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Technical Communication

Development of the Sleeper Pit Lake

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Abstract. The Sleeper open pit gold mine operated from the mid-1980s through the mid-1990s. Operations were mostly sub-water table and extensive dewatering was required to lower groundwater levels by 180 m. Dewatering flows peaked at 930 L/s, with most flow contributed from an alluvial aquifer. After completion of mining, the pit was rapidly filled with water pumped from the alluvial aquifer to reduce the exposure time of sulfide wall rocks and waste rocks in the ultimate pit. The pumped alluvial groundwater provided a large volume of low total dissolved solids (TDS), high alkalinity water that controlled the early chemistry. The rising lake waters were amended with lime to buffer excess acidity contributed to the lake from reactive pit wall rocks during submergence. The pore water contained in submerged waste rock at the base of the pit was elevated in TDS and subsequently of higher density that the lake water. The density contrast and waste rock location limited contributions of waste rock pore water to the main body of the lake. Some stratification of the early lake occurred, with shallow water characterized by higher pH, low dissolved metals, and sulfate; deeper water had lower pH and higher dissolved metals and sulfate. The reservoir of alkalinity in the shallow layer mixed with the deeper waters and created a stabilized lake with a homogenized column that exceeded water quality expectations. Current water quality meets all Nevada primary drinking water standards with the exception of sulfate, TDS, and manganese, which are slightly elevated, as predicted. Chemistry has remained stable since development of the initial lake.

Key words: Dewatering; filling; geochemistry; lime; turnover; waste rock

Background

Sleeper Mine was the first of a new generation of open pit gold mines developed in Nevada, USA. Groundwater levels in the mine area were encountered at 4.5−9 m below ground surface and major dewatering operations were required. After completion of operations in the mid-to-late 1990s, a lake was developed in the pit as part of the site-wide closure plan. A rapid filling plan was implemented with chemical amendments to submerge reactive rocks and to stabilize the lake chemistry. This paper provides an overview of the development of the pit lake hydrogeology and geochemistry.

The Sleeper Mine is located in the Basin and Range physiographic province and is on the east side of Desert Valley, at a surface elevation of approximately 1,265 m above sea level. Desert Valley is about 20 km wide and flanked immediately to the east of Sleeper by the Slumbering Hills and to the west by the Jackson Mountains. Figure 1 shows the general location of Sleeper. The mine sits in a prominent rain-shadow caused by the Jackson Mountains. Annual precipitation at the site is approximately 14.5 mm and estimated annual Class A pan evaporation is 183 mm (Water Management Consultants 1995).

Figure 2 is a generalized cross section of the eastern half of Desert Valley, showing the geological setting of the mine. Gold mineralization is hosted in Tertiary volcanic bedrock consisting of rhyolites and andesitic basalts that are hydrothermally altered to silica and argillite assemblages. Bedrock is unconformably overlain by late Tertiary and Quaternary basin fill deposits. Basin fill deposits include the 'Older Alluvium,' which consists of unconsolidated silty, sandy, poorly sorted gravels, and 'Younger Alluvium,' which is predominantly composed of silty, sandy lacustrine deposits.

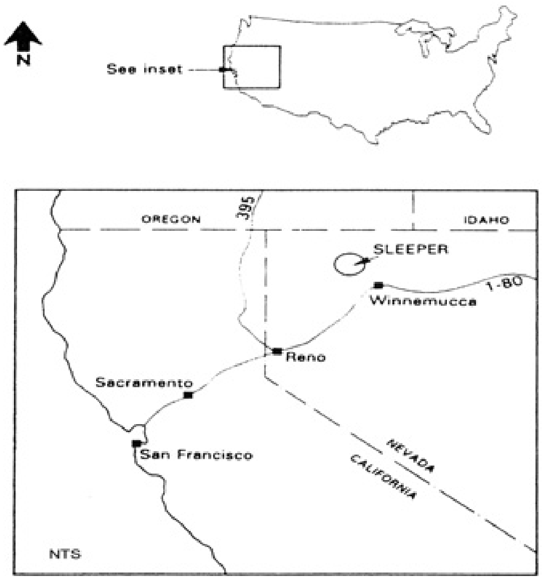

Figure 1. Location map

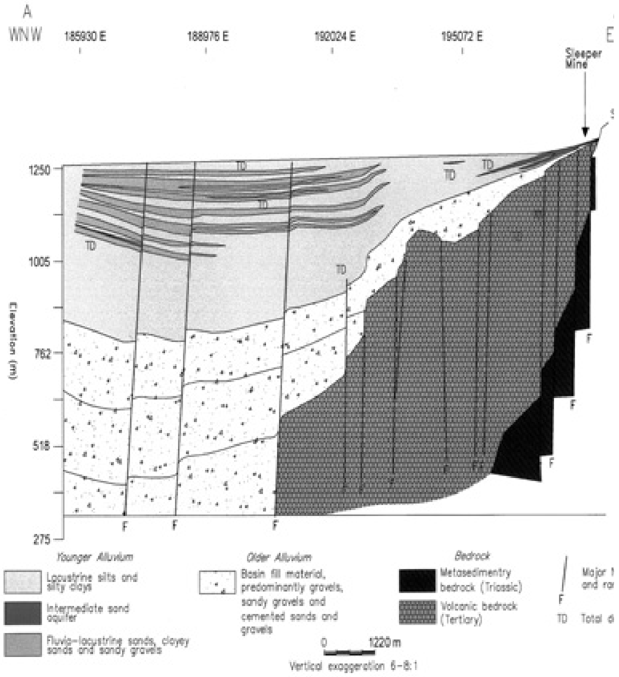

Figure 2. Generalized E-W geological section

In the Sleeper area, the bedrock surface dips rapidly west towards the center of Desert Valley. Overburden thickness is approximately 6 to 9 m along the east side of the mine footprint, increasing to 36 to 52 m along the west side.

