

SECTION 5

Contaminant Fate and Transport

Past activities at the Lava Cap Mine have impacted the local environment, including soil, sediment, and water (surface water and groundwater). There is also the possibility of periodic impacts to air from mine wastes. The potential for further migration leading to human and/or ecological exposure is discussed in this section. Routes of exposure have both physical and chemical factors that may either limit or enhance migration. The physical factors are discussed for sediment, water, and air in Section 5.1, and a brief geochemical evaluation of the water at the Site and potential for contaminant migration is presented in Section 5.2.

5.1 Potential Routes of Exposure

Migration of contaminants from the mine has occurred primarily via tailings transport in LCC southward. Historically, this occurred during active mining operations (primarily 1934 through 1943) via direct release of tailings into LCC for transport to Lost Lake, which served as a tailings impoundment. Since the end of mining operations, tailings releases have occurred through the tailings dam by leakage, flooding, or partial dam failure. Dissolved contaminant concentrations in surface water and groundwater constitute another potential route of mass transport from the site. Elevated arsenic concentrations were found in surface water throughout the area investigated during the RI field program. There are currently insufficient data available to conclude whether or not significant migration of dissolved contaminants away from the mine is occurring in groundwater. Air transport of fine tailings, though not confirmed during the RI field activities, remains a viable route of exposure. A discussion of each of these routes follows.

5.1.1 Sediment

Constituents are concentrated in the tailings at the mine, as evidenced by elevated concentrations in source area soil samples. The catastrophic flood event, which caused partial tailings dam failure during January 1997, also caused an estimated 10,000 cubic yards (cy) of tailings to be transported down the LCC/CC/Lost Lake/LGC drainage system. Evidence of tailings deposition was observed throughout all reaches of this system. Prior major storm events over the past 50 years would also have resulted in significant releases from the mine, although not likely as large a release as the 1997 event because of the dam failure. In addition, it is probable that small but steady releases of tailings past the log dam have been occurring routinely since mining operations ended in 1943.

Continued movement of contaminated sediment and tailings will happen because of continued transport through the dam, flood events that wash tailings over the dam, surface runoff through tailings deposition areas that transport the tailings into the creek, and additional movement of tailings already in the creeks to downstream deposition areas.

Repair or replacement of the log dam on the tailings pile would eliminate or greatly reduce the transport through the dam and flood event routes. Until this is done, some tailings will continue to flow into the drainage system, though this mass will be low, except during significant winter storm events.

Because past flooding events have established the large Deposition Area immediately north of Lost Lake, this area must be considered another tailings source area. Overland flow during winter storms and spring runoff could potentially transport some of these tailings back into CC, where they would migrate further downstream. The expected amount of mass transport would not be high, except during major storms that flood the Deposition Area.

5.1.2 Surface Water and Groundwater

Elevated constituent concentrations are present in the mine discharge that occurs through the caved adit and tailings pile seeps. These discharges flow into LCC, impacting downstream surface water. The mine discharge through the adit represents water draining the subsurface shafts and tunnels of both the Lava Cap and Banner Mines, which are interconnected. Groundwater in contact with the mine adit water has also been affected, as evidenced by the elevated arsenic concentrations in Well 5A (screened adjacent to and beneath the adit discharge point). Shallow groundwater beneath the waste rock/tailings pile has also been impacted, as indicated by the elevated arsenic concentrations in underlying Wells 5D, 5E, and 5I.

There are currently no physical controls on migration of dissolved contaminants. Migration will continue as long as untreated mine discharge (adit and seeps) continues into LCC and groundwater continues to be influenced through contact with mine deposits, adit discharge, or infiltrating water from the waste rock/tailings pile. Groundwater flowpaths are not well known, because of the fractured nature of the aquifer and the paucity of data currently available. If groundwater flow closely follows topographic relief, impacted groundwater would likely be confined to the LCC and CC drainages. However, fracture patterns may run independent of topography, producing groundwater flow directions that are quite different from surface water flowpaths. Additional information is needed to address these issues. Transport of reactive species, such as arsenic, is subject to the important chemical factors discussed in Section 5.2.

5.1.3 Airborne Particulates

Arsenic is identified in Section 4 as the most widespread contaminant detected throughout the Lava Cap Mine Site. Arsenic is reported above the detection limit in only two ambient air samples (Sites 6G and 10C; Tables 4-15 and 4-20). However, the potential for airborne transport of arsenic and other metals may have been underestimated in this study, because of field conditions at the time of sampling and the limited number of samples collected. Two rounds of 24-hour composite sampling were conducted: one during late October-early November 1999 and one in May 2000. During both sampling events, wind velocities were very low. Because meteorology and human activity varies throughout the year, it is likely that conditions could occur that would cause concentrations to exceed the levels reported for these two sampling events and elevate the potential for exposure.

