GROUNDWATER RESPONSE TO THE END OF FORTY YEARS OF COPPER HEAP LEACH OPERATIONS, BINGHAM CANYON, UTAH[1]

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Abstract. There are many mature Cu heap leach facilities in the western United States that will face closure in the next decade. However, there is little published information on the response of groundwater systems to the cessation of leaching. Copper dump leaching was conducted on the Bingham Canyon Eastside waste rock dumps between 1963 and 2000. Leach water discharging from the toe of the waste rock dumps had a typical pH of 2.9 and a total dissolved solids concentration of about 90,000 mg/L. During active leaching this water was recirculated, but now it is neutralized as it enters the mine's tailings and process water circuit. With the end of leach water application, average annual flows discharging from the toe of the dumps have declined rapidly from 1500 L/s in 1998 to approximately 45 L/s in 2004. Average acidity in water discharging from the toe of the dumps declined by almost thirty percent between 2000 and 2005, and since 2003, most solute concentrations have declined by about ten percent. The only exception is Cu concentration which has increased by a factor of four since 2000. Water quality in the underlying saturated bedrock has also begun to improve. Since 2000, sulfate concentrations have declined by a third, alkalinity has increased, and Cu and Zn concentrations have declined by up to ninety percent in water from tunnels that receive at least a portion of their inflows from beneath the waste rock footprint. Water quality in bedrock and alluvium down gradient of the dump toe began to improve after the leach water collection system was upgraded between 1994 and 1996. Arithmetic mean sulfate concentrations in down gradient alluvial monitoring wells declined from a high of 6000 mg/L in 1994 to less than 1000 mg/L in early 2004. These data illustrate how the groundwater system responds to the termination of waste rock and heap leach operations and may provide a useful analogue for the closure of other Cu heap leach operations.

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Introduction

With the advent of solvent extraction-electrowinning technologies in the 1970s and 1980s large scale Cu heap leach operations have become increasingly common. Leaching at many older operations was conducted on unlined Cu-bearing heaps and waste rock dumps which resulted in groundwater contamination beneath and adjacent to the facilities. Many of the mature heap leach operations will also face closure in the next decade. Although there is much information available on the closure of CN Au heap leach operations, few papers have been published on the closure of large Cu heap leach facilities (Ford, 2000; Drummond, Robinson and Smith, 2003).

The Bingham Canyon porphyry Cu deposit is located in the Oquirrh Mountains immediately west of Salt Lake City, Utah. Large scale open pit Cu mining began at the Kennecott Utah Copper Bingham Canyon Mine in 1906 and mining is currently planned to continue for more than a decade. The great majority of Cu has always been produced by beneficiation and smelting operations, but since 1941 Cu has also been recovered from the waste rock dumps by active heap leach operations. In 1963 leaching began on the Eastside waste rock dumps, which are the subject of this study. The waste rock dumps are unlined and the leach operations generally recovered the water as it perched at the bedrock/waste rock contact and discharged from the toe of the dumps. In September 2000 all leach water applications were terminated, and drain down water has been collected, treated and used in the process water circuit. Since 2000 water quality and flows have been monitored at all significant surface discharge points, in tunnels, and in an extensive monitoring well network. These data illustrate how the groundwater system has responded to the termination of long-term waste rock dump leach operations and may provide a useful analogue for the closure of other large unlined Cu heap leach facilities.

Physical Setting

Waste rock placement on the eastern margin of the Oquirrh Mountains began in 1953 and is still ongoing. The dumps were originally constructed by the advancement of large angle of repose dump faces from near the top of a ridge that separates the Bingham Pit to the west from the Jordan Valley to the east (Fig. 1 and 2). Historically, the waste rock was dumped directly on the pre-mining topographic surface. All current waste rock placement on the Eastside dumps is occurring on existing waste rock surfaces with a substantial step back from the outer angle of repose slopes to avoid increasing the waste rock footprint. The total mass of waste rock contained within the Eastside dumps is estimated at approximately 2.2 billion tons. The Eastside dumps cover approximately 1100 hectares with a maximum thickness of about 300 meters and range in elevation from 1700 to 2300 meters above sea level. The waste rock is composed of a mixture of quartzite, monzonite and lesser limestone that is variably mineralized with pyrite and lesser chalcopyrite, sphalerite and galena. Copper concentrations within the placed waste rock have averaged less than 0.1%. Most of the waste rock is net acid generating and will acidify when exposed to surface weathering conditions (Borden, 2003).

The original ground surface beneath the waste rock dumps slopes between about 15 to 25 degrees to the east. The dumps completely fill a series of east-west trending drainages that are separated by buried bedrock ridges. The western portion of the waste rock dumps are underlain by a Pennsylvanian and Permian sedimentary sequence composed of interbedded quartzite and calcareous sandstones with lesser limestone and siltstone (Welsh and James, 1961). A thick wedge of Tertiary volcanic rock is present on the eastern flank of the Oquirrh Mountains and beneath the eastern margins of the waste rock dumps (Fig. 2). The volcanics are composed of volcanoclastic latite porphyry flows, breccias and agglomerates with minor latite dikes and sills (Smith, 1961). A relatively impermeable clay layer is commonly present on the upper weathered portion of the volcanics. The contact between the volcanics and the underlying Paleozoic bedrock dips approximately 25 degrees east and the volcanics have been measured to be more than 700 meters thick immediately down gradient of the Eastside waste rock dumps. The contact between the volcanic rocks and overlying Plio-Pleistocene alluvial fan and basin fill deposits is exposed approximately one kilometre east of the dump toe. However, thin fingers of alluvium also extend up the major east-west trending drainage lines and in some drainages alluvium may extend beneath the waste dumps. The unconsolidated alluvium is predominantly composed of sand and gravel with lesser silt and clay interbeds near the range front. The sediments thicken and become more fine-grained to the east and are more than 300 meters thick towards the center of the valley. The saturated Plio-Pleistocene alluvial sequence is the most permeable geologic unit in the area.

The following flow paths have been identified (Fig. 2):

1) Between 1963 and September 2000, leach water was applied to the top of the Eastside waste rock dumps. Precipitation that is not removed from the dump surface by runoff or evapo-transpiration also infiltrates into the dump. On average the Eastside waste rock dumps receive between about 400 mm/year of precipitation at lower elevations and 600 mm/year on higher dump surfaces. Evaporation is about twice the precipitation rate.

2) The great majority of the water that infiltrates into the waste rock surface perches at the base of the waste rock due to the lower permeability of the underlying bedrock (Solomon et al, 2001). It then flows to the east where it ultimately discharges at the toe of the dump. Since the mid 1990's when accurate measurement began, more water has been collected at the toe of the dumps than was applied to the top of the dumps. Given the geometry of the buried drainage divides and the up gradient location of the dewatered open pit, this extra water is likely derived from precipitation that has infiltrated into the Eastside dumps rather than from some up gradient source (Fig. 1).

