WATER BALANCE MANAGEMENT APPROACH TO MINE CLOSURE AT THE ROYAL MOUNTAIN KING MINE, COPPEROPOLIS, CA

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ABSTRACT

This case history outlines a water balance management approach to closure of the Royal Mountain King Gold Mine near Copperopolis, California.

The Royal Mountain King Mine operated from 1988 through 1994. It includes three open pits, a 150-acre flotation tailings reservoir, 250 acres of over burden disposal systems, a leached concentrate residue facility, and a process water pond.

As a result of the mine's location in the mineralized Hodson fault zone, the groundwater and low flow conditions in the local creeks are impacted by elevated levels of total dissolved solids, chloride, sulfate, and traces of arsenic and selenium. During mining, water quality conditions at the Site improved due to the fact that the pits acted as large extraction sumps for groundwater and reduced poor quality spring flows to the creeks. The pits filled after mine closure, forming lakes. Water quality has worsened, both because the extraction sumps are no longer present and because of the effects of the various mine waste management units.

The waste management units have been closed either in accordance with regulatory prescriptive closure standards or engineered alternatives to these standards. In recognition of the naturally occurring poor quality water at the Site, consideration is being given to re-classifying the designated beneficial uses of groundwater. This will facilitate regulatory approval of closure of those waste management units which were temporarily closed using engineered alternatives to the regulatory prescriptive standards.

The major focus of closure is on site-wide water management. This involves collecting seepage from the toes of the overburden disposal systems, in addition to collecting the water in the flotation tailings reservoir and transferring it to one of the pits for seasonal storage. A discharge permit has been obtained allowing pit water to be released to the local creek during infrequent high flow rainstorm conditions. An automated computer controlled discharge system has been installed.

This case history is an example of achieving a moderate life cycle cost solution by satisfying regulatory agency concerns and thereby avoiding the high costs of the fully prescriptive regulatory closure requirements.

INTRODUCTION

In the summer of 2008, the authors toured the Royal Mountain King Mine (RMKM) site with the staff of the Regional Water Quality Control Board (RWQCB). As a result of a change in regulatory staff, there was a new motivation to finalize the mine closure after almost 13 years of closure and reclamation construction. In what turned out to be a breakthrough, the regulator purveyed the Site (Figure 1) and finally concurred that; "this mine closure is an exercise in water balance management, not in containment of mine waste under the prescriptive requirements of the California regulations." As a result, the approaches of the mining company and the regulators were aligned and a plan for mine closure was agreed upon.

The RMKM, operated by Meridian Beartrack Company (MBC) between 1988 and 1994, is located in the foothills of the Sierra Nevada near Copperopolis, California, in Calaveras County. MBC has been performing management, reclamation, and closure construction of the Site from the onset of mining to the present.

The RMKM Site includes the following areas:

- Three engineered waste management units (WMUs): a six million, 150-acre flotation tailings reservoir (FTR), a six-acre process water pond (PWP), and a 0.4 million ton, 18-acre leached concentrate residue facility (LCRF). In accordance with California Title 27 prescriptive requirements, the LCRF and PWP have been closed with geomembrane and soil caps. The FTR was graded for drainage, and covered with topsoil and vegetated. During the final years of mining tailings deposition was managed to maximize surface slope toward the drainage outlet.

- The FTR is a clay lined valley fill impoundment and both groundwater and rainfall infiltration accumulate in the stored tailings. The water contained in the tailings was initially discharged from the FTR Leachate Collection and Recovery System (LCRS) to Skyrocket Pit Lake. However in an effort to reduce the amount of poor quality water accumulating at the Site, the LCRS was closed in 2002 and hydraulic pressure was allowed to build up in the FTR. At best this experiment was anticipated to reduce groundwater inflow and increase evapotranspiration sufficiently to avoid having to remove water from the FTR. At worst, it is expected to reduce the amount of water that has to be removed. A small surface seep appeared near the edge of the FTR in 2008 indicating that at least some water will need to be transferred out of the FTR.
- Three overburden disposal sites (ODSs) covering approximately 250 acres and containing 54 million tons of waste rock: FTR ODS, West ODS, and Gold Knoll ODS. The ODSs have been reclaimed by grading, placement of topsoil cover and vegetated. The RWQCB also considers their closure as an engineered alternative to the Title 27 requirements.
- Two former pits filled with water: Skyrocket (55 acres) and North Pit (23 acres) Lakes.
- One backfilled pit: Gold Knoll.