Several factors that could contribute to elevated concentrations of arsenic in ambient air near contaminated areas are:

- Gusty winds
- Dry soil
- Motorized vehicle activity
- Human foot traffic
- Wildlife
- Construction activity
- Removal of vegetation

In general, the highest winds will be present in canyon locations with limited surface friction, such as forests and heavy vegetation. In dry soils, the low moisture content typical of summertime conditions makes the soil particles more susceptible to entrainment because of the loose texture. Human and wildlife activity, also significantly enhance the entrainment process by disturbing the soil surface. Therefore, a high wind event in late summer with substantial human (vehicles, construction, or walking) activity would likely create worst-case conditions. It should be noted that wind speeds in the Nevada County Area average less than 10 miles per hour (NRCS, 1993), indicating that soil disturbed by human activity (and to a lesser extent animal activity) may be the main root of exposure in this area.

Additional sampling in the future will be needed to better assess the impacts of the Lava Cap Mine Site on the ambient air. These future sampling efforts should attempt to quantify contaminant concentrations during the four seasons, with special attention given to wind and soil conditions during sampling. Also, either the collection time or airflow rate during sampling should be increased to provide more sample mass for analysis. This would result in a lower detection limit because of the larger volume of air sampled (air sample results are reported in $\mu\text{g}/\text{m}^3$).

5.2 Contaminant Geochemistry Evaluation

Numerous geochemical factors affect the mobility of trace elements in groundwater and surface water. The most commonly cited is precipitation of minerals, such as oxides, hydroxides, or carbonates (in the case of heavy metals), or salts of barium or manganese (in the case of arsenic). A more common geochemical control is adsorption to soil mineral surfaces. The most common adsorbents are iron oxides and clay minerals. Adsorption or precipitation reactions may maintain dissolved concentrations in very low levels under certain conditions. These conditions include:

- **pH.** Trace heavy metals, such as lead and cadmium, will be less favored thermodynamically to precipitate or adsorb at lower pH values (and therefore be more mobile in the environment). Arsenic behaves in the opposite way, being more mobile at higher pH values (above 7). The pH of water from all monitoring and residential wells sampled was recorded at the time of sampling.
- **Redox potential (measured as Eh).** Some trace elements exist in different states, depending on whether conditions are oxidizing or reducing. Of the COPCs/COPECs at the Lava Cap Mine Site, antimony, arsenic, manganese, and mercury may vary in state over the pH and redox ranges found across the Site. Different states of an element will

have different reactive properties, so changes or variations in redox environment can affect mobility. Redox potential and dissolved oxygen were measured at the time of sample collection for many of the groundwater and surface water samples. However, the samples were exposed to ambient air during the measurement process, which may lead to rapid oxygen exchange and erroneous results. Future groundwater and surface water monitoring will make use of an enclosed flow-through cell to provide more reliable results. Laboratory analyses of sulfide will also be performed to help further characterize whether oxidizing or reducing conditions are present.

- **Ionic strength.** Waters of higher ionic strength (related to TDS, specific conductance, or salinity) will inhibit trace elements from forming precipitates, compared to the same concentration of trace elements in a lower ionic strength water. Adsorption reactions are also affected by changes in ionic strength, as more ions in solution compete for mineral surface adsorption sites. The ionic strength of water is calculated using results from a bulk water analysis or general chemistry analysis. These analyses were performed on monitoring well samples, but not on residential well samples. Bulk water analyses will be performed on selected residential wells as part of future monitoring efforts.
- **Organic matter content.** Natural organic matter often acts as a complexing agent, keeping trace elements in solution that would adsorb or precipitate in the absence of the natural organic matter. In these cases, natural organic matter would increase the mobility of trace elements. Such an occurrence is dependent on the properties of the natural organic matter, the trace element, and the mineral surface. Natural organic matter concentrations were not measured during the RI field effort but are expected to be relatively low.
- **Bulk composition of the water.** Common inorganic constituents in water can, like natural organic matter, form complexes or precipitates with some trace elements. The relative amounts of iron, manganese, sulfate, calcium, and other ions will help determine trace element fate in the environment. Similar to ionic strength (discussed previously), a complete bulk water analysis is required for evaluating possible formation of complexes or precipitates. More complete analyses will be performed on selected wells as part of future monitoring efforts.

All these properties must be accurately measured and carefully examined to assess precipitation or adsorption potential.

