RECLAMATION AND CLOSURE OF SUMMER CAMP PIT LAKE, NEVADA: A CASE STUDY[1]

Jeffery V. Parshley[2], Robert J. Bowell, and John Ackerman

Abstract. The Summer Camp Pit (SCP) is situated on the Placer Dome owned Getchell Property in Northern Nevada. The deposit is a typical Carlin type partly oxidized disseminated sulfide-micron gold deposit in strongly deformed and altered Paleozoic metasediments. The pit was mined by a former site owner from March 1990 to December 1991. Although the pit was mostly dry during operations, flows increased as mining deepened the pit, forcing the operators to begin periodic pumping of a small sump in the SW corner of the pit. A small sump developed which due to sulfide oxidation showed low pH and elevated metals and sulfate. To buffer this chemistry the pit was partly filled by water from the underground mining operations approximately 1 mile to the north of the pit and the water level maintained above the oxide-sulfide boundary.

The pit lake was monitored at the site for approximately 10 years and during this time the pit was used as part of the site water management strategy. For operational reasons, water was removed from the pit in 2002 and this resulted in exposure of sulfides in the pit wallrock, causing further oxidation and acid generation to occur. The chemistry of contact water created by exposure to these materials exhibited low pH with elevated metals and sulfate concentrations. Getchell Gold Corporation evaluated various options for closure of the pit. Draining and partial backfill provided the most suitable closure alternative for this pit, because it would eliminate the pit lake, reducing the potential for future groundwater impacts and risks to terrestrial and avian wildlife.

In order to evaluate the pit backfilling alternative, it was necessary to 1) identify appropriate and available backfill materials, and 2) ensure that those materials do not present an equal or greater risk to groundwater than the existing in-pit materials. The evaluation of potential backfill materials in the vicinity of SCP was based on environmental risk assessment, geochemical testwork and engineering considerations.

---

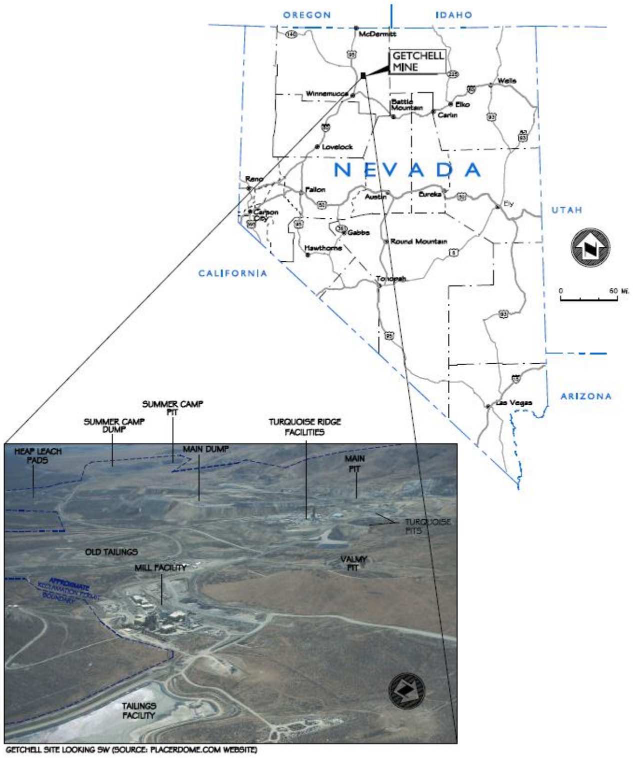
[1] Paper presented at the 7th International Conference on Acid Rock Drainage (ICARD), March 26-30, 2006, St. Louis MO. R.I. Barnhisel (ed.) Published by the American Society of Mining and Reclamation (ASMR), 3134 Montavesta Road, Lexington, KY 40502

[2] Jeffrey V. Parshley, Director, SRK Consulting (U.S.), Inc., Reno, NV, 89502. Robert J. Bowell, Direcctor, SKR Consulting (U.K.), Cardiff, Wales, CF10 3BX, UK. John Ackerman, Placer Turquoise Ridge Inc., Golconda, NV, 89414.

7th International Conference on Acid Rock Drainage, 2006 pp 1495-1513
DOI: 10.21000/JASMR06021495
https://doi.org/10.21000/JASMR06021495

Introduction

Summer Camp Pit (SCP) is located on private property owned by the Placer Turquoise Ridge Inc. (PTRI), near the south end of the Getchell Gold Mine. PTRI purchased the property from the Getchell Gold Corporation (GGC) in the late ‘90s. The mine is on the eastern flank of the Osgood Range, approximately 28 miles northeast of Golconda in Humboldt County, Nevada (Fig. 1). In accordance with State of Nevada regulations, PTRI prepared a detailed closure plan to achieve stabilization and final closure of the Summer Camp Pit.



GETCHELL SITE LOOKING SW (SOURCE: PLACERDOME.COM WEBSITE)

Figure 1. Location and layout of the Summer Camp Pit and adjacent facilities.

Exploration at SCP began in 1987 and continued through 1990 when mining began. Mining continued through September 1991. SCP remained inactive until 1993 when GGC began using the pit to temporarily store dewatering water pumped from the Getchell Main Underground mine (GMU). This water was subsequently pumped to the arsenic treatment plant and used as makeup water for the process circuit. In 1995, dewatering of the Turquoise Ridge Underground (TRU) mine began, and this water was added to SCP as well. During this period, sediment from the underground workings also accumulated in the pit; generally in the area around the water discharge point(s) and as a fan along the base of the pit.

In February 2000, GGC expanded the capacity of the arsenic treatment plant to treat all of the water from both underground mines and SCP was no longer needed as a temporary storage basin. The static water level in SCP has been recovering since that time. Following the complete removal of water from SCP in October 2001, GGC allowed the pit to refill three times to establish the natural rate of recharge.

GGC evaluated various options for closure of the pit. Draining and partial backfill provided the most suitable closure alternative for this pit, because it would eliminate the pit lake, reducing the potential for future groundwater impacts and risks to terrestrial and avian wildlife.

This paper describes the assessment of the pit lake and development of criteria for the closure options. The design of the backfill and regulatory requirements of pit lake closure in Nevada are also discussed.

Methodology

All data collected by SRK Consulting (U.S.), Inc. (SRK) and referenced herein was analyzed by Sierra Environmental Monitoring, Inc. (SEM) utilizing methods approved by the Nevada Division of Environmental Protection (NDEP). All water samples collected by SRK were sampled, preserved, transported and analyzed using standard Chain-of-Custody procedures and in accordance with NDEP approved methods (NDEP, 1990b).

Whole rock analysis was undertaken using the EPA method 3050. The leaching characteristics of rocks and sediments were assessed using the Meteoric Water Mobility Procedure (MWMP) following the ASTM protocol E-2242-02 (NDEP, 1991; 1996).