The Skyrocket and North Pits have filled with groundwater and runoff from adjacent areas. Water levels in both pit lakes have reached equilibrium, with levels fluctuating seasonally from year to year, depending on the amount of rainfall. A 35-foot high earthen dam (Skyrocket Dam) has been constructed across the low point of the Skyrocket Pit Lake rim to contain the stored water without spillage (Figure 2). The dam is a jurisdictional structure, and is operated and maintained under a permit from the California Division of Safety of Dams.

Three seeps emanate from locations at the toes of the Gold Knoll and West ODSs (Figure 3). Water from these seeps is managed by collection and storage in Skyrocket Pit Lake. Water removed from the FTR is also placed in Skyrocket Pit Lake. This dewatering reduces the potential for seeps occurring along the sides of the FTR.

SITE CONDITIONS

Climate

The Site has a Mediterranean climate with warm, dry summers, and cool, wet winters. The average winter temperature is about 43 degrees Fahrenheit (°F) and the average summer temperature is about 71° F. Mean monthly extremes vary from 33°F to approximately 92°F. The mean annual precipitation is 25 inches, approximately 80% of which occurs in the winter months of November through March. The mean annual gross pan (Type A) evaporation at the Site is 68 inches.

Geology

The mine is in the western portion of the foothills metamorphic belt in Western Calaveras County. Gold mineralization occurs locally along a northwest-trending, east-dipping thrust fault zone, dominated by the Hodson and Littlejohns Faults (Figure 4). These structures juxtapose Upper Jurassic carbonaceous phyllite (shale and slate) against the greenstone (altered mafic metavolcanic units) of similar age.

There is extensive alteration, with the occurrence of quartz, pyrite, sericite, mariposite, serpentinite and ankerite, within the fault zone. This alteration resulted in the deposition of gold, both as free gold and within pyrite and arsenopyrite. The three pits are located within this fault zone.

The regional strike and structural grain of the major rock units in the Hodson district are northwest. Well-developed foliation dips 50 to 80 degrees to the northeast.

Groundwater

Groundwater occurs in bedrock fracture systems and migration generally follows the surface topography from the northeast to the southwest. There are three general groundwater zones defined by the geologic conditions: the phyllite, the fault zone, and the greenstone.

The phyllite has the lowest rate of movement due to limited fracture systems and the relatively plastic nature of this rock. The hydraulic conductivity ranges from 2×10^{-7} to 5×10^{-4} cm/sec.

The fault zone and greenstone have more extensive fracture systems and therefore experience higher groundwater migration rates. The hydraulic conductivity of these zones ranges from 5 x 10^{-5} to 5 x 10^{-3} cm/sec.

Because the least transmissive rock is located along the downgradient boundary of the RMKM, the phyllite acts as a barrier to westward groundwater flow. Groundwater backs up within the fault zone and greenstone, resulting in a relatively flat gradient in the Skyrocket Pit Lake area. The depth to groundwater becomes very shallow, and surface springs occur at low points such as the bed of Littlejohns Creek, which flows through the Site. From 1994 through the early 2000s, during and after mining while the pit lakes filled, groundwater at the Site migrated into the deep dewatered mine pits where the water was collected and used for mining purposes. As a result, these surface springs largely dried up during the mine's operating life and for a period thereafter.

Groundwater quality at the Site depends upon the chemical composition of the host geologic formations, the extent to which the groundwater migration pattern has been modified by the WMUs and the pits and to some extent by seepage from the WMUs.

The greenstone formation that underlies the eastern portion of the Site contains groundwater of relatively good quality with lower total dissolved solids (TDS) concentrations and few detections of metals. The fault zone that traverses the western and central portion of the RMKM contains significant natural mineralization, which results in poor quality groundwater containing elevated TDS and sulfate concentrations and a greater frequency of detection of arsenic, iron, manganese, nickel, and selenium. The phyllite formation along the western portion of the Site has the highest TDS concentrations and detections of chloride and sulfate and metals such as iron and manganese. (See Table 1)

There have been changes in groundwater quality, particularly in areas around former mine facilities. These changes generally consist of increases in TDS, sulfate, and in some cases nitrate concentrations.

Littlejohns Creek flows across the Site and into Flowers Reservoir just downstream. Numerous ephemeral drainages around the Site flow into Littlejohns Creek. Significant flows in these tributary drainages occur for periods during and after significant rainfall. During the summers months spring flows occur in the creek bottoms and at the ODS-2, ODS-5 and Gold Knoll.