3) Some of the water passes through the waste rock/bedrock contact and travels vertically through the vadose zone to the regional water table. The vadose zone has been measured to be up to 230 meters thick beneath the bedrock/waste rock contact. Infiltration through the Paleozoic bedrock (3a) is likely more significant than infiltration in the volcanics (3b) because in bulk the Paleozoic bedrock is at least an order of magnitude more permeable. Fine grained soils, clay-rich weathered horizons and cemented layers immediately beneath the base of the waste rock may locally produce low permeability horizons that also inhibit infiltration.

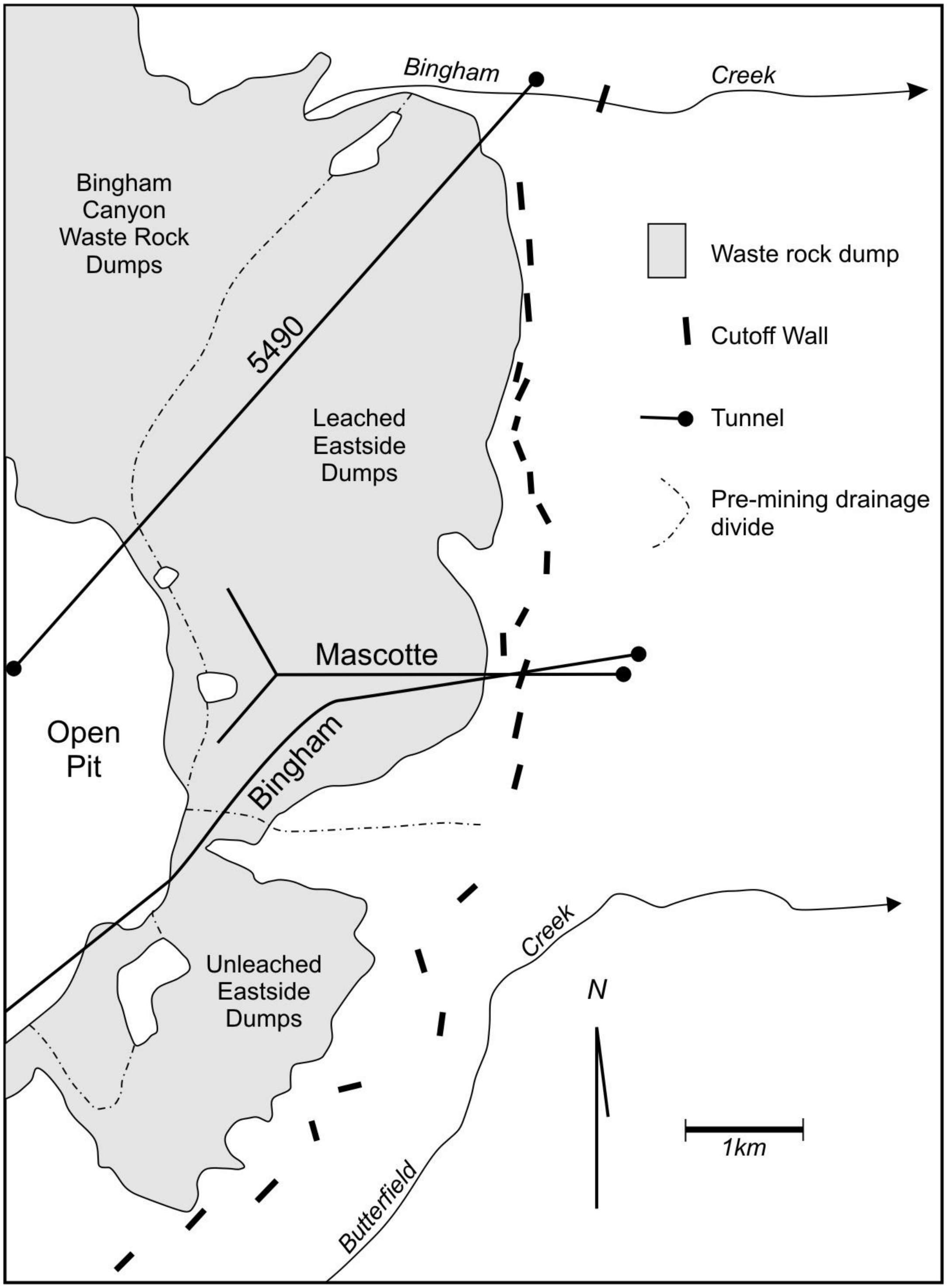

Figure 1. Map of the Eastside Waste Rock Dumps

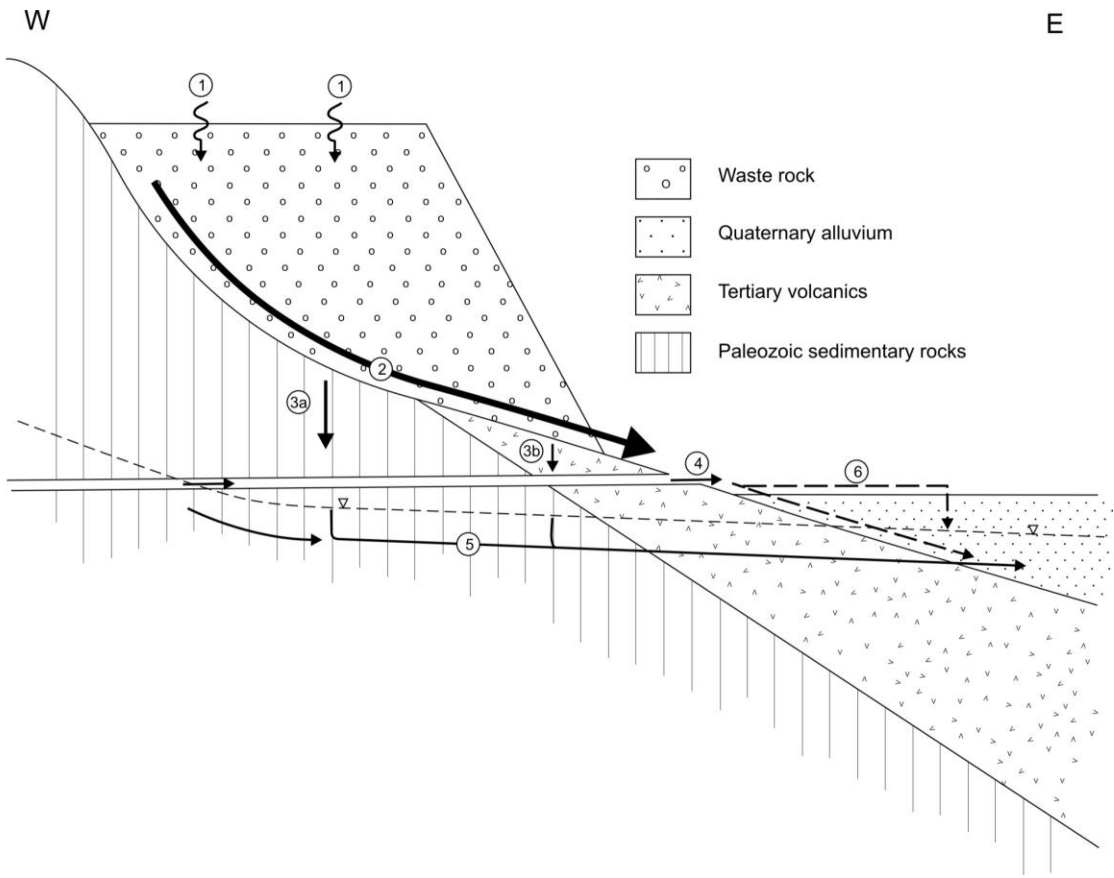

Figure 2. Conceptual model of water movement in the vicinity of the Eastside waste rock dumps (not to scale) (see text for explanation of flow paths).