Excavation of the Sleeper pit began in 1985. In 1987, development of a second area (the Wood pit) commenced just to the south of the Sleeper pit. The two pits were merged in 1989. A northeast extension was later added to the Sleeper pit and two smaller extensions of the Wood pit were excavated: the Office and West Wood pits. Mining operations removed mostly overburden and oxide bedrock until 1992, and then mostly unoxidized sulfide bedrock in the lower benches from 1992 until mining ceased in the Wood pit in December 1995 and in the Sleeper pit in March 1996. Figure 3 shows the ultimate open pit layout. The final open pit was approximately 1,675 m in length, 760 m in width, and had a maximum depth of about 177 m below the original ground surface. Approximately 7.3 x 10^6 m^3 of waste rock was placed in the pit, mainly in the lower parts of the West Wood pit, the Office pit, and the Sleeper northeast extension. Approximately 5.2 x 10^6 m^3 (20x10^6 tons) of this material was unoxidized sulfide rock. The maximum elevation for unoxidized sulfide backfill was 1,219.5 m.

Hydrogeology and Mine Dewatering

Overview of Hydrogeology

The natural groundwater table in Desert Valley falls gently from the flanks of the ranges towards the main

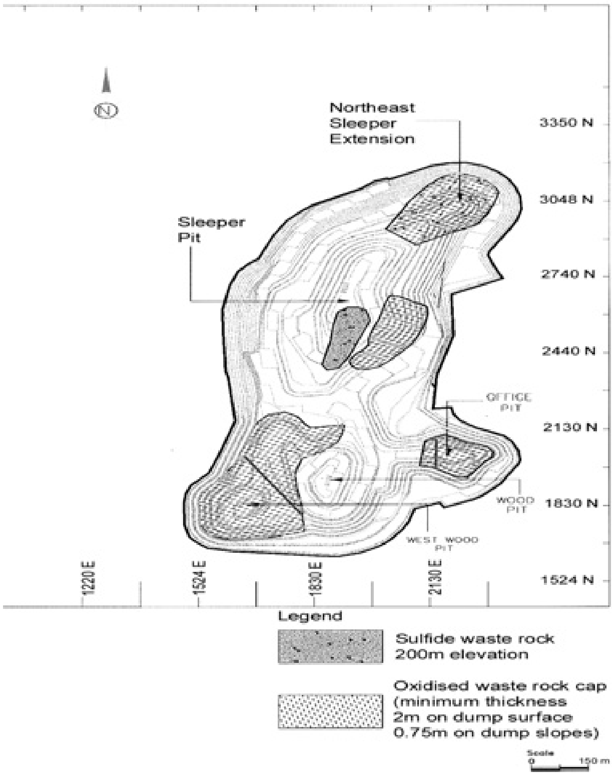

Figure 3. Ultimate pit layout

valley floor. Groundwater flows predominantly north and west, towards the center of the valley and the Quinn River. Pre-mining groundwater levels in the area were at approximately 1,254 m, or about 4.5 to 9 m below the ground surface; dewatering was required almost as soon as mining commenced.

Most regional groundwater flow in the Valley occurs in the Older Alluvium, called the Basal Gravel Aquifer, which before mining was dry east of the mine site, but wedged steeply with a typical saturated thickness of 27.5 m at the west perimeter and further increasing towards the Valley center. Hydraulic conductivity determined from dewatering pumping was typically 23 to 30 m/day, but up to 150 m/day in the basal units (Water Management Consultants 1995). The overlying Younger Alluvium occurred above the water table in the east part of the mine footprint and generally had a saturated thickness of 18 to 20 m at the west perimeter. The upper 15 m of Younger Alluvium consists of silty clay lacustrine sediments of the Quaternary Lake Lahaton, with a measured hydraulic conductivity range of 0.15 to 15 m/day, with the upper range due to the presence of fissures. The lower part of the Younger Alluvium consists of the 'Intermediate Sand,' which is a coarser unit but with similar measured hydraulic conductivity to the overlying silty clays. The overall pre-mining saturated thickness of overburden materials in the west wall area was approximately 49 m.

Groundwater occurrence and movement in bedrock is highly variable and controlled by fracturing and alteration. Brittle units containing open fractures occur in the volcanic sequence and contain major local groundwater flow. These are heavily inter-layered with softer and variably argillized rocks exhibiting low hydraulic conductivity. Steeply inclined range-front faults, which strike north northeast to south southwest, cause strong compartmentalization within the bedrock. These faults create stratigraphic offsets, displacing the permeable layers within the bedrock. Very high local flows were encountered in fractures sub-parallel to the faults during dewatering development drilling and testing, with measured transmissivity values up to 3,050 m^2/day. However, because of layering and structural complexity, widespread groundwater movement in bedrock on a regional scale is limited.

Groundwater Chemistry

The lacustrine silty clays of the Younger Alluvium have predominantly sodium chloride and sodium sulfate type waters. The total dissolved solids (TDS) content is typically 15,000–20,000 mg/L and the pH ranges from 7.0 to 9.0. Naturally elevated concentrations of dissolved metals, including arsenic, boron, cadmium, copper, iron, lead, magnesium, manganese, nickel, selenium, silver and zinc, are common. The hydrochemistry indicates dissolution of evaporite minerals and aggressive evapo-concentration of dissolved constituents during formation of a fossilized brine. The Basal Gravel Aquifer contains mixed waters that are strongly sodium dominant, and are either bicarbonate rich or have no major anion. TDS is typically around 700 to 1,000 mg/L and pH ranges from 7.8 to 9.3. Metals concentrations are low. The hydrochemistry indicates recharge through a flow path containing abundant evaporite minerals. Most of the hydrochemistry data available for bedrock indicates similar water to the overlying Basal Gravels Aquifer, possibly reflecting downward leakage and mixing, which would have greatly increased during dewatering.

Dewatering Operations

Major dewatering operations commenced in May 1986 and peaked at a flow rate of approximately 930 L/s in 1993. At the time, this represented one of the largest mine dewatering operations worldwide. Approximately 80-85% of dewatering flow was pumped from the Basal Gravel Aquifer using a line of 24 interceptor wells located immediately behind the west wall perimeter. The remaining 15-20% of flow was pumped from 11 in-pit bedrock dewatering wells. Of these, four were installed to below the ultimate pit floor with the remainder pumping from relatively shallow fractured bedrock horizons, mainly at the north end of Sleeper pit. Most of the flow from the bedrock was derived from downward leakage of groundwater from the Basal Gravel Aquifer. Figure 4 is a schematic east-west hydrogeological cross section through the Sleeper pit, and illustrates groundwater units and key elements of the operating dewatering system.