There is extensive anecdotal and quantitative information that indicates that the Site had a year-round presence of poor quality surface water well before mining occurred. Historically, poor quality seeps and springs were observed in the area where the current pit lakes are located. The results of archeological investigations in the area of Skyrocket Lake indicate that the area was continuously occupied by pre-historic Native Americans due to the year-round availability of water from local springs and the value of salt that was abundant in the area. Pre-project water quality data indicates baseline surface water quality at and around RMKM was poor and did not meet all the applicable water quality goals for potential beneficial uses that are currently designated in the relevant Basin Plan, a document that describes the beneficial water uses in the area and applicable water quality goals and standards. The principal constituents that are typically elevated include TDS, mineral constituents, i.e., sulfate, chloride, sodium, calcium, and magnesium, as well as manganese and iron. Traces of arsenic were also detected.

The quality of the RMKM surface water flows is influenced by the groundwater quality. During low flow periods in the spring, summer and fall, water in the creeks is predominantly spring flow, and the quality is similar to that of groundwater in the fault zone and phyllite. During the high flow season, particularly in the winter months, the effect of spring flows on creek water quality is diluted by the better quality surface runoff entering the creeks. Figure 4A presents a chart of TDS concentration over time for Littlejohns Creek at monitoring locations at the downstream boundary of the RMKM. It clearly illustrates how surface water quality was improved during mining with the dewatering of the pits.

The results of salt load evaluations indicate that if the ODS spring flows are discharged, the salt loading will be of the same order of magnitude as the pre-mine salt loadings. This is not surprising, as the salt load is determined by the amount of rainfall infiltration and poor quality groundwater that emerges as springs. Mining has not significantly changed the quality or amount of this spring flow.

Pit Lakes

The long-term average rate of groundwater migration into the pit is a function of how much lower the level in the pit lake is, relative to the surrounding groundwater levels. Where pit lake levels and the surrounding groundwater levels are higher than the creek bottoms, there is potential for groundwater to migrate to and discharge into creeks. Lowering the pit lake level can therefore reduce or eliminate discharge of groundwater into Littlejohns Creek during the dry season.

Skyrocket Pit Lake water quality (Table 1) is determined by the quality of the groundwater, since this is the primary source of constituents in the pit lake. The water quality is stable. In addition, water quality depth profile data collected for Skyrocket Pit Lake indicates that there is stratification, with a shallow seasonal thermocline (typically within the top 25 feet) and a deep pycnocline at approximately 150 feet. Below the pycnocline, conditions are anoxic and sulfate reduction appears to be taking place. In addition, TDS and arsenic concentrations are higher below the pycnocline than at the surface of the pit lake.

North Pit Lake reached equilibrium levels relatively rapidly, and the water level typically varies seasonally. Both TDS and arsenic concentrations are lower in North Pit than those in the Skyrocket Pit. The pit water quality appears to be stable and there is no stratification.

MINE CLOSURE

Development of Closure Concepts

Initially the regulatory agency, the RWQCB, reviewed the mine closure as a need to require compliance with the prescriptive closure requirements outlined in Title 27. These requirements included impermeable clay/soil or geomembrane/soil covers of the 400 acres of the ODSs and the FTR at a net present value (NPV) cost of approximately $80 million. MBC would also be required to maintain the FTR and ODSs in a drained state, with treatment and discharge of any groundwater that migrated into these WMUs and out through the drains or to the seepage collection areas, resulting in a cost of another $50 million NPV.

This initial viewpoint was held because of the following:

- During mining poor quality spring flow into Littlejohns Creek was minimized. After cessation of mining, as the pits filled and the seeps re-appeared, and much of the apparent worsening water quality was incorrectly attributed to leakage from the WMUs.
- Pre-mining background data was collected during a dry period when there was less of an impact to surface water from poor quality groundwater seeps. Less poor quality groundwater was available to flow into Littlejohns Creek as springs. As the pits filled and the seeps re-appeared, average water quality conditions were worse than even during the pre-mining period, again this worsening was incorrectly attributed to leakage from the WMUs.
- The RWQCB felt uncomfortable in allowing engineered alternatives to the prescriptive standard necessary to approve the closure that had been completed, particularly in light of seemingly worsening water quality that occurred in the late 1990’s and early 2000’s (Figure 4A).
- Under the circumstances, it was difficult for MBC to commit to the significant cost of the comprehensive field investigations and study programs that would have been needed to demonstrate that pre-mining conditions were poor and closure allowing for some sort of residual impact was the only feasible approach. As a result, the closure plan development was piece-mealed and several closure plans, RWQCB’s orders, and in one instance an appeal to the overseeing State Water Resources Control Board were needed before the current closure plan approach was developed and accepted by the RWQCB.
- The late appearance of the seep from the FTR in 2008, even though it was stated that drain closure was to be a test, continues to introduce uncertainties into how effective the final closure plan will be.