4) Three sets of free draining underground workings beneath the Eastside waste rock dumps capture some of the bedrock groundwater (Fig. 1). This water is collected when it discharges from the mine portals. The underground workings are generally located between 50 and several hundred meters below the bedrock/waste rock contact.

5) Water that reaches the regional water table will generally flow down gradient to the east, ultimately discharging from the bedrock to the alluvial aquifer. However, flow is inhibited by the thick low permeability volcanic sequence that is present along the eastern range front. Dewatering in the Bingham open pit (Fig. 1) may also cause some westward flow towards the pit within the Paleozoic bedrock beneath the waste rock dumps.

6) Water is currently collected and contained as soon as it discharges from the dump toe (generally within 50 meters of dump toe). However, before 1993 water discharging from the toe was allowed to flow for up to 1200 meters to the east in a series of unlined drainages, ditches and ponds. This allowed some leach water and acid rock drainage (ARD) to reinfiltrate into the underlying alluvial aquifer.

Operational History

Since 1941, Cu recovery from leach water has been performed at a variety of sites and facilities but has always involved the use of scrap iron to remove the Cu from solution via an ion exchange process. In the 1960s and 1970s, at the height of the Cu waste dump leach operations at Bingham Canyon, about 3000 L/s of Cu-bearing leach water was being treated, producing about 50,000 tons of Cu per year. The recycled leach water had a low pH because of natural acid generation in the waste rock and because sulfuric acid was periodically added to enhance Cu leaching. The leach water also had a total dissolved solids (TDS) content of almost ten percent because of solute contributions from the waste rock and evapo-concentration as the water was continuously captured, recirculated and sprayed onto the waste rock surfaces.

Leach water application sites were located on the northern 840 hectares of the Eastside dumps. The southern 260 hectares, separated from the northern area by a bedrock ridge, were never leached (Fig. 1). Leach water was applied to the top of the Eastside dumps by flooding or by application with sprinklers. It was then collected as it discharged to the surface from the toe of the dumps. Leach water applications to the top of the dumps increased significantly between 1995 and 1998, and flows from the dump toe which averaged about 900 L/s in 1992 and peaked at about 1500 L/s in 1998 (Fig. 3). The initial collection system was composed of a series of earthen dams and unlined channels and ponds located in each major pre-mining drainage down gradient from the Eastside waste rock disposal area. Before 1993 the leach water was allowed to flow anywhere from 400 to 1200 meters down-drainage below the dump toe before it was collected and piped to the processing plant. This old leach collection system allowed significant volumes of leach water to infiltrate into the underlying alluvium and volcanic bedrock after it had discharged from the toe of the dump. Between 1993 and 1996 Kennecott Utah Copper completed a major upgrade to the Eastside Collection System at a cost of approximately fifty million dollars. The point of leach water capture was moved to the immediate toe of the waste rock dumps from which the water was transported in pipes to the Cu precipitation plant. Lined ponds with multiple leak detection systems were constructed to contain the water until it was recirculated to the top of the waste rock dumps. Waste rock and contaminated soils from the drainages below the Eastside dumps were removed and returned to the main waste rock dump footprint. Concrete cut-off walls were also constructed in the 24 drainages down gradient from the toe of the Eastside dumps (Fig. 1). The cut-off walls were installed by excavating through the alluvium and weathered bedrock and keying the base of the structures into the underlying fresh bedrock. Cutoff wall depths vary from approximately 2 up to about 30 meters. Sumps, drains and pumps were established on the up gradient side of the cut-off walls to collect any water that is impounded by the structure.

The cut-off walls thus prevented any down gradient contaminant migration in the alluvial filled drainages on the east side of the waste rock dumps. However, with the termination of leach water applications and the upgrading of the surface collection systems at the immediate toe of the dumps, most of the cutoff walls have very low flows and some are now dry because there is little perched water in the alluvium between the walls and the toe of the dumps. The Eastside Collection System is not intended to capture groundwater flow within the underlying volcanic bedrock. However, the permeability of the alluvium is two to three orders of magnitude higher than for the underlying Tertiary volcanics, so the most significant contaminant migration pathway has been effectively controlled (Kennecott Utah Copper Corporation, 1998).

Leach water applications to the Eastside Waste Rock dumps were reduced in 1999 and all leach water application at the Bingham Canyon mine was terminated in September, 2000. The drain down water and meteoric acid rock drainage (ARD) is still collected by the Eastside Collection System, and the water is still treated by ion exchange to recover the Cu. However, from the Cu recovery plant, the water is now transferred to the tailings line where it mixes with the much larger flow of the mine's process water circuit. Lime is added upstream at the concentrator to maintain the basic pH needed to optimize Cu recovery during flotation. When necessary to maintain a neutral pH, lime is also added to the tailings line immediately below the inflow point for the acidic waste rock dump flows. This treatment precipitates most of the metals from solution along with a large mass of gypsum which is co-disposed with the tailings. Acid/base accounting samples collected in the tailings line above and below the point of acid water addition since 2000 indicate that there is no statistically significant change in neutralization potential in the solid tailings. However, there is an approximately 50 percent increase in the sulfate concentration in the solid tailings before and after the addition of the acidic water. Those solutes that are not precipitated within the tailings (such as sodium, chloride, magnesium and residual sulfate) are stored in the process water circuit and are either recirculated with the water used in the concentrator or discharged to the Great Salt Lake when Kennecott releases water from its permitted outfall point. The Great Salt Lake has a natural salt content that is an order of magnitude higher than the process water. The natural dissolved solids content of the lake fluctuates around ten percent and is dominated by Na, Cl^-, SO_4^{-2}, Mg, and K.

In compliance with its groundwater discharge permit for the Eastside Collection System, Kennecott measures monthly flows in each of the drainages below the waste rock dumps. Water samples are also collected semi-annually from each drainage and analysed for a broad suite of solutes. Tunnel flows are measured quarterly and sampled semi-annually. A network of approximately 60 operational and compliance monitoring wells has also been established within the down gradient bedrock and alluvium. About 40 of these wells have been sampled regularly since 1992. These wells are generally located within the individual drainages from 20 to 1300 meters down gradient from the toe of the waste rock dumps. These data provide an excellent record of the response of the groundwater system to the upgrading of the Eastside Collection System between 1993 and 1996, and the termination of leach water applications in 2000.