Pit Lake Development Considerations

Wall Rock and Waste Rock Geochemistry

Development of the pit lake at Sleeper involved the submergence of unoxidized sulfide pit wall rocks and waste rock. These materials represented a potentially major source of acidity, sulfate and metals load to the evolving pit lake. It was important to characterize the geochemistry of the wall rocks and waste rocks so that possible impacts to lake chemistry could be assessed and mitigated during lake development.

The topography of the oxidized-unoxidized surface varies considerably in the ultimate pit walls, with an average elevation of 1,186 m, and a maximum of 1,220 m. The exposed wall rocks and waste rocks in the pit were characterized based on static and kinetic testing (Figure 5). Samples from each major unit were tested and geochemical zones were defined as:

- *Unoxidized (sulfide) bedrock*: acid generating with moderate to high potential for leaching of metals

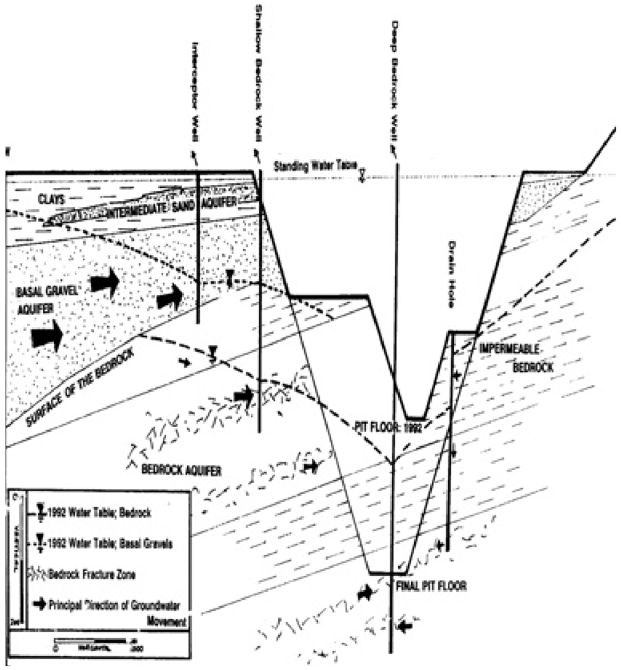

Figure 4. Generalised E-W section showing dewatering operations

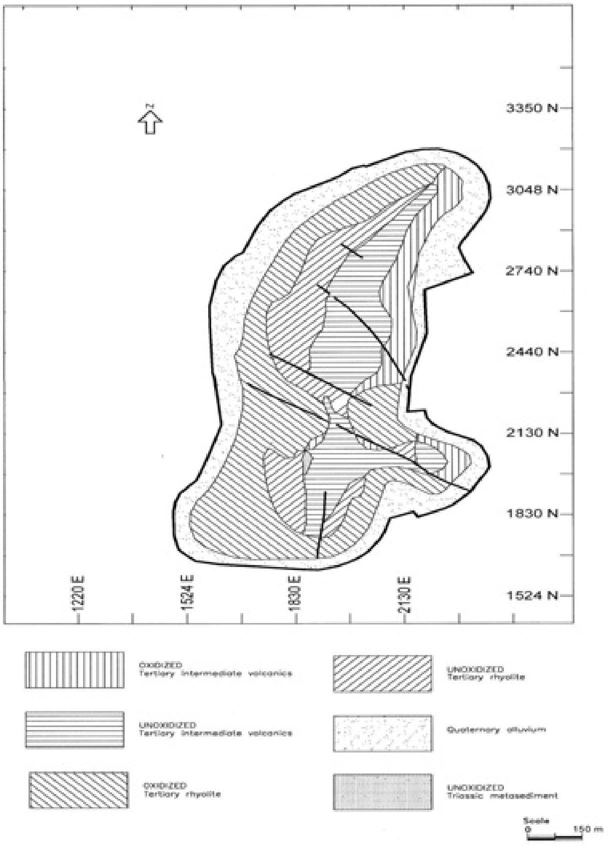

Figure 5. Major geological units exposed in the ultimate pit walls

(leachate iron concentrations typically 50-100 mg/L), sulfate (leachate concentrations typically 1,000-3,000 mg/L) and acidity (leachate concentrations typically 100-200 mg/L), but with very low alkalinity (often below detection). The unoxidized sulfide bedrock zone occupied the mid-lower benches with a general trend of increased reactivity with depth that coincides with increased total sulfur content. There is no unoxidized sulfide bedrock above 1,220 m.

- *Oxidized bedrock*: generally with a net-neutralizing capacity and with low potential for mobilization of metal ions. The oxidized bedrock zone occupies benches at or above 1,220 m.
- *Alluvium/overburden*: with a net neutralizing capacity and moderate potential for mobilization of major ions and some metals from the dissolution of evaporite minerals and release of sorbed ions. Alluvium occupies the upper benches, mainly in the west pit wall.

Figure 6 shows an excess of acid generating potential (AGP) over acid neutralizing potential (ANP) for the tested rocks, and therefore net acidity in most unoxidized sulfide rock samples.