Geochemical equilibrium modeling was performed using MINTEQA2 utilizing a modified MINTEQA2 mineral equilibrium database available from SRK (U.K.) (Bowell and Parshley, 2005; http://www.srk.co.uk/pages.asp?pagename=pubarticles).

The methods of sample collection, handling, analysis and modeling used in the preparation of data referenced in this paper are provided in detail in several reports submitted to the NDEP including "Groundwater Chemistry Review, Getchell Mine, Nevada" (SRK, 1999a), "Geochemical and Limnological Assessment of Summer Camp Pit Lake" (SRK, 2001), "Closure Plan and Backfill Assessment: Summer Camp Pit Lake" (SRK, 2004), and Bowell and Parshley (2005).

Regulatory Framework

In the state of Nevada, laws designed to protect water resources are administered by the NDEP. The sections of the Water Pollution Regulations (NAC 445A.350 – NAC 445.447) that pertain to mines are administered by the Bureau of Mining Regulation and Reclamation (BMRR). Generally, these regulations require that mine operators "*must institute appropriate procedures to ensure that all mined areas do not release contaminants that have the potential to degrade the waters of the State*" (NAC 445A.429(1)).

Additional sections of the regulation specifically address the closure and long-term conditions of pit lakes and require that *"[o]pen pit mines must, to the extent practicable, be free-draining or left in a manner which minimizes the impoundment of surface drainage and the potential for contaminants to be transported and degrade the waters of the State*" (NAC 445A.449(2)). Because the SCP will not and cannot be made to be free draining, the long-term closure plan for SCP developed by GGC had to address three other requirements for open pit closure contained in the Nevada mining regulations. Specifically, these regulations require that:

3. Bodies of water which are a result of mine pits penetrating the water table must not create an impoundment which:

(a) Has the potential to degrade the groundwaters of the State; or

(b) Has the potential to affect adversely the health of human, terrestrial or avian life.

(NAC 445A.429)

Options for closing pit lakes

In general most open pits in Nevada will not be free draining at closure, and some will intersect the groundwater table and develop pit lakes at closure. Because of the semi-arid conditions in the Great Basin, many of these pit lakes will be hydrologic sumps rather than significant sources of groundwater recharge. However, even in these cases, there is a potential for pit lake chemistry to evolve in a manner that there is a potential to adversely affect human, terrestrial or avail life.

Several methods for effective pit lake closure have been implemented at various mines in the state and these methods also represent the primary methods proposed for future pit lakes. These include:

- Natural refilling (e.g. Yerington, Aurora);
- Accelerated refilling to rapidly raise the water level above the most reactive rocks exposed in the pit wall (e.g. Sleeper, Pinson);
- Sequential backfilling (e.g. Borealis); and
- Post-mining backfilling (e.g. Hollister, Getchell (North Hansen pit).

Site Climate

The climate of this region is semi-arid or steppe characterized by dry, hot summers and cold winters. Annual precipitation is low (less than 10 inches) with low relative humidity, clear skies, and large diurnal temperature variations because of the dryness of the air. Rainfall data from the Getchell site has been collected since 1980. The average annual precipitation over this period has been approximately 9.4 inches, with an annual high of 18.69 inches recorded in 1983 and an annual low of 5.84 inches in 1990.

The climatic record indicates normal maximum temperatures vary from 80° to 100°F in the summer and 30° to 40° F in the winter. Normal minimum temperatures range from 40° to 50°F in the summer and 15° to 25°F in the winter. The 1994 meteorological data from the Twin Creeks Mine (located approximately three miles east of the Getchell site) show a maximum temperature of 98.6° F occurring in July and a minimum of -0.2°F occurring in December, with an average temperature for the year of 50.3°F (BLM, 1996).

Geology of Summer Camp Pit

The host rocks of the SCP lie within the Preble Formation of Middle to Upper Cambrian age and Ordovician Comus Formation (Bowell et al., 1998). This unit comprises a tightly folded series of metamorphosed volcano-sedimentary rocks. The rocks have been fractured by the

Getchell Fault Zone and high-angle normal faulting trending N-S and N40-60°E. The primary geology and mineralogy of the wallrock and ore zones in SCP have been extensively described in earlier studies (SRK, 1997; 1998). A geologic summary is given in Fig. 2.

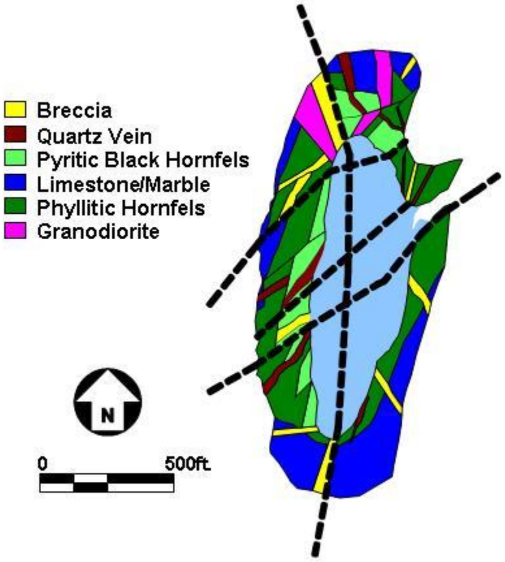


Figure 2. Exposed geology in the Summer Camp Pit (light blue is pit lake as of April 2002).

The deposit is a typical Carling type partly oxidized disseminated sulfide-micron gold deposit in strongly deformed and altered Paleozoic metasediments. The major focus of gold-earing mineralization is breccias that are associated with the north/south-trending shear zone, the Getchell Fault Zone (GFZ). Some of the silica-rich breccias in SCP appear to occur preferentially in the marble. These zones have been termed “jasperoids” and often carry high grades of 0.5 oz/ton Au or more and contain abundant fine-grained idiomorphic pyrite (up to 20%). The principal sulfide is pyrite and Au occurs as finely disseminated grains within pyrite (Bowell and Parshley, 2005). Pyrite occurs principally in the pyritic black hornfels and, breccia and quartz veins associated with the North-South trending GFZ and the Northeast-Southwest trending secondary shears (Fig. 2). The hydrothermal alteration of the wallrocks has led to an illite, quartz, goethite and calcite assemblage being dominant within the GFZ. Along secondary shears graphitic carbon and massive kaolinite-illite zones are present. The trace element geochemistry displays higher than average crustal abundance values for Ni, As, Ag, Sb, and Hg (Bowell and Parshley, 2005).

Post emplacement oxidation of the deposit has been extensively developed with the sulfide-oxide boundary in the pit developed at a depth of 150 to 200 feet below present land surface (at an elevation of approximately 5250 feet elevation in the south to 5325 elevation in the north of the pit.