Response of the Groundwater System

Three distinct components of the local groundwater system have been impacted by ARD and leach water applications: 1) the perched flow that discharges to the surface from the toe of the dumps, 2) saturated Paleozoic bedrock that underlies the waste rock/bedrock contact, and 3) saturated alluvium and volcanic bedrock that is located down gradient from the waste rock dumps (Fig. 2).

Water Perched at the Waste Rock/Bedrock Contact

The mean annual flow discharging from the toe of the Eastside waste rock dumps has declined from 1500 L/s in 1998 to 45 L/s in 2004 and 2005. This represents a 97 percent reduction in flow over six years. The initial drain down was even more rapid, with a 94 percent reduction in discharge in only three years (Fig. 3). The initial rapid drain down likely occurred as preferential permeable flow channels were rapidly dewatered. This has been followed by a slower decline as the larger mass of less permeable waste rock surrounding the channels gradually dewaters.

Figure 3. Eastside collection system mean annual flows.

The actual behaviour of the toe discharge is more complicated than the annual averages suggest (Fig. 4). Monthly flows declined steadily until the end of 2003 when they reached a low point of 33 L/s. Since then they have actually increased to an average of 45 L/s. This increase in flow from the leached areas on the Eastside dumps corresponds to the beginning of a sustained higher precipitation period in late 2003 (Salt Lake City [SLC] precipitation on Fig. 4). There has been a corresponding increase in toe discharge from portions of the Eastside waste rock dumps that were never leached during the 2004/2005 period (south end flows on Fig. 4). This increased flow is likely the result of increased meteoric water infiltration into the Eastside waste rock dumps.

Water discharging from the dump toe is highly acidic and averages 9% dissolved solids dominated by SO_4^{-2}, Mg. and Al (Table 1). Iron, Mn, Cu and Zn are also significant metals in solution. Because this water was continuously recirculated, the feed solution that was applied to the top of the dumps during active leach water applications had the same chemistry except that Cu concentrations were much lower and Fe concentrations were higher. Concentrations of all these solutes except Cu have been relatively constant or have exhibited a small decline since leach water application was discontinued (Fig. 5). However, due to the rapidly decreasing flows and the relatively minor changes in water quality, the flux of all solutes has decreased by more than an order of magnitude since 1999 (Fig. 6).

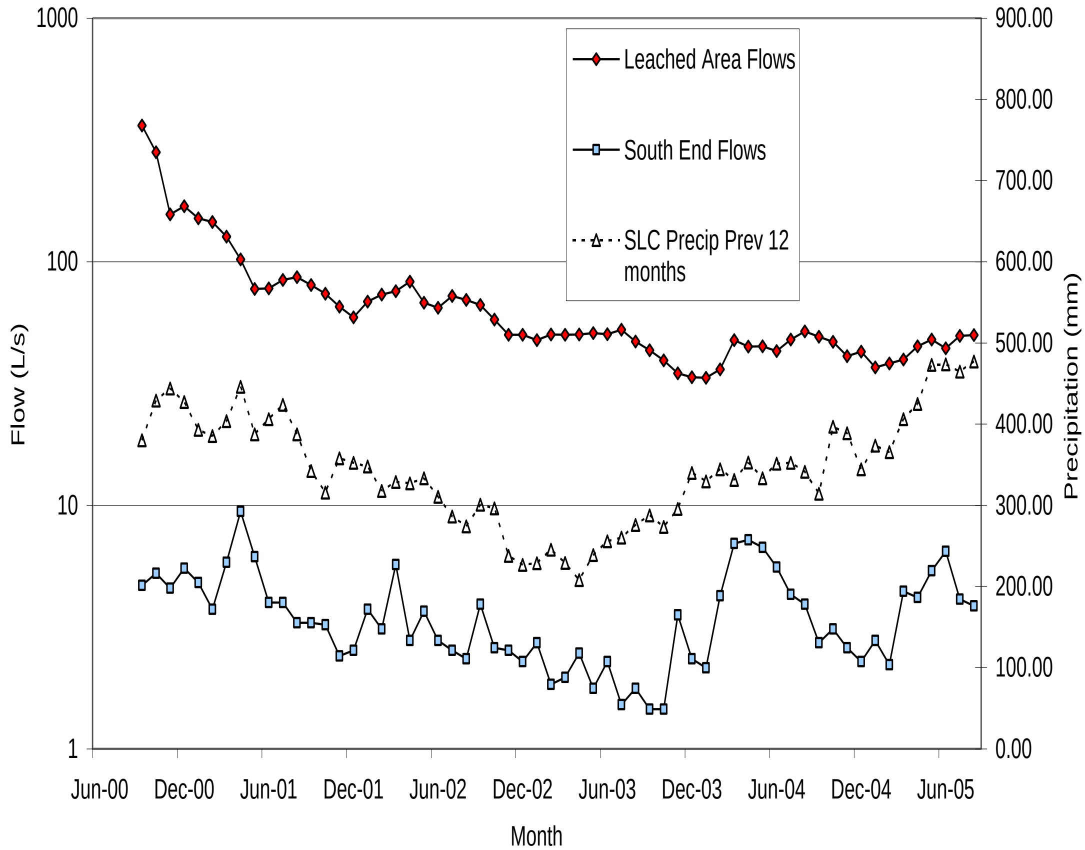

Figure 4. Eastside collection system monthly flows.

Between 1999 and 2005 mean Cu concentrations in the toe discharge have increased from 140 to 600 mg/L. During active leaching, Cu-depleted water was applied to the waste rock dumps. The rapid drain down indicates that much of this water flowed through preferred pathways and had insufficient contact with Cu-bearing rock to entrain much additional Cu. As drain down has progressed, a higher percentage of the water reporting from the toe is likely derived from less permeable and slower flow paths within the dumps, increasing contact time with Cu-bearing waste rock and contributing to the higher Cu concentrations. Similar increases in Cu concentration have been noted during the decommissioning of other Cu heap leach operations (Ford, 2000).

Table 1. Typical Water Quality for Eastside Collection System Flows

Solute	Typical Concentration (mg/L)
pH	2.9
Total Dissolved Solids	90,000
Sulfate	60,000
Acidity	30,000 (as $CaCO_3$)
Magnesium	10,000
Aluminium	3000
Calcium	500
Manganese	350
Iron	250
Chloride	250
Copper	140 increasing to 600
Zinc	170
Sodium	40
As,Cd, Cr, Se	<1

Mean acidity in the drain down water has declined by almost thirty percent since leach water applications were ended in 2000. Some of this decline occurred immediately after leach water applications were terminated (2000 to 2001) and the remainder has occurred between 2003 and 2005. The acidity value is particularly important because it is closely related to the lime additions required to neutralize the ARD discharged to the process water circuit. Between 2003 and 2005, mean annual TDS, SO_4^{-2}, acidity, Mg and Zn concentrations in the dump toe discharge have all declined by between 8 and 13%. This water quality improvement corresponds to the period with increased precipitation and with evidence of an increasing meteoric component in the toe flows. These relatively minor improvements in mean water quality may represent the first evidence of measurable dilution of the drain down water with infiltrating precipitation since leach water applications were discontinued in 2000.