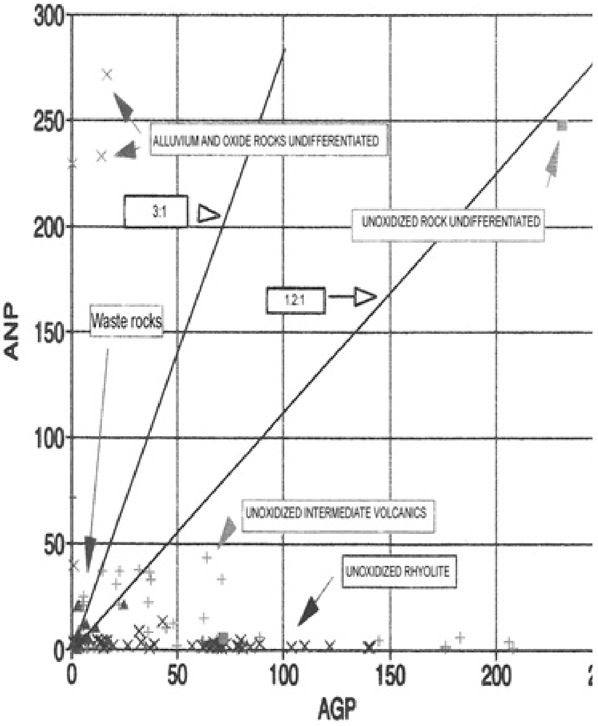

Figure 6. ANP versus AGP for tested wall rocks and waste rocks

The waste rock materials showed a broad range of geochemical characteristics, mainly related to type of alteration, level of mineralization, and degree of weathering. The most reactive waste rocks had variable sulfide content but were weathered materials containing argillic clays. Leachate samples had low pH (2-3), no measurable alkalinity, and high sulfate (2,000-20,000 mg/L), high iron (1,000-4,000 mg/L) and trace metal concentrations. The least reactive waste rocks were unweathered low-sulfide bearing argillic and silicic rocks. Leachate samples had moderately acidic to slightly alkaline pH (5.5-7.5), low to high alkalinity (100–3,000 mg/L) low sulfate concentration (100–1,000 mg/L), and low to moderate iron (0.4–100 mg/L) concentration.

Overall, the unoxidized sulfide pit walls represented a significant source of acidity, sulfate, and metals to the rising lake waters. The waste rocks were an additional source but of reduced significance due to their placement on pit floor areas; any dissolved oxidation products would significantly increase the specific gravity of the waste material pore water and restrict it from mixing with the main body of the lake.

Water Level Rebound

Due to the nature of the wall rocks, it was realized from an early stage that rapid submergence and stabilization of these materials would be required. A rapid filling approach using pumped groundwater to submerge the reactive wall rocks and waste materials to the 1,220 m level was adopted as the preferred closure option. Rapid submergence provided a cost effective mechanism to minimize the impacts of wall rocks and waste materials on the final pit lake chemistry by limiting the opportunity for ongoing oxidation of the sulfide materials.

Predictive assessments of water level recovery in the pit and dewatered groundwater system were made using the MODFLOW 3D finite difference groundwater model code and manual water budget estimations. Evaluations were made of natural recovery and alternative rapid filling scenarios for pumped inflow rates of 315 L/s and 630 L/s. Figure 7 is a plot of predicted pit lake recovery times for natural recovery and rapid fill. The 630 L/s and 315 L/s inflow rates were predicted to give filling times to the 1,220 m level of about 2 years and 6 years respectively. Natural recovery to the 1,220 m elevation was predicted to take 9 years.

An equilibrium water balance was developed and indicated a long-term average pit-lake water level approaching the pre-mining groundwater level of about 1,254 m. However, natural recovery to this level would take 50-100 years. The significant slow down in recovery above 1,220 m is due to: 1) the uptake of storage in the extensively dewatered, high porosity overburden, 2) the increased lake surface area and subsequent evaporation losses, and 3) the progressively increasing water volume required to affect unit water level increase in the middle-upper benches.

The low annual average precipitation rate at Sleeper and aggressive evaporation environment indicated an annual net water loss of approximately 30 L/s from the lake surface. The deficit of water would be made up by inflow of groundwater from the Basal Gravel Aquifer and Younger Alluvium. A slight permanent inward gradient would result, maintaining the pit as a permanent hydraulic sink. Figure 8 illustrates the predicted short-term filling water balance for the pit lake, net of groundwater inflow.

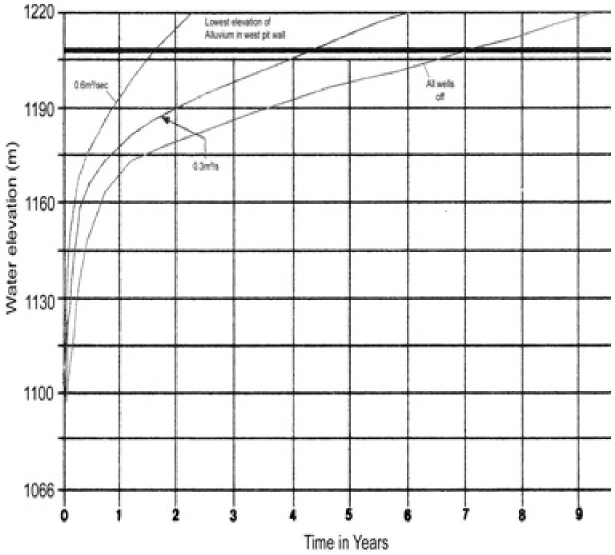

Figure 7. Predicted pit lake filling times

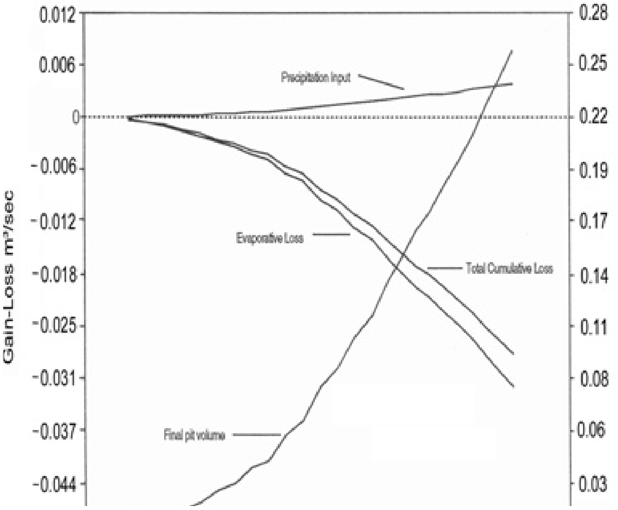

Figure 8. Predicted filling water balance

Estimates of Pit Lake Chemistry

Pit lake chemical model simulations were prepared to identify the principal controls on pit lake chemistry and evaluate how the pumping rate would affect lake chemistry up to the 1,220 m elevation. Estimates of pit lake chemistry were made based on mixing possible volumes of pumped groundwater input (variable based on potential pumping rate) with estimated volumes of water required to completely flush oxidation products from the re-wetted pores of the reactive wall rocks and waste rock material surfaces. Mixing scenarios were evaluated for varying volumes of pumped groundwater and pore water from the oxidation rind developed in the unoxidized sulfide pit walls and backfill surface material, and by varying the pore water chemistry. The thermodynamic equilibrium PHREEQE code was used for the initial lake chemical estimates. Additional simulations using the equilibrium thermodynamic code MINTEQA2 to include the effects of mineral precipitation and adsorption were conducted to further refine the predicted lake chemistry.