Arsenic (with an element abbreviation of As) exists in natural waters in two redox states: As(III) and As(V). They are present as oxyanions (HAsO_2^0 and H_2AsO_4 , respectively, in the pH-Eh range expected at the site). Of the two, As(III) is the more toxic and mobile form. Although the solubility of arsenic minerals is not well understood (Hem, 1985), under oxidizing conditions, As(V) may form insoluble precipitates with calcium, manganese, or barium. Also, arsenic is commonly coprecipitated with iron oxides/hydroxides in these environments (Fuller et al., 1993). Many wells in the study area have elevated dissolved iron (greater than 1 mg/L), indicating at least slightly reducing conditions. Unpublished analyses of mine adit discharge indicate that approximately 50 percent of the dissolved arsenic is As(III) (U.S. Geological Survey, personal communication with Roger Ashley, October 2000). This further supports the idea that groundwater is reducing, in which case,

As(III) would predominate. Surface water is generally very oxidized, strongly favoring As(V).

Though a relatively limited amount of data is available, a brief evaluation of site geochemistry and the potential for arsenic mobility follows.

5.2.1 Surface Water

Reference Area 1 surface water from LCC above the mine (samples 1H, 1I, 1J) has very low TDS concentrations, ranging approximately 20 to 50 mg/L in both winter and spring samples. The positively charged major ions (cations: sodium, potassium, calcium, and magnesium) and negatively charged major ions (anions: chloride, bicarbonate, and sulfate) show a dominance of calcium and bicarbonate, respectively. This is a typical water chemistry type for creek and river waters (Hem, 1985). The pH ranges between 5.7 and 6.5, typical of waters not in contact with carbonate minerals. Available water chemistry for Reference Areas 2 and 3 had similar TDS and general chemistry data. Reference Area 2 includes samples along CC above the LCC/CC confluence (2A, 2B, 2C, 2G, and 2H) and Reference Area 3 includes the sample from LGC (20) above the LGC/CC confluence. One sample, the October 1999 sample from 2C, contained higher concentrations of most constituents.

Water in LCC as the creek enters the source area at the mine has similar general chemistry to the reference areas, but samples below the tailings dam (location 4A) display a distinctly different chemistry: a higher TDS (between 120 and 410 mg/L) and a calcium-sulfate/bicarbonate chemistry. The pH is significantly higher than reference (6.4 to 7.4), probably due to the influence of carbonate material in the ore zone. Sulfate is more concentrated during winter months. This is likely due to increased discharge and runoff through waste rock and other sulfur-bearing materials at the mine site. The chemistry reverts back to a calcium-bicarbonate type during drier periods.

Mine adit discharge (3A), along with seeps from the tailings pile (3B and 3C), is similar in TDS and, during winter sampling, displayed a calcium-sulfate character. Ponded water at the mine displayed a mixed chemistry (calcium with either sulfate or bicarbonate predominant), depending on location. It is clear that TDS and chemical character of the LCC water are altered by the mine discharge.

Samples collected from LCC downstream of the log dam (12F through 12J) are similar in general chemistry to location 4A at the base of the dam. Calcium-sulfate chemistry was observed in January samples, whereas calcium-bicarbonate characterized the October and May samples. The pH varies widely, between 5.7 and 8.6, with higher values typical in winter months, again reflecting the mine's influence. As the distance from the mine increases, the carbonate-rich ore zone is diminished or absent, resulting in lower pH values observed in drier months. Samples in the Deposition Area downgradient of the LCC/CC confluence (14A, 14B, and 14C) display a mid-range TDS (33-77 mg/L) and calcium-bicarbonate chemistry in all seasons. The pH values exhibit a smaller range (6.1 to 7.5) and the seasonal trend observed upstream is not apparent. The confluence of LCC with CC dampens the chemical signature and, as expected, the water chemistry reflects a mixture of Reference Area 2 water from CC with mine-impacted LCC water.

Ponded water in the Deposition Area (15A, 15C, 15D, and 15F) has variable, but generally higher, TDS and is a calcium-bicarbonate type. Tailings would be expected to have lower sulfur content than waste rock, because the tailings have been leached. This may explain why sulfate is not influential in the water chemistry of this area the way it is when closer to the waste rock-dominated surface at the mine.

Lost Lake water is similar to Reference Area 2 surface water in the northern lobe of the lake (16A and 16B), but in the smaller, more tailings-influenced, southern lobe (16C), the TDS is similar to samples from CC upstream of the lake (i.e., 14A, 14B, and 14C). All samples are calcium-bicarbonate type. The pH is generally lower in the northern lobe, when further removed from the mine influence.