MBC has demonstrated to the RWQCB that because of the way the WMUs were constructed, the prescriptive approach would be infeasible. Furthermore, because water quality can be managed to improve conditions it is not necessary to achieve complete containment of all the surface wastes, making a water management approach to closure the only feasible solution. Also, contingency plans can be established to deal with any uncertainties associated with the water management approach.

Water Management Closure Approach

The water management closure approach essentially formalizes the interim closure construction and operations that MBC had already installed. The elements include: (Figures 3 and 4).

- Ongoing collection of seepage flows from three locations at the toes of the ODSs and the storage if these flows in Skyrocket Pit Lake.
- Transferring sufficient water from the FTR LCRS to maintain water levels within the FTR below an elevation where surface seeps can occur. This water is also stored in the Skyrocket Pit Lake.
- Periodically discharging water from Skyrocket Pit Lake during high flow conditions under a National Pollution Discharge Elimination System permit.
- Maintaining the existing WMU covers and the surface water diversion facilities.

While closure procedures are simple, long-term closure feasibility had to be demonstrated. For this purpose, extensive field data on seepage volumes and natural flows in the creeks were collected and used in conjunction with a series of computer models to demonstrate the plan's feasibility. These computer models were also useful in demonstrating that whether or not the prescriptive covers were installed, a water management system would still have to be put in place. Models were developed for the ODSs, the two pit lakes, and Littlejohns Creek. These simulated monthly water mass balances, as well as TDS and arsenic concentrations. During the closure period, the ODS seepage flows were applied to the surface of the ODSs with some of this water re-infiltrating and being recycled as continually increasing seepage flows. The ODS models were useful in removing this recycling effect from the measured data and in predicting future realistic seepage rates.

Some of the more innovative closure features that were provided include the following:

- During the closure period 12 acres of available lined surface was used to evaporate the initial 90 acre-feet of very poor quality process water without having to resort to costly physical/chemical treatment. Spray systems were installed in the lined surface of the LCRF, sprinkler systems were used to wet the sides of the PWP and a turbo-mister was used in the North Pit Lake. This was coupled with removal of accumulated salts and the cleaning of the PWP liners so that winter rainfall could be discharged. A covered water storage system was constructed in the PWP through the placement of tailings to hold the water and the construction of a temporary cover over the top of the tailings.
- Construction of a 35-foot high fill dam across the lower end of the Skyrocket Pit Lake, to provide for poor quality water storage during the closure period.
- Installation of a fully automated discharge system that allows up to 30,000 gpm to be discharged to Littlejohns Creek during short storm periods when flood flows occur and receiving water quality standards can be achieved.

It is intended that in time, the above approach will also improve the existing surface water quality. It is also intended that the Skyrocket Pit Lake level will be lowered to a level at which the seepage of groundwater to Littlejohns Creek is minimized.

Resolving the groundwater quality issues has been another topic of discussion. The Basin Plan for the area is general and it considers groundwater to be suitable for municipal and agricultural supply without recognizing that naturally occurring poor quality water exists. MBC has been able to demonstrate to the RWQCB that there is no need, nor is it feasible, to attempt to restore the poor quality groundwater zone to what it was before mining. Furthermore, to address the Basin Plan issue, MBC is proposing to apply for an amendment to the plan that incorporates recognition of the existing poor quality groundwater in the area.

Contingency plans have been established to cope with unforeseen issues should they arise; these include:

- Construction of an evaporation pond system on the surface of the FTR should too much water accumulate in Skyrocket Pit Lake, resulting in the need for transfers from the FTR to be curtailed.
- Land-application and evaporation as methods to reduce water inventory on a sporadic basis.

CONCLUSIONS

A reasonably cost-effective approach to mine closure has been achieved and while long-term active care has not been eliminated, it has been minimized. The need for active water treatment and costly covers has been avoided. Certain closure activities, including finalization of the closure of the PWP and the long-term operational procedures, and obtaining Basin Plan Amendment, are still ongoing.