An extensive assemblage of secondary minerals identified in the pit wall reflects the geochemical complexity of the Summer Camp Pit system (Table 1). The complex mineral-water interactions that formed these minerals explain the difficulty associated with numerical predictions of water quality as many of these secondary minerals and salts are not covered within the standard thermodynamic database of most geochemical prediction codes (Bowell and Parshley, 2005). These modeling difficulties were overcome by adding the thermodynamic data for the Getchell mineralogy to a modified MINTEQA2 mineral equilibrium database (Bowell and Parshley, 2005).

Table 1. Secondary mineralogy of Summer Camp Pit (from Bowell and Parshley, 2005).

Mineral	**Formula**
Sulfur	S
azurite	$Cu_3(CO_3)_2(OH)_2$
malachite	$Cu_2CO_3(OH)_2$
Illite	$KAl_2(Si,Al)_4O_{10}(OH)_2$
smectite	$(K,Na)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2.nH_2O$
scorodite	$FeAsO_4.2H_2O$
pharmacolite	$CaHAsO_4.2H_2O$
Weilite	$CaHAsO_4$
legrandite	$Zn_{14}(AsO_4)_9OH.12H_2O$
austinite	$CaZnAsO_4OH$
cornwallite	$Cu_5(AsO_4)_2.12H_2O$
ilsemannite	$Mo_3O_8.nH_2O$
goethite	FeOOH
pyrolusite	MnO_2
manganite	MnOOH
hausmannite	$Mn_2(Mn,Fe^{3+})O_4$
pararealgar (sediment on ramp only)	AsS
mirabilite	$Na_2SO_4.10H_2O$
gypsum	$CaSO_4.2H_2O$
Barite	$BaSO_4$
brochantite	$Cu_4(SO_4)(OH)_6$
Langite	$Cu_4(SO_4)(OH)_6\ .2H_2O$
jarosite	$K\ Fe_3^{3+}(SO_4)_2(OH)_6$
copiapite	$Fe^{2+}Fe_4^{3+}(SO_4)_6(OH)_2.20H_2O$
halotrichite	$Fe^{2+}Al_2(SO_4)_4.22H_2O$
melanterite	$Fe^{2+}SO_4.7H_2O$

Hydrogeology of Summer Camp Pit

Pre-mining groundwater levels near Summer Camp Pit were approximately 200 feet below ground surface (Grimes et. al., 1995). Groundwater flow in this section of the GFZ is heavily compartmentalized due to;

- East-west faults in SCP are clay-filled and as such are effectively barriers to flow;
- Granodiorite on west side of GFZ does not produce water; and
- Bedrock in SCP is within the metasomatic aureole of the Osgood stock and as such is recrystallized leading to negligible storage in the rock mass for water.

Due to the heterogeneous, anisotropic nature of the hydrostratigraphy, groundwater occurrence is random and isolated. There are no apparent continuous water-bearing zones within the SCP hydrostratigraphy.

The compartmentalization regime appears to be controlled by faults that exhibit visible displacement along dip. Figure 3 represents the re-interpreted potentiometric data collected during exploration.

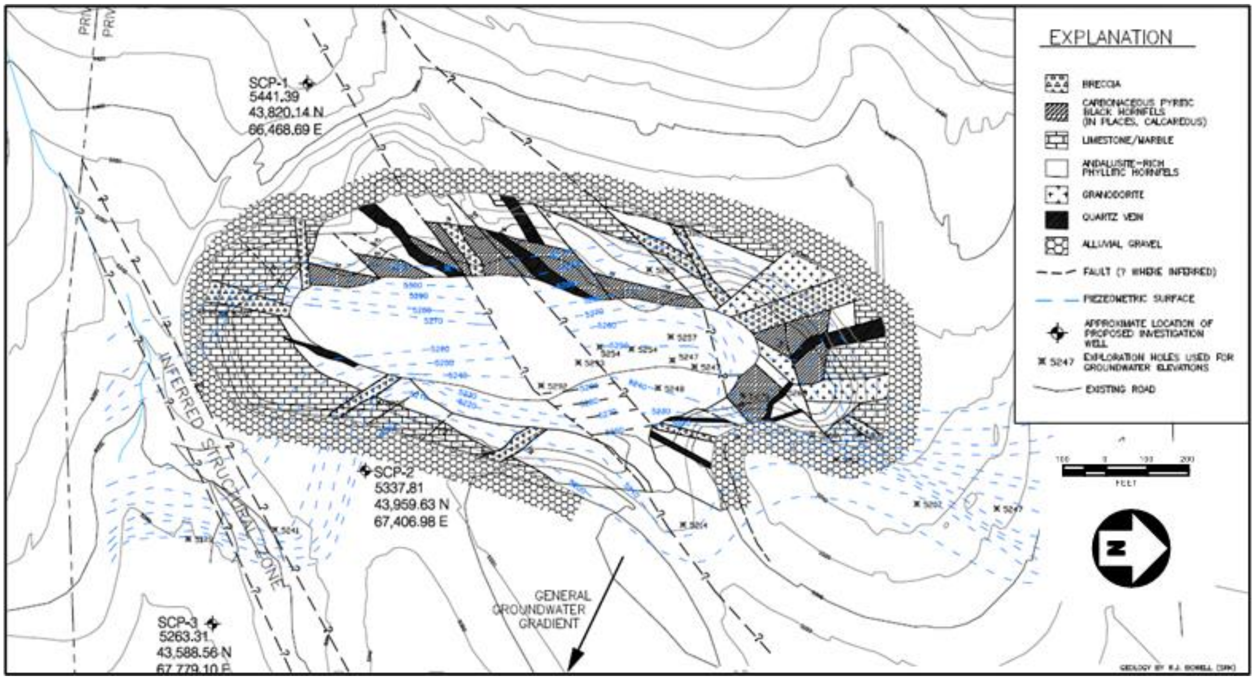


Figure 3. Detailed Summer Camp Pit geology and pre-mining potentiometric surface.

This figure indicates an apparent structural control within the central zone of SCP. This area is bounded to the north and south by faults that exhibit visible displacement. Given the amount of displacement, it would be reasonable to assume that clay rich gouge is present along the fault plane. This clay-rich gouge would retard flow through the central zone, and consequently confine groundwater under pressure. By evaluating the change in head in the central zone when compared to the north and south zones, it is apparent that a structural influence is present (Fig. 3).

There also appears to be potential structurally related groundwater controls present in the north zone of SCP (Fig. 3). Exploration data suggest that the head changes approximately 90 feet over a horizontal distance of less than 150 feet. It is likely that a compartmentalized zone is present within this area, and the potentiometric surface could also be offset, similar to that of the central zone.