Bedrock Beneath the Waste Rock Footprint

The bedrock beneath the footprint of the Eastside waste rock dumps is intersected by three sets of underground workings and a single boring. The Mascotte tunnel workings extend beneath the southern half of the leached area footprint and probably provide the most representative sample of average conditions in the bedrock beneath and immediately east of the Eastside waste rock dumps (Fig. 1). The Mascotte tunnel has a mean flow of about 0.3 L/s. The Bingham tunnel workings are much more extensive, but are located on the southern margins of the leached area. The Bingham tunnel workings flow at approximately 60 L/s, but the great majority of this water is derived from areas outside of the Eastside waste rock dump footprint. The 5490 tunnel passes beneath the northern end of the leached area. It is located above the regional water table and it has never produced flows greater than 0.1 L/s. The 5490 tunnel has been too dry to sample since the spring of 2002.

All of these Paleozoic bedrock sampling points have been impacted by ARD and leach water leakage. Samples from all three locations have elevated sulfate and TDS, but it is apparent that the acidity of the leach water has been neutralized before reaching the water table and solute concentrations have been attenuated (Table 2). Since sampling was initiated in 1998, the pH at all three locations has always remained above 6.0 and alkalinity has always remained above 100 mg/L. It is likely that the acidity has been neutralized by contact with calcareous sandstone and volcanic rock along the flow paths in the vadose zone and in the saturated bedrock.

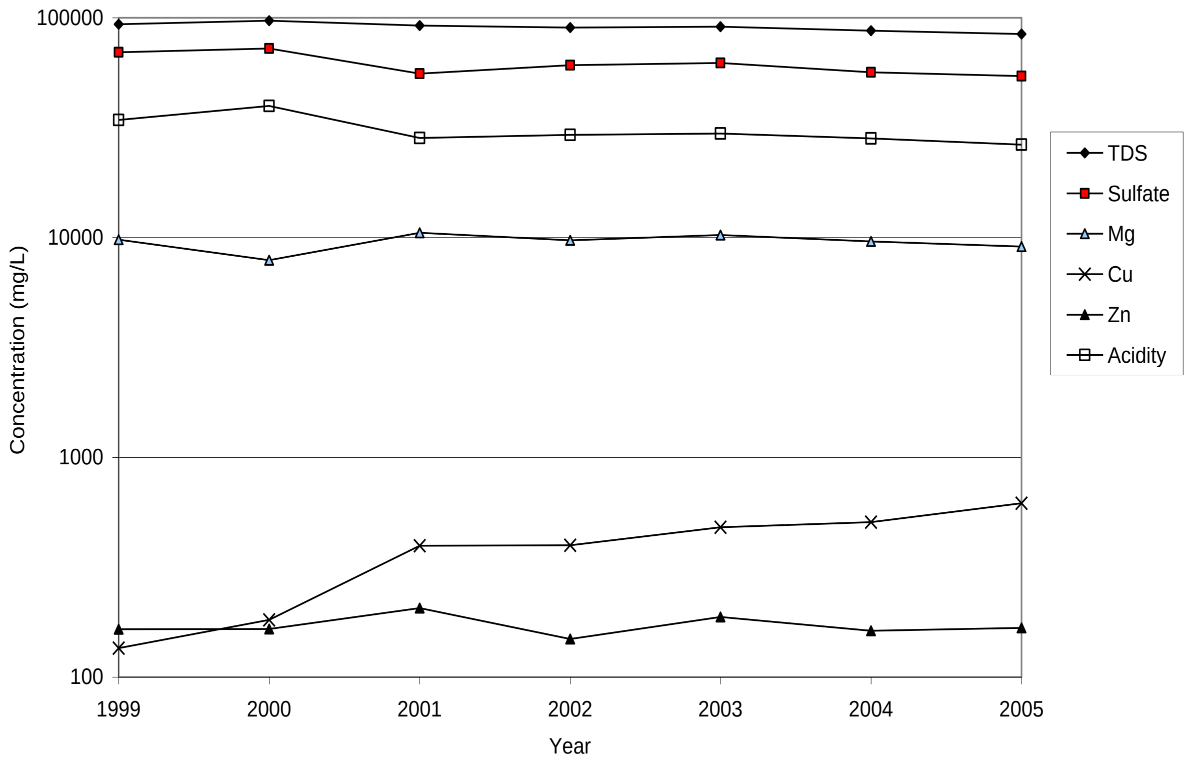

Figure 5. Annual mean solute concentrations of flows discharging from the toe of the Eastside waste rock dumps.

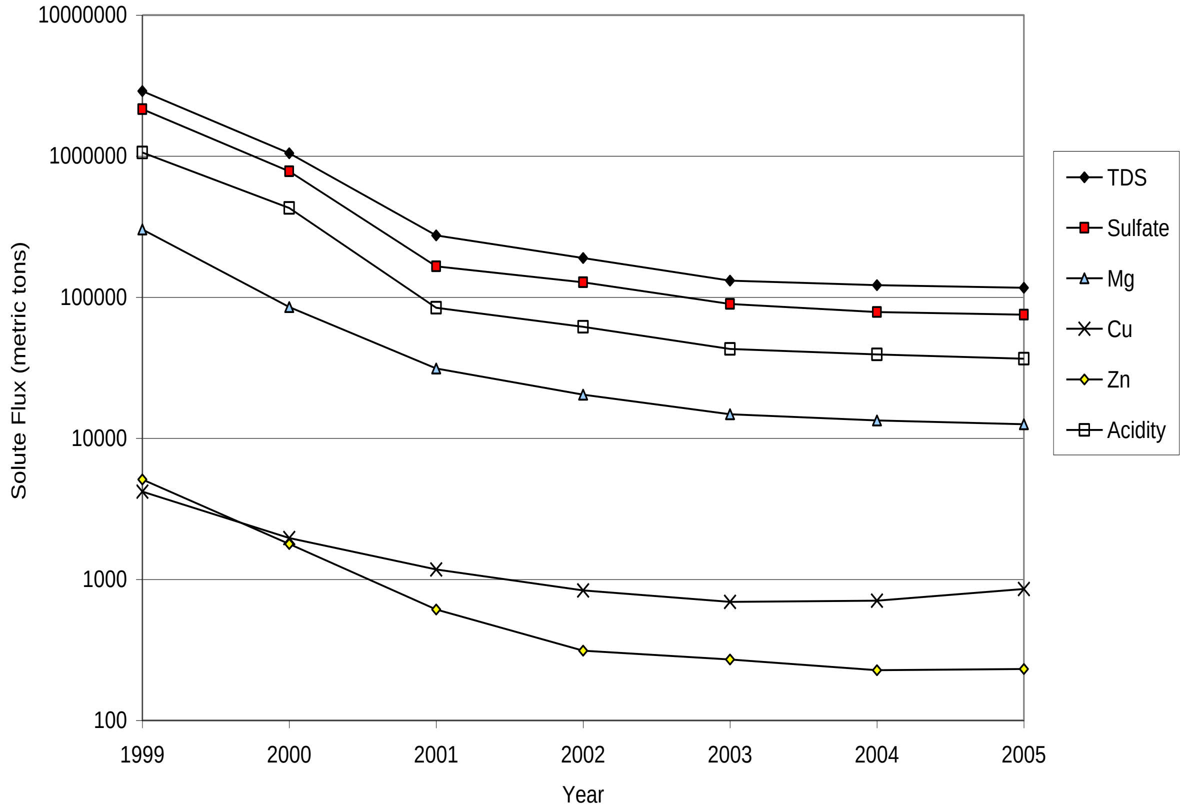

Figure 6. Annual flux of solutes from the toe of the Eastside waste rock dumps.