While this closure approach is generally consistent with what was envisaged at the time the mine was planned in the early 1980's, the significant effort required in conducting the necessary studies and in obtaining the regulatory approvals was not anticipated. In hindsight, the following activities that would have allowed closure to occur more rapidly and possibly at a lower cost could have been completed earlier:

- During the permitting process, more extensive background water quality data could have been obtained through more frequent monitoring of quality and flow. A site and surface water conceptual model could have been prepared. This model would have highlighted the impact of groundwater on surface water quality and the fact that the data collected represented unusually good water quality because of the initially dry conditions followed by the dewatering of the pits, and that after mining water quality would again worsen. Having this information up-front would have made it significantly easier to obtain approvals for the current closure plan.
- A closure preliminary design could have been produced. This would have required consideration of how surface and subsurface drainage was to be managed and might have resulted in the ODS and FTR footprints and designs being modified, and would certainly have resulted in more realistic closure costs being determined.
- More comphrensive waste characterization testing would have indicated that the ODS leachate would pose a threat to water quality even though it does not have a net acid potential. This would have facilitated a better design for the waste location and the infiltration and drainage controls.

ACKNOWLEDGEMENTS

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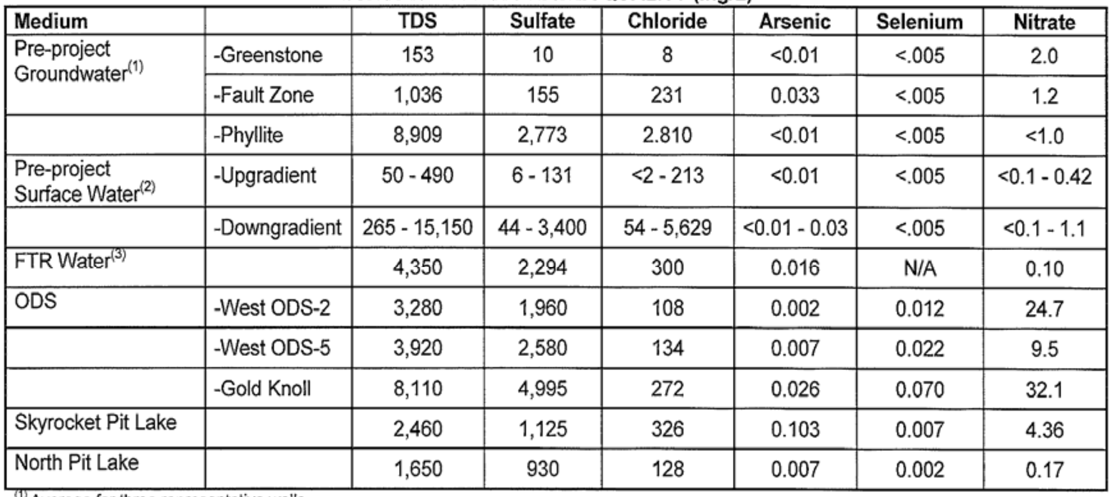
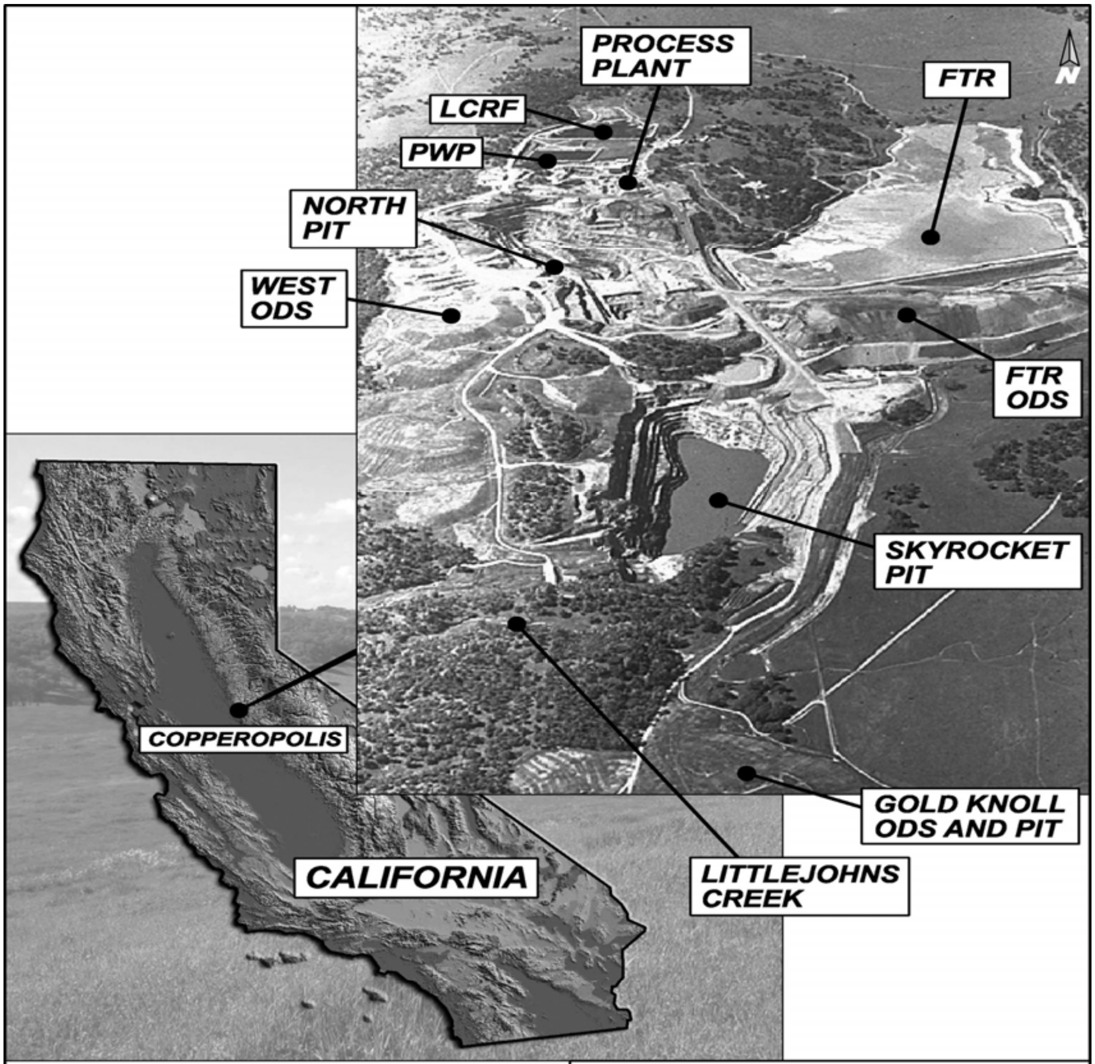
TABLE 1: TYPICAL WATER QUALITY (mg/L)