The PHREEQE and MINTEQA2 simulations suggested that the lake chemistry was most strongly influenced by the mineral acidity and volume of weathered wall rocks. Varying the pumped input rate or the wall rock pore water chemistry had comparatively limited impact on the final lake chemistry. All model simulations suggested the lake would be slightly acidic with a pH generally less than 6 with elevated TDS and sulfate concentrations. Metal concentrations remained elevated because an amorphous iron oxy-hydroxide phase, such as ferrihydrite, did not precipitate at the slightly acid predicted pH and therefore did not scavenge metals from the lake water.

MINTEQA2 simulations using lime as a finite solid showed that the pH of the final lake water could be raised to near 7 with the addition of around 0.2 g/L lime. Results of empirical testing where lime was added to low pH pore water from the laboratory test columns confirmed that a lime application rate of roughly 0.2 g/L lime could raise the solution pH to near 7.

To summarize, the model simulations showed that the natural alkalinity in the pumped alluvial groundwater of near 200 mg/L would lead to a slightly acidic pH between 5 and 6 in the lake. Additional model results supported by empirical test work showed that the addition of small amounts of lime to the lake could raise the pH to neutral or alkaline levels. Lime application to the lake during filling provided a flexible contingency mechanism to accommodate the uncertainty of model and bench scaling testing.

Pit Lake Development Plan and Objectives

Based on the hydrological and geochemical conditions at Sleeper, the overall plan and objectives for pit lake development were:

- to rapidly submerge the sulfide-bearing wall rocks and backfill materials. This would actively flush all or most of the soluble metals and acidity from the pit walls during the initial flooding and reduce the exposure time for wall and waste rock oxidation.
- to flood the pit with low TDS, high alkalinity alluvial groundwater. Flooding would control the initial chemistry by providing a dilute medium to dissolve soluble salts and acidity from the pit walls and backfill, and would have the added advantage of creating a positive head in the initial lake to hydraulically isolate dissolved oxidation products within dewatered bedrock behind the pit walls.
- to proactively add lime to the lake during the initial flooding to compensate for anticipated dissolution of soluble salts and acidity from the sulfide-bearing pit walls.
- to actively monitor the lake chemistry during flooding to identify any changes.
- to have dosing options in place (such as lime) to be prepared for changes in chemistry from events such as pit slope failures and to bring the lake chemistry back to neutral on an ‘as required’ basis.
- to shut off the pumping and steady lime dosing once the sulfide-bearing wall rocks and backfill were submerged and allow alluvial groundwater to maintain the lake, while retaining a dosing mechanism as backup.

Initial Filling of the Pit Lake

Water Level Recovery

Rapid filling of the pit commenced in July 1996. Dewatering discharge from the Basal Gravel Aquifer interceptor wells was re-directed to the Sleeper and Wood pits. Initially, separate lakes developed in the two pits, until the two lakes merged at the 1,198 m elevation. The initial rate of rapid filling was 567 L/s and this was gradually increased to 740 L/s by March 1997. The initial target water level of 1,220 m was achieved in September 1997, at which time all of the unoxidized sulfide wall rocks and waste rock were submerged. The actual filling time was 16 months, which closely matched predictions. Figure 9 shows the actual filling curve for the pit lake. After the proactive filling was completed, pumping continued into the pit lake but at a reduced rate of 6 to 24 L/s to allow for lime addition. Figures 10 and 11 are schematic sections showing the initially developed pit lake and submerged wall rocks and waste dumps.

Before rapid filling commenced, oxide waste rock was used to cap the waste rock dumps, to physically