Summer Camp Monitoring Wells

GGC installed three monitoring wells in early 2000 to determine the hydraulic relationship between the water in the pit lake and surrounding groundwater in the bedrock (SRK, 1999b; SRK, 2000). The upgradient well (SCP-1) was installed on the west highwall of the Summer Camp Pit. SCP-2 was installed on the east highwall as close to the pit wall as was safe and practical. Well SCP-3 was located east of the northeast-trending fault aligned with the drainage south of the pit, to test the hypothesis that this structure acts as a barrier to groundwater flow. Figure 3 illustrates the location of each well.

Initial static water levels in the wells indicate that the storage of water in SCP had created a localized groundwater mound. Groundwater in SCP-1 was approximately 37 feet above the elevation of the pit lake surface, while SCP-2 and SCP-3 were 25 feet and 60 feet below the surface of the lake, respectively. As the pit lake level decreased with the cessation of pumping, the static water level in all of the wells decreased, significantly so in SCP-2. By May 2000, this well was dry. The water levels in the other two wells decreased more slowly and less drastically.

Background Groundwater Chemistry

Two types of groundwater occur in the bedrock aquifers in the vicinity of SCP, based on their background water quality and on their proximity to mineralized zones:

- Type 1: waters from areas away from the sulfide mineralization or from formations containing significant marble that are $Ca\text{-}HCO_3$-dominated; and
- Type 2: waters from sulfide mineralized zones that are $Ca\text{-}HCO_3\text{-}SO_4$-dominated.

These water types are typically alkaline, with Type 1 having a pH range higher than Type 2. Type 1 waters typically contain Al, As, Fe and Mn in excess of drinking water standards. Type 2 waters typically contain TDS, SO_4^{-2}, Al, As, Fe, Mn and Zn in excess of drinking water standards. Type 2 waters contain As and Fe in a reduced oxidation state as well dissolved sulfide with other minor elements. Naturally occurring constituents of concern are most likely leached from the hornfels and liberated during oxidation of the sulfides, with pyrite supplying Fe, S, As, Mn, Ni and Zn and the As-sulfides supplying As, S and Sb.

A pre-underground mining (1988-1992) hydrogeochemical survey was conducted across the Kelly Creek basin, including the SCP area pre-mining by the USGS (Grimes et al., 1995). A statistical summary of the groundwater hydrogeochemistry, as presented in the USGS work, is provided in Table 2.

Table 2. Groundwater hydrogeochemistry along the Getchell Trend (Grimes et al., 1995).

	pH (s.u.)	Eh (mV)	Au (ng/L)	As+3 (µg/L)	As+5 (µg/L)	As-tot (µg/L)	Sb (µg/L)	Fe (mg/L)	Mn (mg/L)	Ca (mg/L)
Mean	7.80	178.19	739.77	53.55	30.62	146.53	29.88	0.37	0.21	67.32
Median	7.80	190.00	20.00	15.00	24.00	16.00	2.00	0.02	0.13	57.00
Mode	8.00	150.00	1.00	10.00	17.00	5.00	0.20	0.01	0.08	47.00
Standard Deviation	0.42	110.96	1238.73	128.98	27.57	1198.61	146.21	3.51	0.26	38.95
Sample Variance	0.18	12313.18	1534445.17	16636.69	760.19	1436665.31	21377.25	12.30	0.07	1517.09
Minimum	6.50	-210.00	1.00	1.00	2.00	0.91	0.10	0.01	0.01	10.00
Maximum	8.80	410.00	6300.00	760.00	180.00	20000.00	2400.00	48.00	2.32	380.00
Samples	428	242	345	47	131	385	370	189	392	442

	Mg (mg/L)	K (mg/L)	Na (mg/L)	SO4 (mg/L)	Cl (mg/L)	NO3 (mg/L)	Alk (mg/L)	EC (µS)	Temp. (°F)	Pb (µg/L)
Mean	21.84	24.71	44.44	123.00	73.72	6.39	187.52	721.07	64.60	2.80
Median	21.00	4.50	43.00	98.00	40.00	2.30	180.00	640.00	64.45	0.55
Mode	28.00	3.60	44.00	130.00	37.00	2.30	180.00	650.00	63.70	0.10
Standard Deviation	11.71	213.71	17.50	95.57	357.38	37.51	51.75	601.27	4.42	5.02
Sample Variance	137.16	45673.37	306.38	9133.49	127717.83	1406.85	2677.76	361531.36	19.51	25.23
Minimum	3.00	2.00	18.00	3.51	7.70	0.10	72.00	320.00	48.90	0.03
Maximum	96.00	3200.00	190.00	640.00	7200.00	460.00	800.00	10200.00	81.10	24.00
Samples	441	441	442	434	432	150	326	441	220	44

	Zn (µg/L)	Cu (µg/L)	Ni (µg/L)	Cr (µg/L)	F (mg/L)	Ag (µg/L)	Cd (µg/L)	Tl (µg/L)	Se (µg/L)	Ba (µg/L)
Mean	24.55	3.99	16.72	0.87	0.88	< 0.1	2.28	0.85	8.37	51.44
Median	6.25	3.00	11.50	0.60	0.60	< 0.1	0.42	0.55	5.00	42.00
Mode	4.00	1.00	4.00	0.50	0.50		0.20	0.20	3.00	32.00
Standard Deviation	77.17	5.35	34.71	0.92	0.89	< 0.1	8.18	0.89	8.03	38.82
Sample Variance	5955.85	28.59	1205.01	0.84	0.80	< 0.1	66.84	0.80	64.55	1506.86
Minimum	0.60	0.51	1.00	0.20	0.08	< 0.1	0.10	0.20	2.00	5.20
Maximum	1200.00	70.00	600.00	7.50	5.10	< 0.1	84.00	4.00	40.00	250.00
Samples	404	260	368	145	146	< 0.1	149	20	33	135

This survey shows that:

- Background concentrations of Au, As, Sb, W, Mn and Fe were higher in the mineralized bedrock aquifers than in the unmineralized bedrock aquifers by several orders of magnitude for some elements. For example, arsenic in the unmineralized areas was typically around 0.02 mg/L in the vicinity of SCP, but along the GFZ, in the mineralized zone concentrations reached 2.6 mg/L as As(III);
- Some elements show a complex cycling in the bedrock and alluvial aquifers, with partial removal through mineral-water reactions creating a secondary dispersion anomaly; and
- As, Mn, Fe, Co and Sb mobilization is enhanced in reducing conditions and displayed significant enrichment in the alluvium at the current water table. This indicates that water-soil interaction between alluvial materials and groundwater systems around the buried disseminated gold deposits is an ongoing process.

Subsequent sampling and analysis of geochemical equilibrium of the groundwater in the area (SRK, 1999a; 2001) resulted in predicted groundwater chemistry similar to that measured by the USGS (Grimes et. al., 1995; USGS, 1997). Because this work was conducted prior to underground mining and subsequent sampling during underground development confirmed those results, these data are considered to represent background water chemistry.