Medium		TDS	Sulfate	Chloride	Arsenic	Selenium	Nitrate
Pre-project Groundwater(1)	-Greenstone	153	10	8	<0.01	<.005	2.0
	-Fault Zone	1,036	155	231	0.033	<.005	1.2
	-Phyllite	8,909	2,773	2.810	<0.01	<.005	<1.0
Pre-project Surface Water(2)	-Upgradient	50 - 490	6 - 131	<2 - 213	<0.01	<.005	<0.1 - 0.42
	-Downgradient	265 - 15,150	44 - 3,400	54 - 5,629	<0.01 - 0.03	<.005	<0.1 - 1.1
FTR Water(3)		4,350	2,294	300	0.016	N/A	0.10
ODS	-West ODS-2	3,280	1,960	108	0.002	0.012	24.7
	-West ODS-5	3,920	2,580	134	0.007	0.022	9.5
	-Gold Knoll	8,110	4,995	272	0.026	0.070	32.1
Skyrocket Pit Lake		2,460	1,125	326	0.103	0.007	4.36
North Pit Lake		1,650	930	128	0.007	0.002	0.17

(1) Average for three representative wells.
(2) Ranges for several upgradient and downgradient sampling stations.
(3) Average since beginning of 2004.



Royal Mountain King Mine in 1994

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Figure 1

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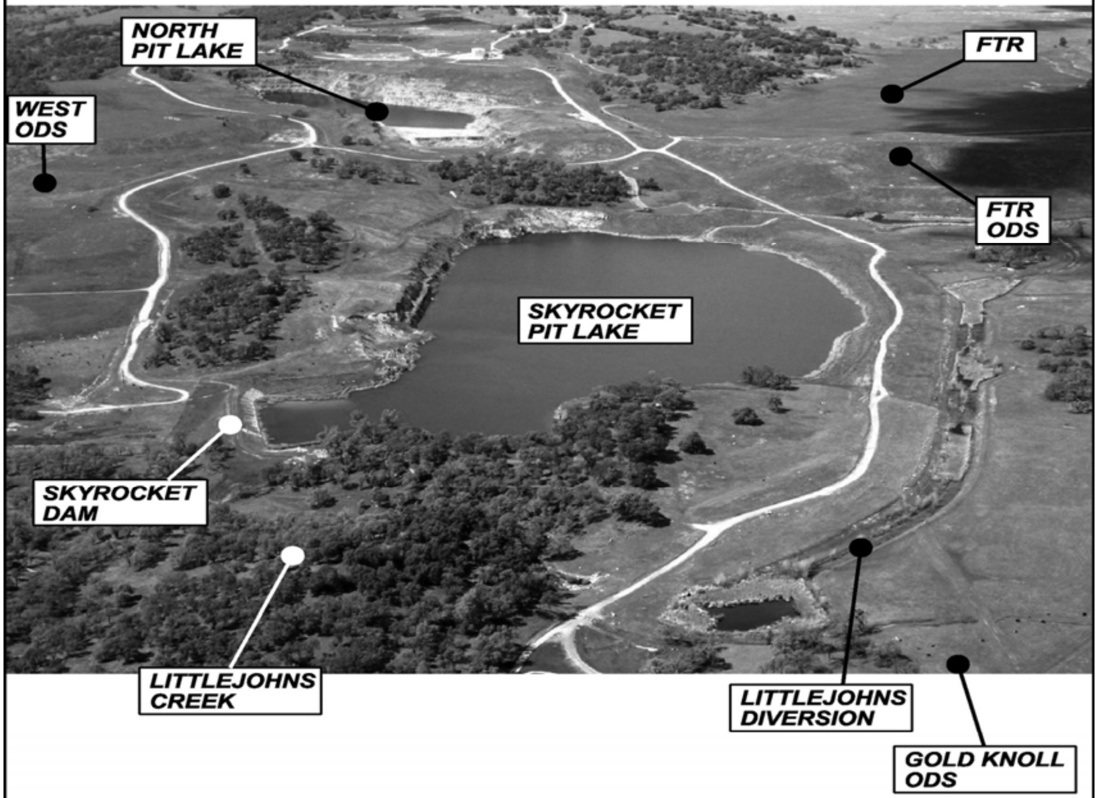

Royal Mountain King Mine in 2008

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Figure 2

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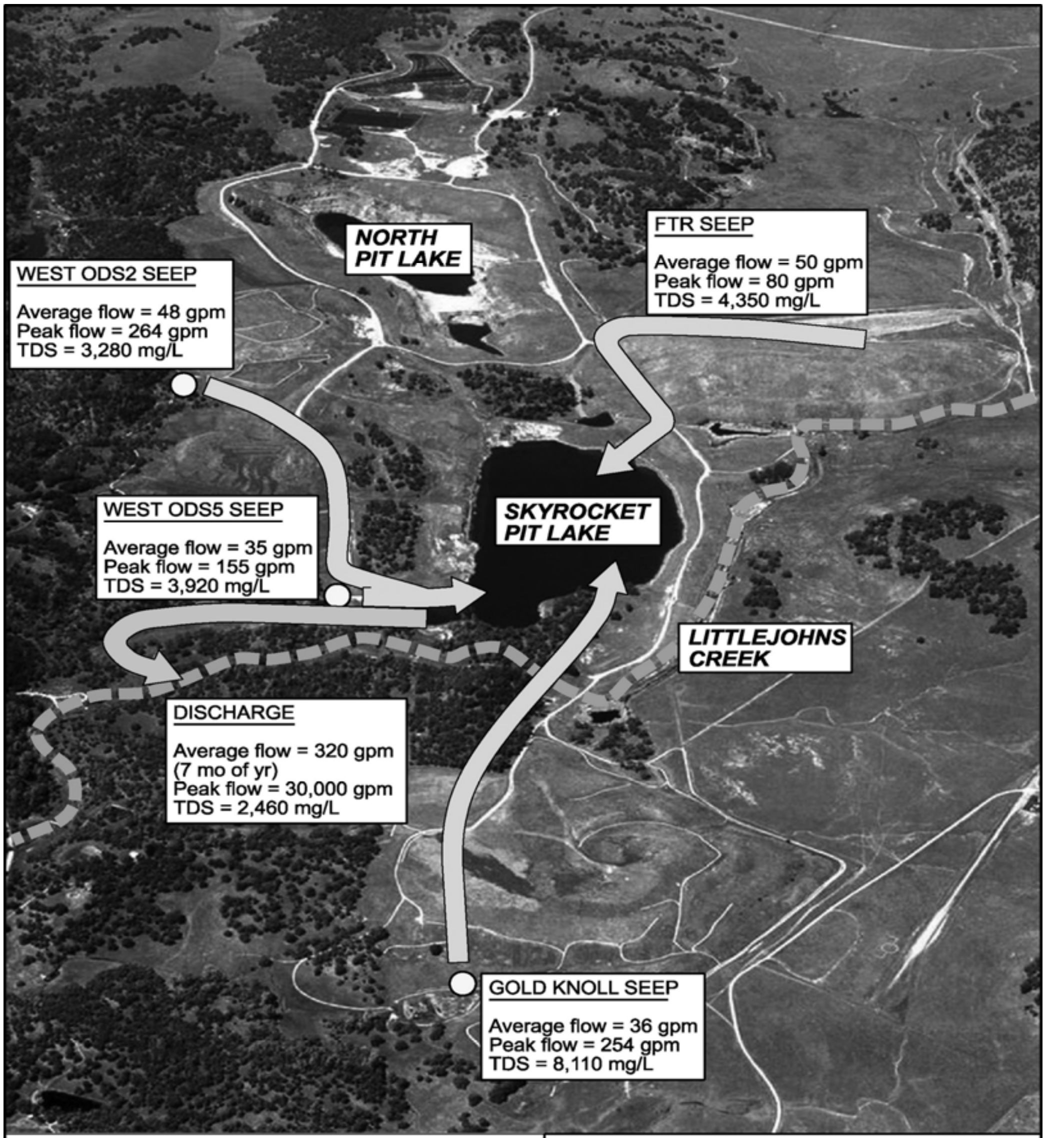