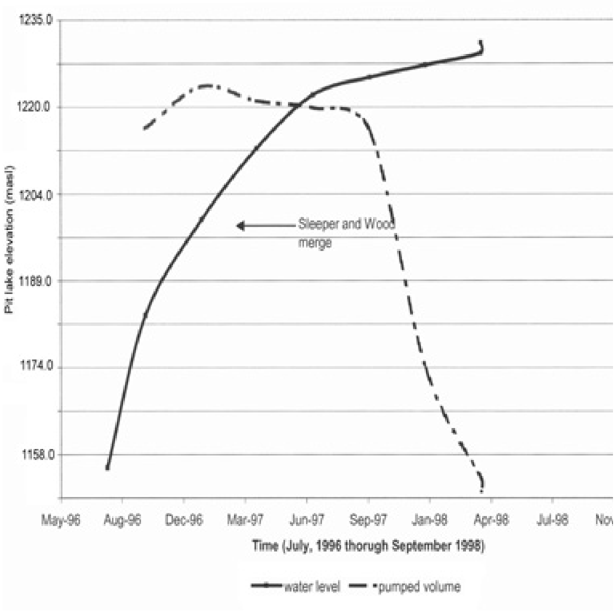

Figure 9. Observed pit lake filling curve

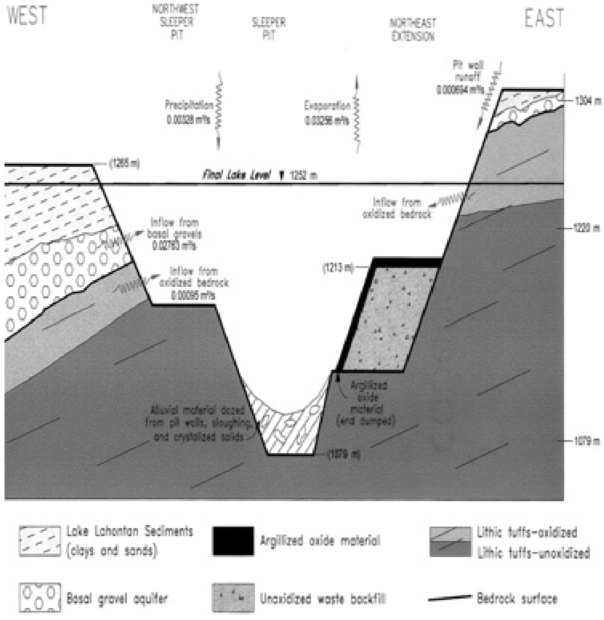

Figure 10. Schematic ESE-WNW section through the pit lake

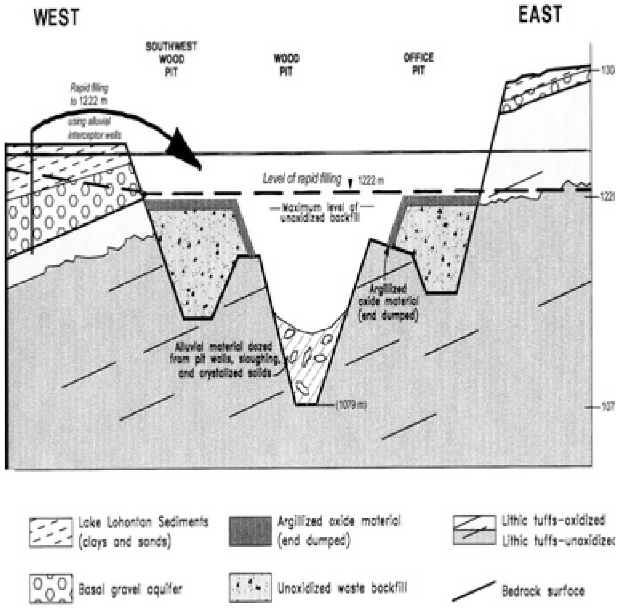

Figure 11. Schematic E-W section through the pit

isolate the sulfide-bearing materials from the atmosphere and the developing lake waters. Alluvial material in the west wall of the Sleeper pit was bulldozed in to the pit during initial filling. The purpose of the alluvial dozing was: 1) to cover potentially reactive wall rocks in the lower walls of the pit with non-reactive alluvium, 2) to add additional alkalinity to the lake water from the calcite and other carbonate cement in the alluvium, and 3) to reduce the pit slope by creating a 3:1 beach slope and a littoral zone habitat.

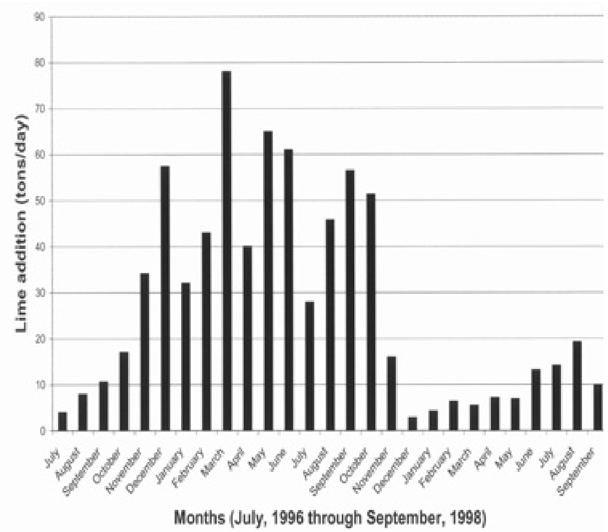

Figure 12. Average lime application rates during filling and stabilization

Hydrochemical Amendments of the Lake Water

Lime application commenced in July 1996. The lime was stored in 2 dry silos and was run through a slaking mill to create a slurry that was injected through the pumping well discharge lines. Lime build-up in the discharge lines later led to the installation of a separate lime slurry line to the lake. Figure 12 shows the average daily quantity of lime added to the lake from July 1996 through September 1998. During filling, the initial average daily application rate was 4 tons/day but peaked at 78 tons/day in March 1997. The application rate was reduced in November 1997 and remained at a low and declining level after that. The key drivers for lime amendment were: 1) maintaining a neutral pH in the water column, 2) responding to release of mineral acidity due to slope failures, and 3) building a reservoir of alkalinity in the epilimnion in late summer prior to anticipated fall turnover, thereby compensating for any lower pH and reduced conditions in the hypolimnion developed during summer stratification. Continuous chemical depth profiling of the lake was conducted twice a month during lake development and adjustments to lime dosing were made based on the results.

To aid circulation of lime within the lake and promote full mixing of the water column, a barge mounted Flygt pump was operated in the Wood pit from September 1997. It circulated water from the surface to a depth of 73 m. A second line was later added to redistribute water in the Sleeper pit. Pumping within the pits was continued intermittently throughout the active filing period.

To propagate algal growth, aquatic development, and organic decay, the lake was also dosed with approximately 200 tons of manure on 4 different occasions during and after the filling program.

Lake Hydrochemistry during Filling and Stabilization

Figure 13 through 15 are annotated time series plots of pH, sulfate, and iron measured in the pit lakes from commencement of filling through stabilization to the end of 1998, and illustrate the evolving chemistry in the lake. Hydrochemistry measurements were made at 3 depth intervals in each pit: 7.5 m (shallow), 48 m (mid level), and 76 to 90 m (deep).