Pit Lake Volume

SRK conducted a bathymetric survey of the Summer Camp pit lake on May 28, 2002. The survey indicates a pre-closure volume of approximately 60 million gallons of water. Visual observations and the bathymetric survey data indicate that the sediments, accumulated during the addition of underground dewatering water, are located in two main areas; on the extension of the pit ramp along the eastern side and in a delta close to the discharge point. The sediment in the ramp area was removed in 2003 and placed in the active tailings impoundment. The remaining sediment was spread across the base of the pit.

The pit water level has gradually reduced since operations at the mine ceased. As a result, sediments that were once underwater were exposed and dried out. The volume of these dry sediments was between approximately 1500 cubic meters (m^3). The majority of these sediments were removed from the pit by the end of 2004.

Geochemistry of Summer Camp Pit

The historical characteristics of the SCP lake has been published elsewhere (SRK, 2001; Bowell, 2002). GGC monitored the Summer Camp Pit lake chemistry from 1990-1999.

Hydrogeochemistry of SCP

These studies indicated that the pit lake had developed a stable stratification comprising three layers. From the bottom of the lake these are the hypolimnion, metalimnion and epilimnion (Table 3).

The hypolimnion observed over 1996-1999 showed a relatively uniform chemistry (Bowell, 2002). Arsenic III was dominant to As V as was Fe^{+2} iron to Fe^{+3} iron. In the October 2001 samples a similar though weaker trend was observed. In March 2002 a reducing sulfide-bearing acidic metal-rich zone was again evident at the base of the pit (SRK, 2004).

Geochemistry of Wallrocks

A number of studies have been conducted on the geology, mineralogy, geochemistry and limnology of SCP during the period 1996 through 2004 (SRK, 1996; 1997; 1998; 1999a, b, c; 2000; 2001; 2004). A detailed description of analysis and collection of samples is given in SRK (1997; 1998; 2001). Wallrock samples were collected from exposed walls and historic drill holes (reverse circulation chips). Whole rock analysis was undertaken using the EPA method 3050.

The leaching characteristics of each of the rock types and sediments were assessed using the Meteoric Water Mobility Procedure (MWMP) analysis following the ASTM protocol E2242-02 (NDEP, 1991; 1996). The average results for selected parameters are provided in Table 4.

Table 3. Summary of SCP lake chemical stratification.

Zone	pH (s.u.)	TDS (mg/L)	As (mg/L)	Fe (mg/L)	Temp. (^{o}C)	Turnover Effects
Epilimnion	Circum-neutral to alkaline	Moderate to low (600-1000 mg/L)	Low to moderate (0.05-1 mg/L)	Low (<1 mg/L)	Ambient	Strong influence, complete mixing in winter
Metalimnion	Circum-neutral to alkaline	Moderate to low (800-1200 mg/L)	Low to moderate (0.05-1.2 mg/L)	Moderate to low (0.2-10 mg/L)	Ambient to cool	Strong influence, complete mixing in winter
Hypolimnion	Acidic	High (>1500 mg/L)	High (0.5-20 mg/L)	High (up to 800 mg/L)	Ambient to cool	Slight influence of turnover, increase in pH, drop in TDS, metals, As

Table 4. Summary of MWMP leachates for SCP lithologies.

		pH	**TDS**	**Fe**	**Mn**	**Zn**	**As**	**Ca**	**SO_4**
NDEP Water Quality Guidelines		6.5-8.5	1000	0.6	0.1	5	0.05	-	500
Hornfels	-oxidized	6.54	729	6.7	0.1	0.1	0.096	27	620
	-transitional	4.47	1398	10.8	0.23	3.2	6.9	415	1220
	-sulfide	4.78	420	11.2	0.11	1.9	5.6	126	398
Quartz-breccia	-oxidized	5.78	1280	11.29	0.98	0.12	2.81	51.68	1196
	Transitional'96	2.67	10500	2150	112	31	165	412	8950
	Transitional'98	3.72	4023	62.5	14.6	8.6	16.2	322	2570
	-sulfide	6.72	612	8.66	0.41	0.26	1.45	9.79	584
Marble	-oxidized	8.24	721	<0.1	<0.1	<0.1	0.006	298	45
	-transitional	7.69	1367	0.22	<0.1	<0.1	0.17	122	130
	-sulfide	8.33	576	<0.1	<0.1	<0.1	0.09	218	74
Ore Stockpile A		2.56		1900	80	33	250	340	9390

All values in mg/L apart from pH, which is reported in standard units (s.u.)

The sulfide-bearing hornfels produces an acidic metal-rich SO_4^{-2} leachate by MWMP extraction. This leachate is pH ~5 s.u. with high SO_4^{-2} (2900 mg/L), Fe (200 mg/L), Al (45 mg/L), Cd (0.038 mg/L), Mn (5 mg/L), Ni (4.9 mg/L) and Zn (8.3 mg/L). By contrast, the andalusite hornfels produce a better quality leachate. Marble wallrocks tend to show an alkaline (pH ~9 s.u.), high salt content leachate (Ca ~500 mg/L, SO_4^{-2} ~1300 mg/L). Some samples show leachable As (up to 0.19 mg/L). Although mineralogically no host was observed, it is believed that these rocks hosted some Ca-Mg arsenate precipitates based on the understanding of the association of these minerals at Getchell with the marbles (Dunning, 1985).

Geochemistry of the pit lake sediments

Samples of the sediment present in the base of the pit once drained were also analyzed by the EPA 3050 and ASTM E2242-02 methodologies. The sediment sample produced a mildly acidic (pH ~ 5 s.u.) metal SO_4^{-2} leachate with SO_4^{-2} ~ 14000 mg/L, Fe ~ 2000 mg/L, Al ~ 800 mg/L, As

~12 mg/L, Cd ~0.4 mg/L, Cu ~18 mg/L, Mn ~38 mg/L, Ni ~23 mg/L, and Zn ~53 mg/L. The high metal release is due to oxidation and leaching of neogenic sulfides and associated SO_4^{-2} minerals. It is considered that these sediments represent the largest reservoir of seasonal metal release in the pit.

Constituent Release Rates. A 95 week humidity cell test using the modified ASTM 5744 method was completed on the hornfels wallrock from Summer Camp Pit. Based on mineralogical work and static testing, it was determined that this was the only wallrock lithology likely to leach metals and SO_4^{-2}. The tests were conducted to assess;

- Potential and rate for acid generation;
- Potential and rate for metal and metalloid release, principally Mn, As, Se, Hg, and Tl; and
- Potential for salt accumulation.