Water quality within the Mascotte and Bingham workings has been improving steadily since regular sampling began in 1998. Sulfate concentrations have declined by approximately a third in both tunnels and alkalinity has increased (Fig. 7). Zinc and Cu concentrations in water from the Mascotte tunnel have declined by almost an order of magnitude (Fig. 8). Copper concentrations in the Bingham tunnel have always been below detection, but Zn concentrations have also declined by a factor of three. It should be noted that the Bingham and Mascotte workings were excavated into the base metal (Zn, Pb, Ag) halo surrounding the Bingham porphyry Cu deposit, so it is likely that much of the Zn and SO_4^{-2} has been derived by sulfide oxidation within the workings themselves. However, the significant decline in solute concentrations since 1998 (when leach water applications began to be reduced) likely indicates that a smaller volume of waste rock contact water is reporting to the workings (particularly for the Mascotte Tunnel).

Table 2. Mean water quality in Paleozoic bedrock sampling points (1998-2005)

Location	pH	Alkalinity (mg/L $CaCO_3$)	TDS (mg/L)	Sulfate (mg/L)
Mascotte Tunnel	6.2	220	4200	2400
Bingham Tunnel	7.7	210	1800	1200
5490 Tunnel	6.4	330	2200	1100

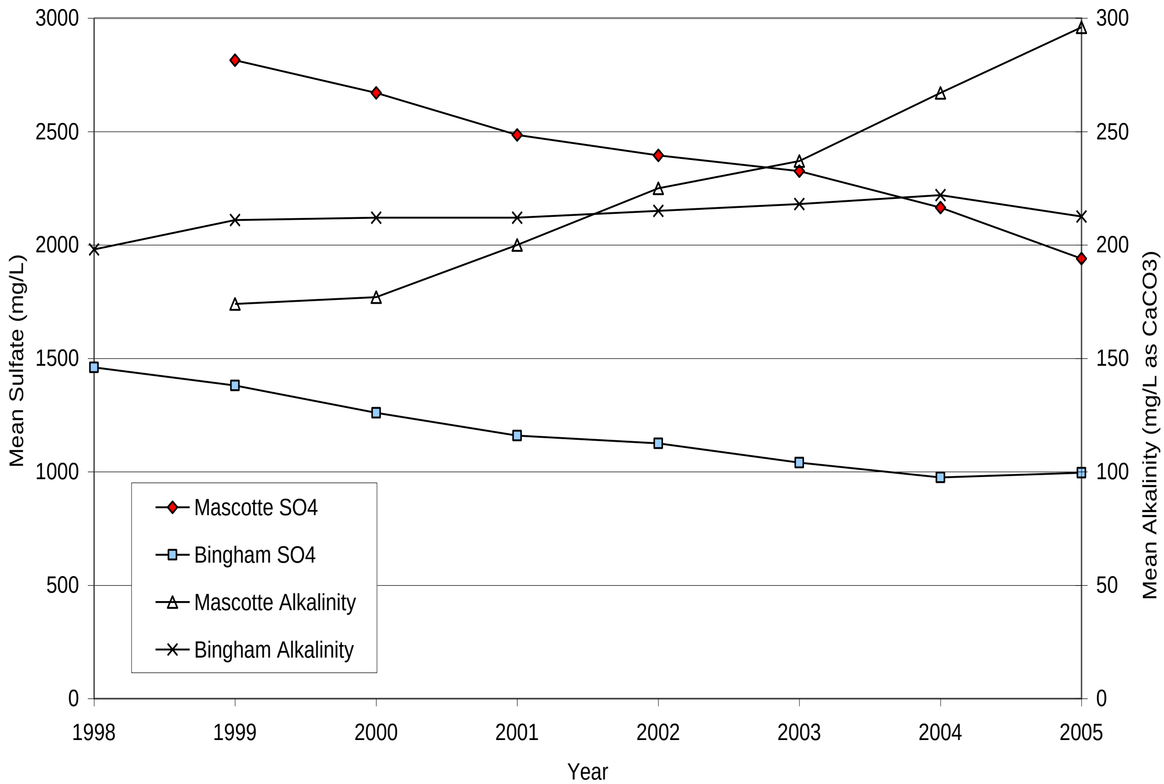

Figure 7. Sulfate and alkalinity in flows from underground workings.

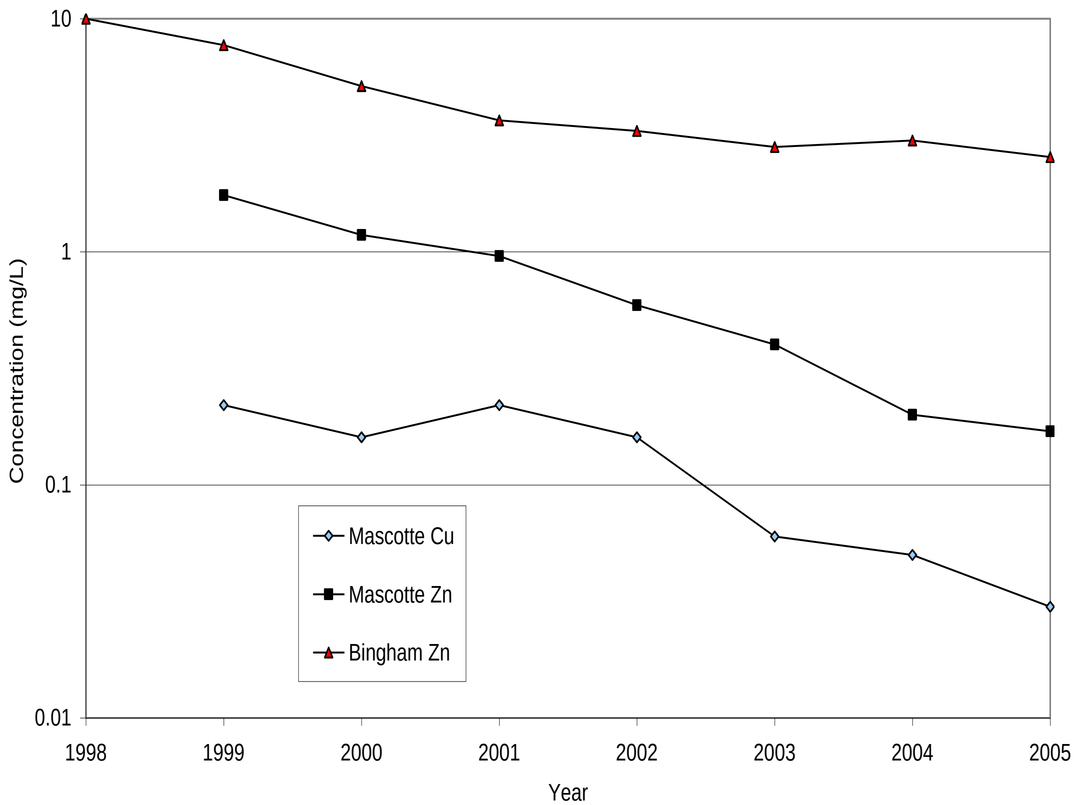

Figure 8. Copper and zinc concentrations in flows from underground workings.