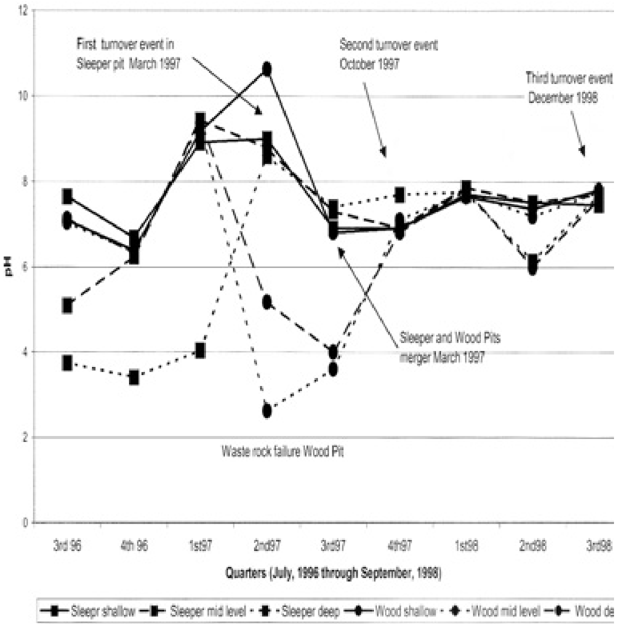

Figure 13. Observed pH during filling and stabilization

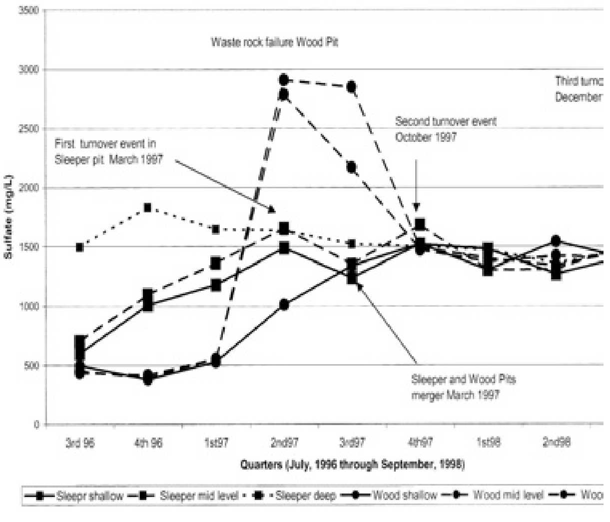

Figure 14. Observed sulfate during filling and stabilization

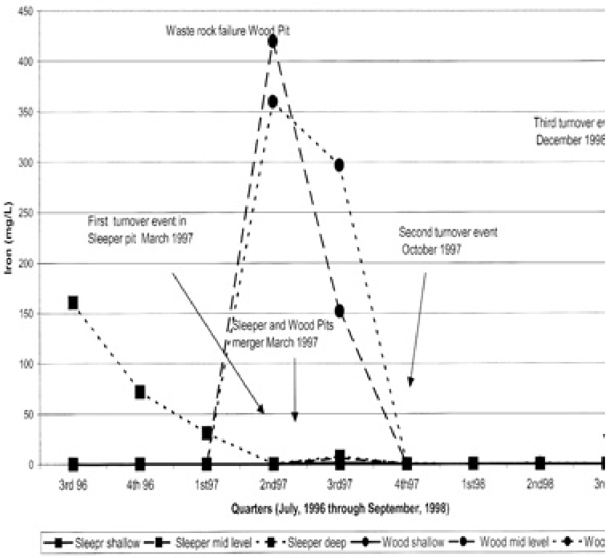

Figure 15. Time-series observed iron during filling and stabilization

During early filling, the Sleeper pit had a pH less than 4.0 due to the flushing and dissolution of mineral acidity from the sulfide materials in the pit walls. Lime dosing in late 1996 and early 1997 buffered the pH in the upper and middle levels to a maximum of approximately 8.0. The upper and middle lake chemistry quickly evolved towards the pumped alluvial groundwater chemistry, with near neutral pH, low iron (and other metals) and low sulfate. The deep lake water stratified and remained influenced by unoxidized sulfide materials, exhibiting low pH, high metal concentrations, and slightly elevated sulfate concentrations. In March 1997, a turnover event occurred that mixed the water column in the Sleeper pit lake and left the pH high, iron and metals concentrations low, and sulfate concentrations moderately elevated throughout the lake.

In the Wood pit area, the early chemistry was similar to that of the pumped alluvial groundwater and was generally significantly less affected by the mineralized wall rocks than was the Sleeper pit. However, in March 1997, a waste dump failure moved 40,000 tons of sulfide waste into the lake water. This caused a distinct pH drop, and increased metals, iron, and sulfate concentrations in the middle and lower lake levels. Increased liming after the failure controlled pH, sulfate, and metal concentrations in the shallow lake.

The pore water in the waste rock materials in both pit areas contained elevated sulfate and TDS concentrations but as a consequence had higher specific gravity than the main body of the lake. Due to the density contrast and the placement of waste in low areas, the pore water remained isolated, with only minor mixing with the lake water.

The merger of the Sleeper and Wood pit lakes in March 1997 allowed the shallow waters in the two lakes to mix; pH, iron, other metals, and sulfate levels rapidly equilibrated. Turnover events occurred in the Sleeper and Wood portions of the lake in October 1997, resulting in homogenous lake profiles characterized by neutral pH, low iron, low metals, and stable sulfate concentrations. Lime that was added in the late summer 1997 created an alkalinity reservoir in the shallow waters to buffer the deeper waters during turnover and stabilize the hydrochemistry of the entire water column.

After the October 1997 turnover and stabilization of lake chemistry, the lime dosing was backed-off. Monitoring showed minimal change in lake pH despite the reduced lime input and pumped input of overburden groundwater. Lime application was slightly increased in late summer 1998 in anticipation of a winter turnover event, which occurred in December 1998 and once again homogenized the lake water column.

Discussion of Turnover Events

Seasonal stratification and turnover events occurred in both the Sleeper and Wood pit areas. Figures 16 and 17 show typical seasonal temperature and dissolved oxygen (DO) profiles representative of the Sleeper and Wood pit areas. In both areas, depth profiling revealed strong stratification developing in late summer due to the high air temperatures heating the surface waters, creating a distinct epilimnion and thermal gradient to cooler mid-bottom level waters. Surface temperatures typically exceeded 22°C with mid-bottom levels reducing to between 19 and 17°C. Strong stratification in DO also occurred, with surface water typically having 6-9 mg/L but middle and deeper water having very little or no DO. During the early fall (September), the surface waters cooled to about the same temperature as the middle and deep levels, but with continued stratification of DO. During the later fall (October-November), further reduction of surface temperatures created a thermal inversion and subsequent turnover, giving rise to a homogenous column temperature of about 17°C and 5 mg/L DO. During the early winter, continuous vertical mixing was observed, with water column temperature falling to 12°C and DO varying between 5 and 8 mg/L.