During the 95 week testing program, the following observations were recorded:

- The cell remained acidic throughout the test showing spikes in acid release in weeks 1-3 related to release of acid salts. This was followed by mineral buffering and pH adjustment. A second dip occurred around week 30 due to oxidation of poorly crystallized pyrite. This was followed by buffering to around pH 3.5 s.u. This pH control reflects the abundance of Fe-Al oxyhydroxides in the test cell that are controlling solution pH. In week 70 another pH drop occurred in response to oxidation of crystalline pyrite in the sample;
- Sulfate was released initially at a rate of 753 mg/Kg/week and after week 1 this increased to 1230 mg/Kg/week. Following this the release rate fell to ~200 mg/Kg/week and showed a gradual increase with time such that from week 65 to 70 it averaged 325 mg/Kg/week;
- Arsenic release mirrored pH and showed initially a large release due to dissolution of secondary minerals (up to 14 mg/kg/week), followed by a second spike over weeks 26 to 32 of 12 mg/Kg/week. As sulfides oxidized, As gradually increased such that by weeks 65 to 70 it was 6-8 mg/Kg/week and continued at this release rate for the reminder of the test program;
- Iron and Al were initially released at very high rates, in excess of 500 mg/Kg/week due to dissolution of minerals such as halotrichite and melanterite. The rate quickly fell to below 50 mg/Kg/week due to formation of stable Fe oxyhydroxides;
- Of the trace elements present, Zn and Ni reflected sulfide oxidation. Both these elements occur as trace elements, particularly in the poorly crystallized pyrite and thus spiked around week 30.

Following the testing program, the mineralogy of the residue was compared to the starting mineralogy. Both poorly crystallized and crystalline pyrite and marcasite showed evidence of oxidation and rimming by oxidation products. Calcite within vein and matrix material showed evidence of corrosion and partial replacement by anhydrite.

Although not assessed by cyclic leaching the sediments in the SCP system are predicted, on the basis of MWMP testwork, to be the main contributor of arsenic, metals and SO_4^{-2} to the pit lake. This is a function of the high solubility of secondary minerals and fine-grained sulfides exposed within the sediments.

Conceptual Model for Long Term Evaluation of Water Chemistry in SCP

Based on the above characterization it was clear that without the addition of alkaline water to SCP that water quality in the much reduced lake volume would significantly degrade. Sulfide oxidation would occur through the seepage of water from the oxide zone into and as runoff over exposed sulfides. Seasonally high runoff from snow melt and fall rain events would add an additional source of water that would in part be contaminated by contact with exposed pit sediments and oxidizing wallrock and would also provide some dilution. Geochemical modeling showed the benefit of this latter event to be negligible.

Evaluation of Closure Alternatives

Following the complete removal of water from the pit in October 2001, the pit was allowed to refill naturally to establish the rate of recharge. This process was repeated in summer 2002 and again in November 2003. From data gathered during the recovery cycles, the recharge rate was found to range from 0.3 gpm to 27 gpm with an average recharge of 6.19 gpm.

Observations of pit water and groundwater chemistry during the pumping and recovery cycle from late 2002 through early 2004 confirmed the conclusions of the previous analytical and modeling work. Once the pit lake depth was reduced to less than 6 m (1,580 m amsl), mineral-water interactions between the sediments, the wallrocks, and the lake water became the primary control on the pit lake chemistry. This resulted in a rapid decrease in pH from 7.1 to 4.2 s.u., between September 2002 and November 2002 with coincident increases in SO_4^{-2} TDS and Zn (see Fig. 4 and 5). In November 2002, the drop in pH coincides with spikes in Zn and As concentrations, and less significant increases in SO_4^{-2} (Fig. 4 and 5) and Fe (not shown). In addition Mg data (not shown) also showed an increase along with TDS (Fig. 5). This indicates that the spike in As and Zn is most likely due to dissolution of the widespread Mg-arsenate and Zn-bearing minerals in response to an acidification event.

After the model results were confirmed in the field during the pit refilling tests, GGC determined that the long-term chemistry of the pit lake would require the development of a long-term closure or management plan for SCP.

Several possible options were evaluated for closure of the pit; these were:

1) Partial backfill of the pit;
2) Create a pit lake and maintain it in perpetuity with passive or active water treatment as required and positive recharge to maintain water level above the sulfide-oxide boundary in the pit (approximately 1600 m amsl); and
3) Pump lake dry and keep it so with continuous water treatment for any collected drainage in the pit.

A risk profile for these options is given in Table 5.

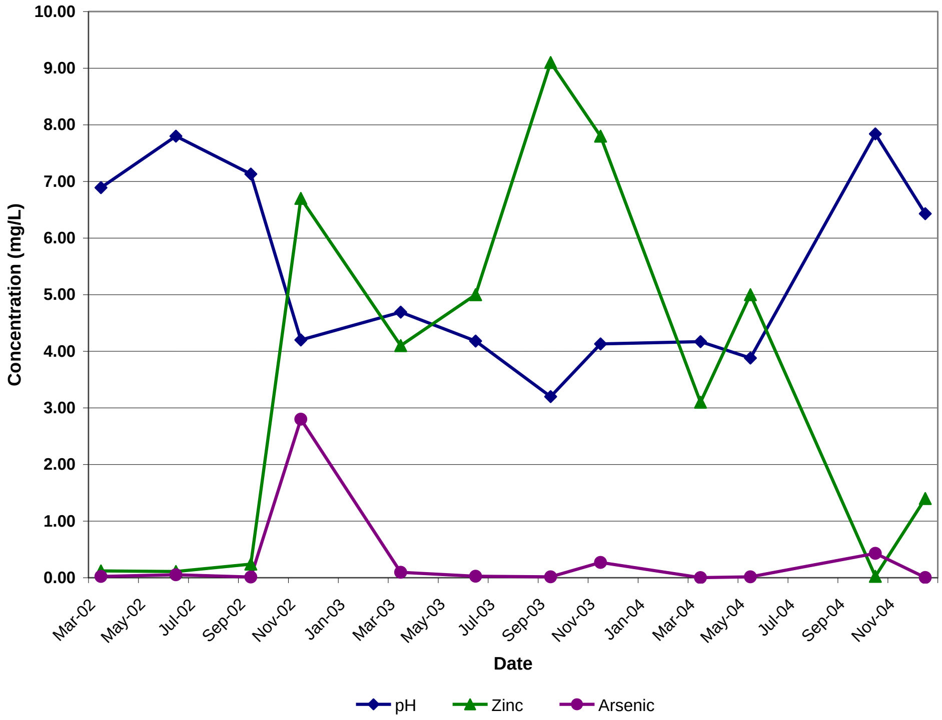


Figure 4. Recent pit lake chemistry in Summer Camp Pit – pH, Zn & As.