Down Gradient Alluvium and Bedrock

Water levels within the down gradient monitoring well network have responded rapidly to changes in leach water management. As flows from the toe of the waste rock dumps increased between 1992 and 1998, mean water levels in the wells increased by about four meters (Fig. 9). With the rapid decline in water discharging from the toe of the dumps since 1998, the water levels in the down gradient monitoring well network have declined almost seven meters from the 1998 peak. It should be noted that the low precipitation in 2002 and 2003, ongoing dewatering around the open pit, and dewatering associated with remedial actions in the alluvial aquifer may also have contributed to the rapidly falling water levels since 1998.

Groundwater in the down gradient bedrock and alluvium is most contaminated at and immediately below the water table (Fig. 10 and 11). Wells that are screened the furthest below the water table tend to be the least contaminated, and bedrock wells tend to be less contaminated than wells screened in the overlying more permeable alluvium (Fig. 12). Figures 10 to 12 are based on the arithmetic and geometric mean SO_4^{-2} concentrations in the forty monitoring wells that have been sampled regularly since 1992.

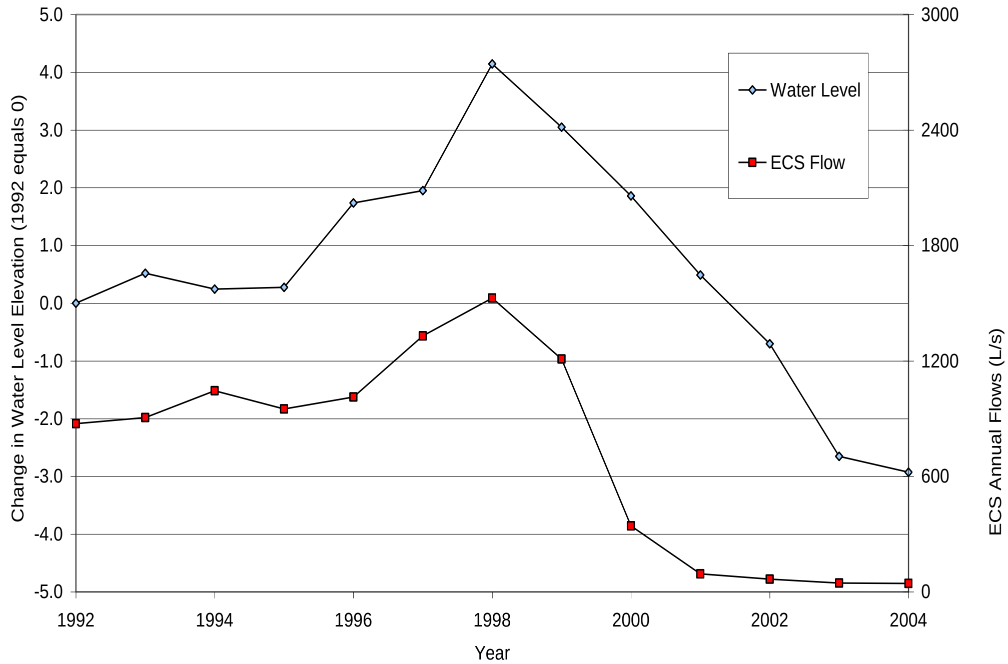

Figure 9. Mean water levels in bedrock monitoring wells.

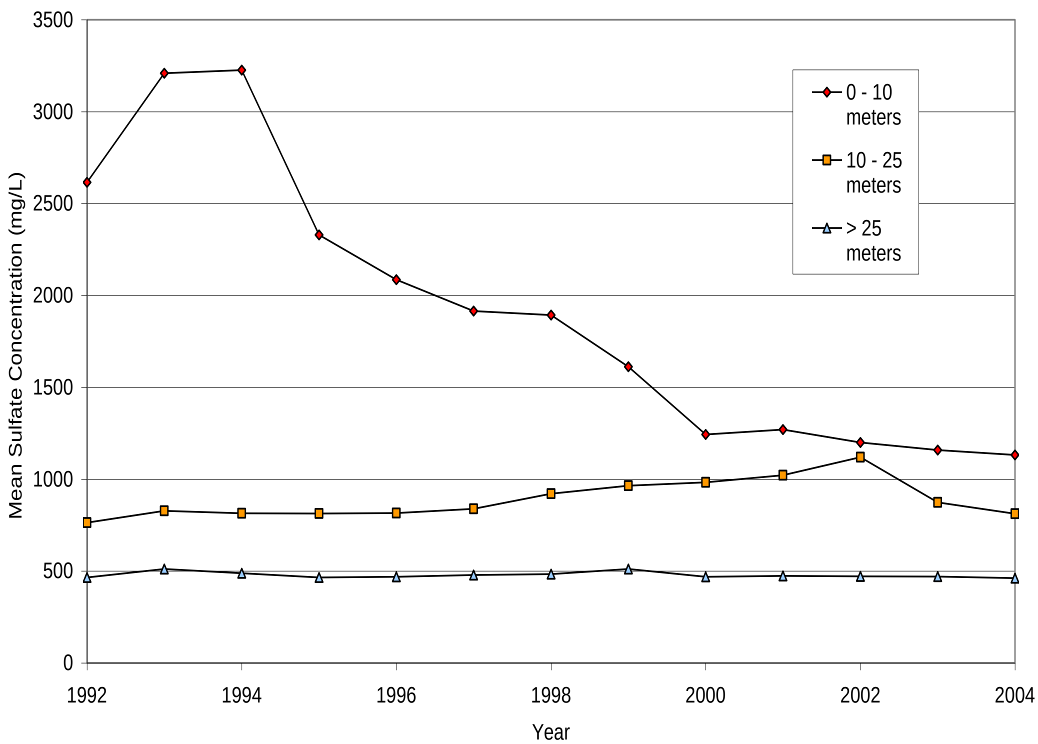

Figure 10. Arithmetic mean annual sulfate concentration in the monitoring well network (wells grouped by average screen depth below water table, includes both bedrock and alluvial wells).