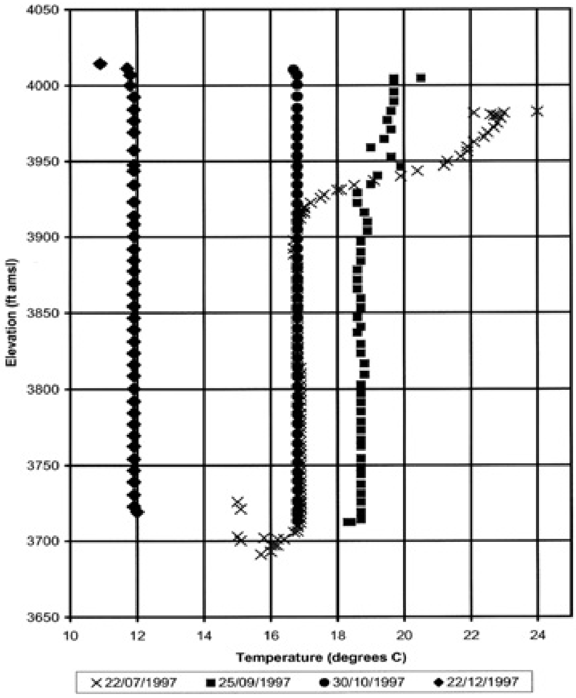

Figure 16. Seasonal temperature depth-profiles for Sleeper pit lake

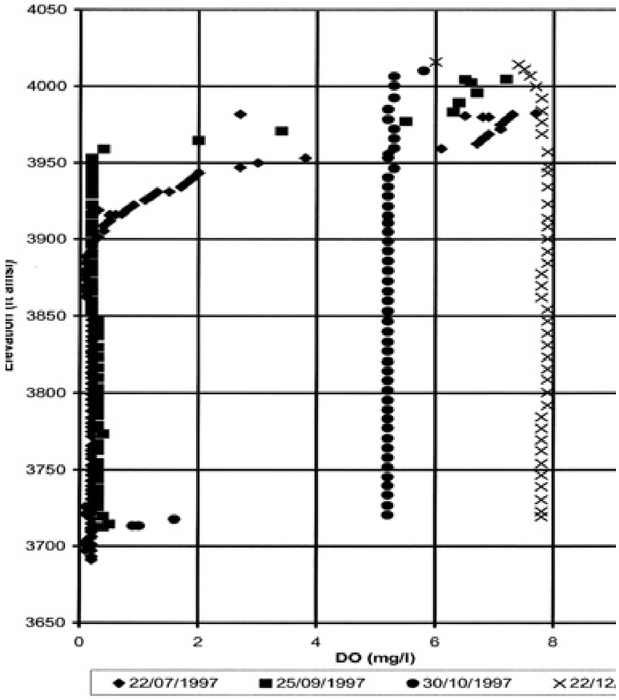

Figure 17. Seasonal dissolved oxygen depth-profiles for Sleeper pit lake

Comparative Assessment of Stabilized Chemistry

Table 1 shows summary pit lake water quality measured in 1998 after turnover and recent measurements from the 3rd quarter of 2002. Overall, the observed stabilized pit lake chemistry exceeded expectations. Comparison of the PHREEQE predicted (without mineral precipitation/sorption) and measured lake chemistry showed higher pH and lower concentrations of metals (including arsenic, iron and zinc) in the observed lake water than expected.

The observed lake water chemistry compared favorably with average alluvial groundwater chemistry. The pH was very similar, while concentrations of metals, including iron and arsenic, were below alluvial groundwater values. Most major ions were above alluvial groundwater concentrations with high calcium due to lime amendment and predicted sulfate due to flushing of the pit walls. The lower than expected metals concentrations in the lake water probably reflected amorphous iron hydroxide precipitation and metals sorption. Red amorphous precipitate was collected from sample buckets suspended in the water column and these contained elevated concentrations of metals including arsenic (up to 1,500 ppm), zinc (up to 650 ppm), manganese, copper, vanadium, nickel, molybdenum and strontium. Detrital mud samples included gangue minerals such as quartz, plagioclase, feldspar, muscovite, and sericite, as well as chemically precipitated calcite and gypsum.

The chemistry of the lake is very stable and meets all of the primary Nevada drinking water standards with the exception of TDS, sulfate, and to a lesser extent manganese; these, as predicted, are slightly elevated. Stabilization occurred in a much quicker time frame than expected because of: 1) removal and co-precipitation of metals with iron, 2) the high density of the pore water in the waste rock materials, isolating this from the main body of the lake, and 3) the dosing of alluvial material from the west high wall during filling, which created a sediment blanket, isolating the wall rocks and further promoting the development of an aquatic system and organic decay.

Table 1. Observed lake hydrochemistry

Parameter	Units	2002 Sleeper 4.5 m	2002 Sleeper 90 m	2002 Wood 4.5 m	2002 Wood 90 m	1998 Sleeper 4.5 m	1998 Sleeper 90 m	1998 Wood 4.5 m	1998 Wood 90 m
Alkalinity (total)	mg/L	60	50	62	40	50.4	53.5	56.6	49.4
Arsenic	mg/L	<0.002	<0.002	<0.002	<0.002	0.018	0.014	0.013	0.014
Cadmium	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Calcium	mg/L	370	370	380	360	320	429	340	462
Chloride	mg/L	250	240	260	230	233	231	230	226
Copper	mg/L	0.008	0.009	0.007	0.008	<0.01	0.015	<0.01	0.014
Iron	mg/L	<0.02	<0.05	0.09	<0.05	<0.02	<0.02	<0.02	<0.02
Lead	mg/L	<0.002	<0.002	<0.002	<0.002	0.05	0.064	<0.007	0.037
Magnesium	mg/L	65	55	58	55	37.3	50.3	37.6	51.9
Manganese	mg/L	0.09	0.53	0.9	0.5	0.384	1.79	0.411	1.93
pH		8.3	6.6	8.4	6.4	7.45	7.70	7.8	7.61
Sulfate	mg/L	1,400	1,400	1,400	1,400	1410	1470	1402	1465
TDS	mg/L	2,600	2,500	2,600	2,600	2250	2780	2420	2500

Note: all 2002 values are 3rd quarter; 1998 values are 4th quarter