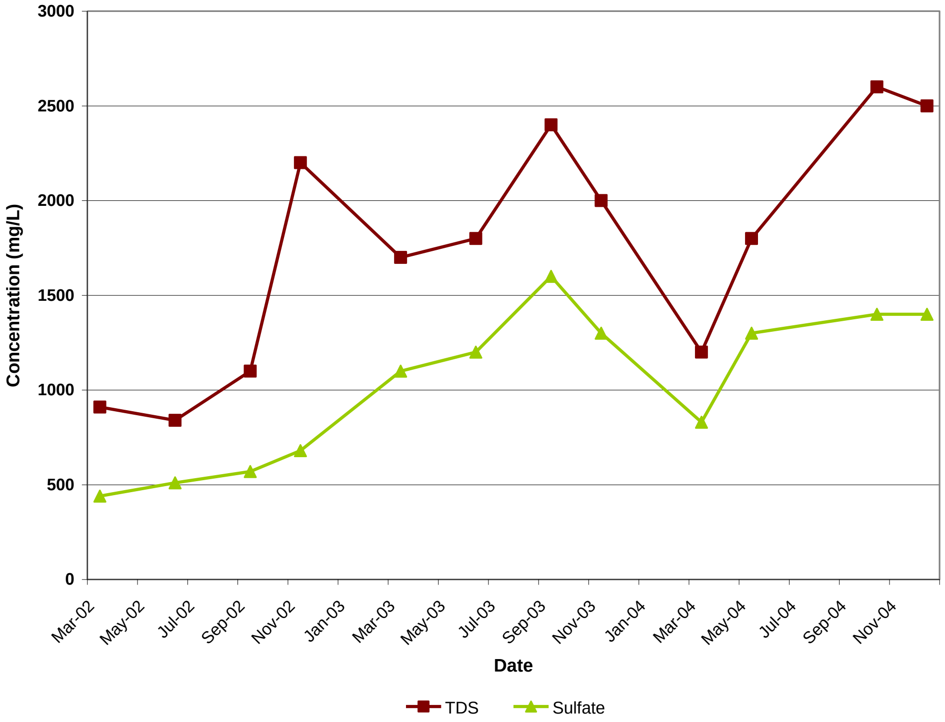


Figure 5. Recent pit lake chemistry in Summer Camp Pit – TDS & sulfate.

Table 5: Management risk profile for the Summer Camp Pit Lake.

Option	Description	Advantages	Disadvantages	Comments
Backfill pit	Backfill pit to a point that no permanent surface water feature was present All sediments would be removed from the pit before backfilling	No risk to wildlife/avian fauna Minimal sulfide oxidation due to lack of oxygen therefore no degradation of groundwater quality Provide a soil and grass cover to pit and landscape remaining benches to mitigate any visual impacts	Cost Identifying suitable backfill material	Lowest long term risk as all potential hazards are mitigated but has a high cost implication. Due to remoteness of pit this option is attract as no further monitoring is required
Maintain pit lake	Manage a pit lake with a water cover above sulfide zone	Potential lower cost than 1) although some water treatment eg lime or inpit development of bacterial activity may be required	Possible need for water treatment Potential risks to wildlife and avian species Need for long term monitoring Potential degradation of groundwater	Least attractive option due to the highest risk profile and negligible mitigation of impacts Site would be monitored continuously so would in the long term be a high cost

Option	Description	Advantages	Disadvantages	Comments
Dry open pit	Pump pit dry, remove sediments and pump any future water to a treatment plant	Lowest cost option Minimal change to the pit	Probable need for water treatment Cost of pumping water seasonally Potential risks to wildlife and avian species Need for long term monitoring Potential degradation of groundwater still a risk	Site would be monitored continuously so would in the long term be a high cost Long term cost of active water treatment Site would not be closed

For the following reasons GGC determined that partially backfilling the pit was the most appropriate option for closing the Summer Camp Pit:

- The pit is small and the water table is low enough to limit the amount of backfill required to fill the pit to above the long-term static water table;
- Adequate volumes of suitable backfill material are readily available from nearby mine facilities that also require reclamation;
- Source-control migration options were not feasible; and
- Long-term active or semi-passive methods would require regular on-site maintenance.

Summer Camp Pit Closure Plan

Based on geochemical, geotechnical and risk evaluations, GGC determined that the most effective long-term closure solution for SCP is a partial backfill above the average pit lake elevation of 1,593 m amsl measured since 2000. Based on the studies and risk analysis, GGC prepared a final closure that incorporated dewatering the pit, selected sediment removal and disposal, backfilling with suitable waste rock from surrounding unreclaimed waste rock dumps, placement of a growth media cover designed to enhance evapo-transpiration of precipitation and surface water inflows, stormwater control inspections, and continued groundwater monitoring.

Water and Sediment Removal

GGC began final removal of the remaining pit water in 2004. As the sediments on the ramp and pit bottom were exposed during dewatering activities between 2002 and 2004, the sediments were removed and hauled to the tailings impoundment. Because of the irregular pit bottom surface, some sediments could not be removed. GGC mixed lime with the sediments remaining in the bottom of the pit prior to backfilling. The lime added at a 1:9 lime to sediment ratio, which will be sufficient to provide excess neutralizing capacity.

Backfill

The long-term water table is expected to stabilize at an average elevation of 1,600 m amsl. Backfilling the pit to this elevation will require approximately 650,000 m^3 of backfill material. Initially, blasting of pit walls was considered, but the volume required and the unsuitability of some of the pit wall material made this impractical. Therefore, GGC determined that selective borrow of suitable materials from surrounding, un-reclaimed waste rock dumps was a more appropriate option.

Geochemical assessment of the backfill material. On the basis of the MWMP leachate chemistry it is clear that not all materials were suitable for backfill in SCP. Consequently a series of large column leach tests were initiated (SRK, 2004). These tests were designed to evaluate the potential geochemistry resulting in the pit from groundwater through flow interacting with the backfill material.

Seven 680 kg columns were assembled comprising of locally derived fill material and blended with limestone. These columns were saturated with one pore volume of pit lake water on a 24 hour cycle from the base of the column, allowed to drain for 48 hours and the process was repeated four times.

The final backfill elevation will be between 1,597 and 1,600 m amsl. Based on the large column testwork, suitable backfill materials were located in the SCP dump and Reilly mine dump. The SCP dump lithologies selected include hornfels, granite and marble. The Reilly mine limestone and marble waste were selected for placement at the base of the pit to provide buffering for inflowing acidic water. This waste rock has extremely low leachable metals and metalloids and high buffering potential. Lime was added to the SCP lithologies used as backfill.

Backfilling began in 2004 and proceeded to an elevation of 1,595 m amsl. In 2005, the water levels in the backfill were monitored with standpipe piezometers installed in the backfill.

Cover and Revegetation

Once the backfill is completed, the pit will be covered with 30 cm of alluvium from the adjacent land, and an evapotranspiration and growth media cover will be developed in order to reduce infiltration of meteoric precipitation. The design of this cover is based on previous design work performed during the closure of the Getchell heap leach pads (SMI, 2001).