The observed vertical contaminant distribution is what would be expected if the contamination was primarily derived from a surface source. As described previously, before 1993 leach water was allowed to flow for up to 1200 meters in a series of unlined drainages, ditches and ponds after it discharged from the toe of the dumps. This allowed some leach water and ARD to reinfiltrate into the underlying alluvial aquifer and saturated bedrock. This conclusion is supported by the fact that there is no systematic relationship between distance from the toe of the dump and the SO_4^{-2} concentrations in the monitoring wells.

Figure 11. Geometric mean annual sulfate concentration in monitoring well network (wells grouped by average screen depth below water table).

When the Eastside Collection System was upgraded in 1993 to 1996, water quality in the shallow saturated alluvium began to improve almost immediately. Water quality in the deeper bedrock wells has responded to the removal of the contaminant loading from the surface much more slowly. In some areas with downward vertical gradients, water quality in the bedrock has continued to decline as water quality in the overlying alluvium has improved. Wells screened more than 25 meters below the water table have maintained an arithmetic mean concentration of about 500 mg/L and a geometric mean of about 300 mg/L throughout the past 12 years (Fig. 10 and 11).

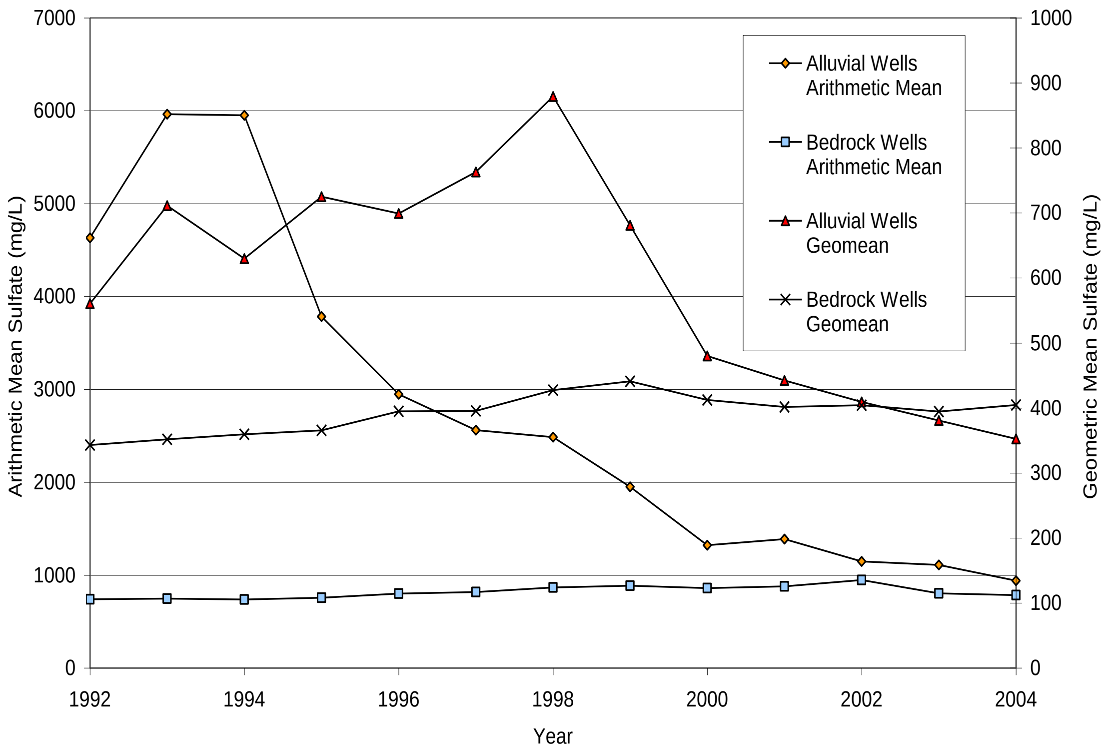

Figure 12. Annual mean sulfate concentration in alluvial and bedrock monitoring wells.

Summary and Conclusions

With the termination of leach water applications in 2000, flows discharging from the toe of the Eastside waste rock dumps have declined from a high of 1500 L/s to 45 L/s in 2004. Water quality discharging from the toe of the waste rock dumps has remained relatively constant except for a 30 percent reduction in acidity and a four-fold increase in Cu concentration. The upgrading of the Eastside leach water and ARD collection system in 1996, and the termination of leach water applications in 2000 have resulted in improving groundwater quality in down gradient saturated bedrock and alluvial aquifers.

Future Trends and Management

The leached north Eastside dumps may, in the long term, behave like the south Eastside dumps, which were never leached, but which occur in the same climatic and topographic setting (Fig. 1). The south Eastside dumps have maintained mean annual flows of between 2 and 8 L/s since 1999, varying in response to wet or dry years. If the mean south dump annual flow of 5 L/s is scaled up according to relative surface area, this implies that the mean flows discharging from the toe of the north Eastside dumps could eventually decline to less than 25 L/s. As leach water drain down progresses, and as the waste rock is slowly flushed by infiltrating precipitation, it is also anticipated that the quality of the water discharging from the north Eastside dump toe will gradually improve. However, given that the waste rock is net acid generating, it is anticipated that ARD discharging from the toe of the north Eastside dumps will, at best, eventually evolve towards the water chemistry observed at the waste rock dumps that were never leached. ARD from the south Eastside dumps typically has a pH of 3 to 4, acidity of 2000 mg/L, sulfate of 15,000 mg/L and TDS of 20,000 mg/L. Although these values are less than a quarter of the concentrations currently discharging from the old leach water application areas, they will still need to be collected and treated in perpetuity.

Mining and ore processing at Kennecott Utah Copper will continue for more than a decade under current mine plans. This will allow on going neutralization and treatment of ARD within the process water circuit and co-disposal of the precipitates within the tailings impoundment. As leach water drain down and flushing by precipitation continues over the next decade, it is anticipated that the flows and solute flux requiring treatment will continue to decline before closure. However, Kennecott is actively monitoring the behaviour of the system and investigating methods to accelerate the decrease in contaminant flux from the dumps. Ongoing programs include: 1) monitoring of flow volume and quality, 2) infiltration and geochemical studies on waste rock surfaces, 3) progressive recontouring, neutralization and revegetation of highly weathered waste rock surfaces to enhance evapo-transpiration and minimize infiltration, and 4) cover design studies intended to minimize infiltration and to allow the establishment of vegetation on phyto-toxic waste surfaces.

It is also anticipated that ground water quality will continue to improve in the future because: 1) the ongoing decline in volume and improvement in quality of water perched at the base of the waste rock dumps will result in declining contaminant fluxes to the underlying bedrock, 2) the continued capture of ARD discharging from the toe of the dumps by the upgraded Eastside collection system prevents its re-infiltration into down gradient saturated bedrock and alluvial aquifers, 3) the drop in the water table below and adjacent to the waste rock dumps has reduced the horizontal gradients driving flow towards the down gradient alluvial aquifer and 4) the ongoing recharge of clean precipitation water through undisturbed and recently remediated lands surrounding the waste rock dumps will dilute solute concentrations in the underlying groundwater.

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