Water Transfers

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Figure 3

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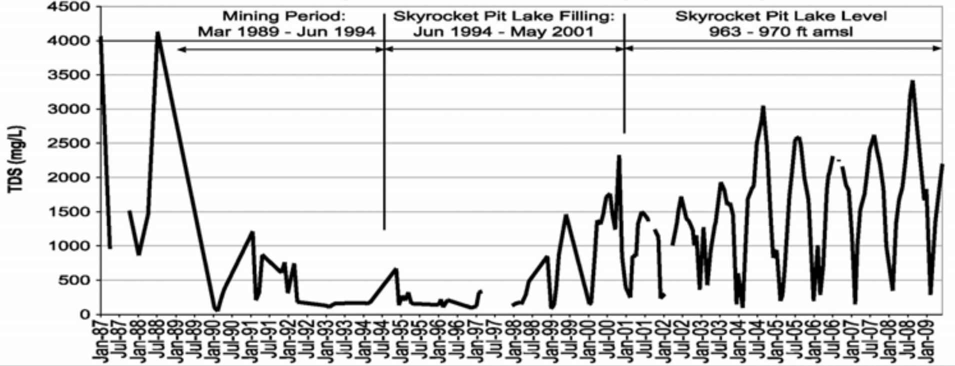
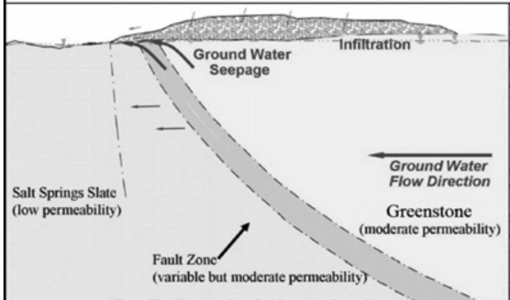
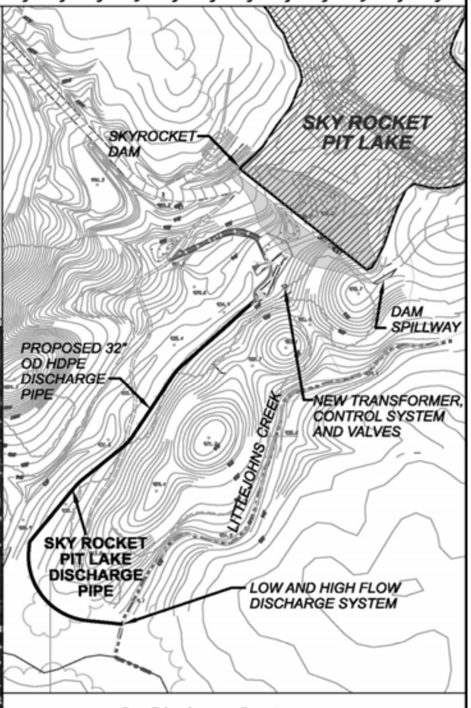
A. Littlejohns Creek Water Quality (1987-2009)





B. Hydrogeologic Cross-Section



C. Discharge System

D. Low and High Flow Discharge System

Closure Features

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Figure 4

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