Downgradient of Lost Lake (19A, 19B, 19C, and 19E), TDS drops from levels that are similar to those in 14B and 14C down to levels consistent with the Reference Area 3 levels in LGC. The water remains a calcium-bicarbonate, and the pH is somewhat higher than in the reference areas (6.7-7.3 at 19E).

In creek stretches downgradient of the mine, arsenic tends toward lower concentrations in winter and higher ones in fall and spring. This suggests that, although the overall chemistry is affected by winter flushing of sediments, the mass release of arsenic is more consistent. Lower winter concentrations of arsenic indicate that increased dilution may be impacting the mine discharge.

Geochemical conditions are favorable for arsenic precipitation in the creeks. Oxidizing conditions exist, with the presence of iron, manganese, calcium, and barium as potential precipitating agents. For verification, sediment would have to be analyzed for arsenic species. Adsorption of arsenic would also take place on iron oxides, though the degree of adsorption would decrease at higher pH values. Overall, chemical controls are potentially in place that can limit arsenic concentrations and migration in the dissolved form, although more specific data is needed to verify this conclusion. Additional data will be gathered during subsequent monitoring to better characterize the geochemistry of the surface water.

5.2.2 Groundwater

Reference Area 1 groundwater (samples from Soil Boring 1A and Well 1B) is of good general quality, with a low to medium TDS (270-400 mg/L). As discussed in Section 4.2.1, trace element concentrations are all well below maximum contaminant levels (MCLs).

Concentrations of iron and manganese exceed Secondary Drinking Water Standards, but there are no health risks associated with these concentrations. Well 1B was screened in the volcanic breccia (Tvb or lava), which imparts a sodium-bicarbonate signature to the groundwater chemistry. The grab groundwater sample from Soil Boring 1A was derived from the fractured metasedimentary rock (Pms) aquifer and has a calcium-bicarbonate chemistry. The ore zones hosted by the Pms contain calcium carbonate material (U.S. Geological Survey, personal communication with Roger Ashley, October 2000), which likely influences this water chemistry. Carbonates tend to buffer pH to higher values, and the pH of 7.3 in the 1A sample is higher than most residential wells located out of the ore zone to the south. In unbuffered groundwater, pH will typically be in the 6 -7 range. Some residential wells have pH values below 5.6, strongly suggesting active sulfide oxidation. Sulfide analysis will be performed as part of subsequent monitoring to assess this potential.

Monitoring Wells 5D, 5E, and 5I in the source area at the mine are screened in the Pms aquifer and, like the sample from 1A, exhibit a calcium-bicarbonate chemistry. All residential wells are believed to be screened in the upper portion of the Pms unit. Calcium is the dominant cation in most residential wells (15 of 18), consistent with the other Pms aquifer wells. The remaining three wells were a mixed cation-type.

Well 5A near the mine discharge from the adit is screened across both waste rock and the shallow Pms zone. The sampled water has a distinct calcium-sulfate character. The waste rock was not processed and, as a result, would contain abundant sulfide minerals; this is a possible explanation for the observed water chemistry. Because the tailings were subjected to a leaching process, the sulfides were likely removed or greatly reduced. Groundwater samples from tailings-dominated soils (5B, 5C, 13A, 13B, 13Q, and 13R) are all calcium-bicarbonate water types with TDS values similar to the Reference Area 1 groundwater.

Under the pH conditions observed at the Site and the estimated redox conditions, calculations indicate that groundwater is likely in equilibrium with iron hydroxides. These are very common adsorbents of both forms of arsenic in natural systems. It is therefore plausible that arsenic concentrations in groundwater may be limited by adsorption to these hydroxide minerals. In fact, many studies have concluded that adsorption is a more effective controller of arsenic concentration than precipitation is. However, given the available data set from the Site, it is not possible to estimate to what degree adsorption is occurring.

The only residential well downgradient of the mine that has significant concentrations of arsenic is Well 11AL. This is also the closest residential well downgradient from the mine. The arsenic concentration ranged from 29 to 46 $\mu\text{g}/\text{L}$ in four samples. Though these concentrations are below the arsenic MCL, they are above the average reference concentration of 24 $\mu\text{g}/\text{L}$. The next downgradient residential well (11AK), approximately 600 feet south of Well 11AL, contained only 1.2 $\mu\text{g}/\text{L}$ arsenic. There is insufficient data to determine whether Well 11AL reflects natural variation or if it has been impacted by Lava Cap Mine activity. Collecting additional information on well completions, more complete chemical analyses, and a larger sample database will help to resolve this question.