Conclusions

Although backfilling, either sequential or post-closure, can be an effective closure method for pit lakes that present water quality concerns, it remains a method of last resort in most cases. Sequential backfilling as part of an over all mine plan can be both cost effective and effective as a closure methods. Post-closure backfilling, however, is extremely expensive and generally impractical on a large scale. However, as with the case at Summer Camp Pit, in some instances, it can be the most appropriate method of pit closure to mitigate potential impacts from a pit lake.

The pit lake closure at Summer Camp Pit illustrates conditions under which partially backfilling a pit is an appropriate and cost-effective method of pit closure. In this instance, a number of key criteria indicated partial backfill would be the most appropriate:

1. The pit lake was predicted to have poor quality, but would be very small;
2. Although groundwater impacts were not predicted, the risks for wildlife impacts, although minimal, were determined to exceed the corporate risk profile for this type of situation; and
3. The mine was still operating and had the infrastructure required to implement a closure plan that included backfilling.

Backfilling, even partial backfilling cannot be universally applied as a closure method for all pit lakes. However, under certain conditions, it can be, and has been an effect approach to limit risk and provide for long-term protection of water and wildlife resources.

Acknowledgements

The authors would like to acknowledge the efforts and support of a number of our colleagues who contributed to the efforts of this project. Mark Willow, Amy Prestia, Richard Connelly, Dave Luppnow, Dave Bentel, Mark Hanneman and Steve Herron, of SRK; Frank Carr, Steve Schoen, Bill Upton, Randy Buffington and John Mansanti of Placer Dome; Lorraine Fillipek; John Barta and Mark Gingrich, formerly of Placer Dome; John Price and Lisa Shevenell, of Nevada Bureau of Mines and Geology, Gina Tempel of Mackay School of Earth Sciences and Engineering at University of Nevada, Reno; James Gannon University of Montana; John Seher at Sierra Environmental Monitoring; and Jim Harrington of Greenworld Science.

References

Bowell, R.J. (1994), "Arsenic Sorption by Iron Oxyhydroxides and Oxides", Applied Geochemistry, v9, pp. 279-286. http://dx.doi.org/10.1016/0883-2927(94)90038-8.

Bowell, R.J. (2001), "Hydrogeochemistry of the Getchell Mine", Part 1: Mine Water Chemistry. Mine Water and the Environment, v.20, pp. 81-97. http://dx.doi.org/10.1007/s10230-001-8086-z.

Bowell, R.J., Barta, J. and Parshley, J.V. 1998 Geological Controls on Pit Lake Chemistry: Implications for the assessment of water quality in Inactive open pit, SCP, Nevada. 6th Mine water conference, Johannesburg, IMWA, September 1998, 375-387

Bowell, R.J. and Parshley, J.V. 2005 Control of Pit Lake Water Chemistry by Secondary Minerals, Summer Camp Pit, Nevada. Chemical Geology, 215, 373-385 http://dx.doi.org/10.1016/j.chemgeo.2004.06.052

Bureau of Land Management (BLM) (1996), “Final Environmental Impact Statement, Twin Creeks Mine”.

Dunnig, G. 1985 Update on the mineralogy of Getchell mine. Mineralogical Record, 19, 253-257.

Gannon, J., B. Wielinga, J.M. Moore, P. Policastro, D. McAdoo, and T. Meikle (1996), “Field Investigations of the Sulfate-Reducing Potential in the Summer Camp Pit Lake”, 12pp.

Gannon, J., J.M. Moore, B. Wielinga, J. Castro, and P. Policastro (1997), “Getchell Gold Summer Camp Pit Lake: Sulfate-Reduction Microcosm Studies: Final Report”.

Grimes, D.J., W.H. Ficklin, A.L. Meier, and J.B. McHugh (1995), "Anomalous gold, antimony, arsenic and tungsten in groundwater and alluvium around disseminated gold deposits along the Getchell Trend, Humboldt County, Nevada", Journal of Geochemical Exploration, v52, pp. 351-371. http://dx.doi.org/10.1016/0375-6742(94)00023-5.

Nevada Division of Environmental Protection (NDEP) (1990a), "Meteoric Water Mobility Procedure".

Nevada Division of Environmental Protection (NDEP) (1990b), "Waste Rock And Overburden Evaluation"

Nevada Mining Association (NMA) (1996), "Meteoric Water Mobility Procedure (MWMP) - Standardized Column Percolation Test Procedure", pp. 5.

National Oceanic and Atmospheric Administration (NOAA) (1973), "NOAA Atlas 2, Precipitation Frequency Atlas of the Western United States. Hydrometeorological Design Studies Center, National Weather Service, Office of Hydrologic Development, Hydrology Laboratory".

Shepherd Miller (SMI) (2001), "Getchell Mine Heap Leach Pad Final Permanent Closure Plan".

Steffen, Robertson and Kirsten (SRK) (1996), "Workplan for the Old Tailings. Prepared for Getchell Gold Corporation".

Steffen, Robertson and Kirsten (SRK) (1997), "Review of Pit Wall Mineralogy and Pit Lake Hydrogeochemistry", Prepared for Getchell Gold Corporation.

Steffen, Robertson and Kirsten (SRK) (1998), "Getchell Gold Mine Amended Reclamation Plan".

Steffen, Robertson and Kirsten (SRK) (1999a), "Groundwater Chemistry Review, Getchell Mine, Nevada", Prepared for Placer Dome Getchell Mine.

Steffen, Robertson and Kirsten (SRK) (1999b), "Hydrologic Investigation Plan for Summer Camp Pit Area, Getchell Mine, Humboldt County, Nevada", Letter to M. Leigh, NDEP, December 10, 1999.

Steffen, Robertson and Kirsten (SRK). (1999c), "Geochemistry in the Old Tailings: Arsenic Uptake in Foliage".

Steffen, Robertson and Kirsten (SRK) (2000), "Sampling Report for Summer Camp Pit Groundwater Monitoring Wells, Getchell Mine, Humboldt County, Nevada", Letter to D. Tecca, NDEP, March 17, 2000.

Steffen, Robertson and Kirsten (SRK) (2001), "Geochemical and Limnological Assessment of Summer Camp Pit Lake", Prepared for Placer Dome Getchell Mine.

Steffen, Robertson and Kirsten (SRK) (2004), "Closure Plan and Backfill Assessment: Summer Camp Pit Lake", Prepared for Placer Dome Getchell Mine.

Strenger, D.P., S.E. Kesler, D.R. Peltonen, and C.J. Tapper (1998), "Deposition of Gold in Carlin-type Deposits: The Role of Sulfidation and Decarbonation at Twin Creeks, Nevada", Economic Geology, v93, pp. 201-215. http://dx.doi.org/10.2113/gsecongeo.93.2.201.

United States Geological Survey (USGS) (1995), "Unpublished Groundwater Geochemistry Database, 1990 - 1995 from Exploration Drillholes, Getchell property, Nevada".