidified ___________ Rock: ___________ ID No.: ___________

1.6 um filtered/unacidified ___________ Type: ______________________

0.1 um filtered/acidified ___________ ______________________

0.1 um filtered/unacidified ___________ Other: ______________________

Photos taken: ______________________

Numbered sequence in roll: ______________________ Roll No.: ___________

Site Description & Comments: