

OPERATING FOR CLOSURE: LIFE OF MINE WASTE MANAGEMENT AT HUCKLEBERRY COPPER MINE

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ABSTRACT

Huckleberry Mine, which started operation in 1998 and is now scheduled to close in 2010, is an example of a mine that developed a life-of-mine waste management plan, and successfully stewarded the plan through the life of the operation. MEM's 'Guidelines for Metal Leaching and Acid Rock Drainage at Minesites in British Columbia' (ARD Guidelines) were being introduced at the time of the mine planning stages, and it was recognized that both tailings and a large proportion of the waste rock would be potentially acid generating. Huckleberry Mine was planned as one of the first mines in British Columbia to design and construct a major water retaining structure for co-disposal of PAG waste rock and tailings. This paper summarizes how Huckleberry developed its waste management strategy and how that strategy has been followed through the life of the mine.

INTRODUCTION

Huckleberry Mine is an open pit, copper-molybdenum mine located approximately 86 km southwest of Houston, British Columbia, as shown on Figure 1. Mine construction began in February 1996, and production began in September 1997. The mine and mill were designed to have an ore throughput rate of about 18,000tpd, with a mine life of about 10 years.

Huckleberry Mine copper-molybdenum ore is contained within a hornfels porphyry-copper deposit situated on the south flank of Huckleberry Mountain, overlooking Tahtsa Reach. Early in the mine planning stages, it was anticipated that a significant portion of the waste rock and most of the tailings produced at Huckleberry would be Potentially Acid Rock Drainage Generating (PAG). This determination was based in part on pre-development geochemical assessments of ore and host rock.

Although not finalized until 1998, drafts of MEM's 'Guidelines for Metal Leaching and Acid Rock Drainage at Minesites in British Columbia' (ARD Guidelines) were available and generally followed well in advance of that time. Even during the mine review process for Huckleberry in 1995, it was well understood that the proven technologies for preventing ARD were limited, and that only a preventative strategy would be acceptable to both the mine owners and regulators. The most acceptable technology for this site was determined to be subaqueous disposal of PAG mine wastes.



Figure 1: Huckleberry Mine Location Plan

Huckleberry became one of the first mines in British Columbia to design and construct a major water retaining structure for co-disposal of PAG waste rock and tailings. This paper summarizes how Huckleberry developed a life-of-mine waste management strategy and how that strategy has been followed through the life of the mine.

Huckleberry Mine is based on two ore zones, the East Zone and Main Zone deposits, which are less than 1 km apart. The site had only a small area of relatively level land available for the mine development, with the steep slopes of Huckleberry Mountain to the north and steep slopes down to Tahtsa Reach to the south. Careful planning was required to develop the site in a cost-effective manner and to meet waste rock and tailings management objectives.

GEOCHEMISTRY

As is common with porphyry copper deposits, much of the mineralization at Huckleberry contains sulphides. Mineralization at Huckleberry occurs primarily as chalcopyrite/pyrite. Early in the project planning, it was recognized that as a result of this mineralization, both tailings and a large proportion of the waste rock would be considered potentially acid rock drainage generating (PAG). Mine waste design and operations were substantially driven by the need to prevent acid rock drainage (ARD).

As required under its Mines Act Permit, Huckleberry developed geochemical sampling and testing programs that were implemented prior to mine development, and substantially expanded and refined during mine operations. Huckleberry developed an 'Acid Rock Drainage and Metal Leaching Prevention and Prediction Plan' in 1997 and continues to adhere to this plan and subsequent refinements which are developed as more information is acquired. Criteria to define PAG versus NPAG status for different rock types were developed pre-mine in conjunction with and as required by MEM and other regulators. These criteria were later adjusted during mine operations based on operational and test work data, including observations and testing of various exposed rock types. Huckleberry works closely with MEM, Ministry of Environment (MoE) and other regulators, and submits quarterly detailed 'ARD and Water Quality' reports as required by Mines Act Permit M-203 and Waste Management Act Permit PE-14483.

Main Zone waste rock consisted primarily of two major rock types, granodiorite and andesite. The granodiorite generally had the lowest sulphide levels, and was the primary source of NPAG rock for construction use. Approximately 80 percent of the granodiorite waste rock in the Main Zone Pit met NPAG criteria, versus only 20 percent of the andesitic waste rock.

The criteria established for NPAG versus PAG classification at Huckleberry are summarized briefly as follows:

- Granodiorite: Defined as NPAG if blast hole analysis indicates that total sulphur was less than 0.35 percent and the Total Inorganic Carbon – Neutralization Potential Ratio (TIC-NPR) was higher than 1; or the NPR was higher than 1 when the NPR was calculated using the Total Inorganic Carbon – Neutralization Potential (TIC-NP), and the NPR was higher than 2 when the NPR was calculated using the Sobek-NP method.
- Volcanics: Andesite (hornfels) waste rock was only defined as NPAG if the total sulphur was less than 0.20 percent and the TIC-NPR was higher than 1; or the NPR was higher than 1 when the NPR was calculated using the TIC-NP, and the NPR was higher than 3 when the NPR was calculated using the Sobek-NP.

Separation of PAG and NPAG waste rock in the Main Zone Pit required that the materials be characterized prior to mining through a comprehensive program of blast hole sampling and analysis. NPR values of the blast holes were used to create blocks and allow the PAG/NPAG boundaries to be drawn on the plans and staked in the field. A conservative approach was taken, and narrow areas of NPAG rock surrounded by PAG were treated as PAG. Where isolated PAG samples occurred, an area of 15m x 15m was designated as PAG around each such blast hole. Kriging was not allowed to change the classification of the material associated with a blast hole where the NPR results were more than 0.7 below the criteria for NPAG.

Huckleberry also carried out a detailed program of post-blast sampling and analysis to verify that pre-blast designations of NPAG waste rock were correct. Sampling of post-blast material was done (and results received) prior to removal of the waste rock. Detailed NPAG rock separation and handling processes in the Main Zone Pit were as follows:

1. Blasts were divided up into ore, NPAG waste and PAG waste, based on the Kriging data, and were staked in the field.
2. Daily dig plans were developed, passed on to operations, and discussed with them. Operations planned the materials movement for the day based on mill requirements and dam construction needs.
3. Equipment operators were given direction in the field as to what materials were to be excavated and where it was to be deposited.
4. Data were compiled from truck counts, drivers' reports and then reconciled to surveyed volumes in the field.

These data were compiled and included in the quarterly 'ARD and Water Quality Reports' submitted to MEMPR and MoE.

Most waste rock from the East Zone Pit is considered PAG, so that detailed material classification was not required for waste handling. However ABA characterization of EZP materials from blasthole samples was continued for verification of PAG waste rock materials.

WASTE MANAGEMENT STRATEGY

In response to the early determination that a significant portion of the waste rock and most of the tailings produced at Huckleberry would be potentially acid rock drainage generating (PAG), Huckleberry became one of the first mines in British Columbia to design and construct a major water retaining structure for co-disposal of PAG waste rock and tailings. Several potential disposal sites were identified and investigated. Tailings Management Facility #2 (TMF-2) was selected as the preferred alternative due to its proximity to the mill and because it could incorporate the Main Zone Pit within the ultimate flooded impoundment. All tailings and almost all East Zone and Main Zone Pit PAG waste rock produced during Huckleberry Mine operations have and will continue to be disposed of into the ultimate flooded area. Small amounts of PAG rock have been placed at documented locations in the plant site area, including on roads. These materials will be excavated at closure and disposed of in the flooded impoundment.

TMF-2 is a large flooded impoundment in which PAG waste rock and tailings are co-disposed and where these wastes will eventually be permanently submerged below a water cover. Only NPAG materials are permitted for use for the downstream shell construction of TMF-2 and for other infrastructure construction outside of the ultimate flooded perimeter.

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Mining is by conventional shovel/truck methods. Ore and waste rock are drilled, blasted and loaded into haul trucks. Ore is hauled to the crusher and all waste rock is now disposed of in the TMF-2 Impoundment where it will eventually be flooded. Soils and overburden removal is now complete, and materials suitable for and needed for reclamation have been stockpiled at various locations. Excess or unsuitable overburden was spoiled in the TMF-2 Impoundment.

ARD prevention has been central to mine operations since the early mine planning stages. ARD prevention and geological characterization are integral to each other and mine operations, and are therefore both included as major components of the mine plan. Other major components of the mine plan

are geotechnical assessment, and engineering and operational aspects of the major mine facilities, including TMF-2, the pits, roads, and surface water diversion and collection systems.

MINING SEQUENCE

The mining sequence was developed with the objective of mining the best grade ore at the most favourable strip ratio first, while meeting the objectives of the waste management plan. A view of the overall layout of the Huckleberry site is shown on Photo 1 below.

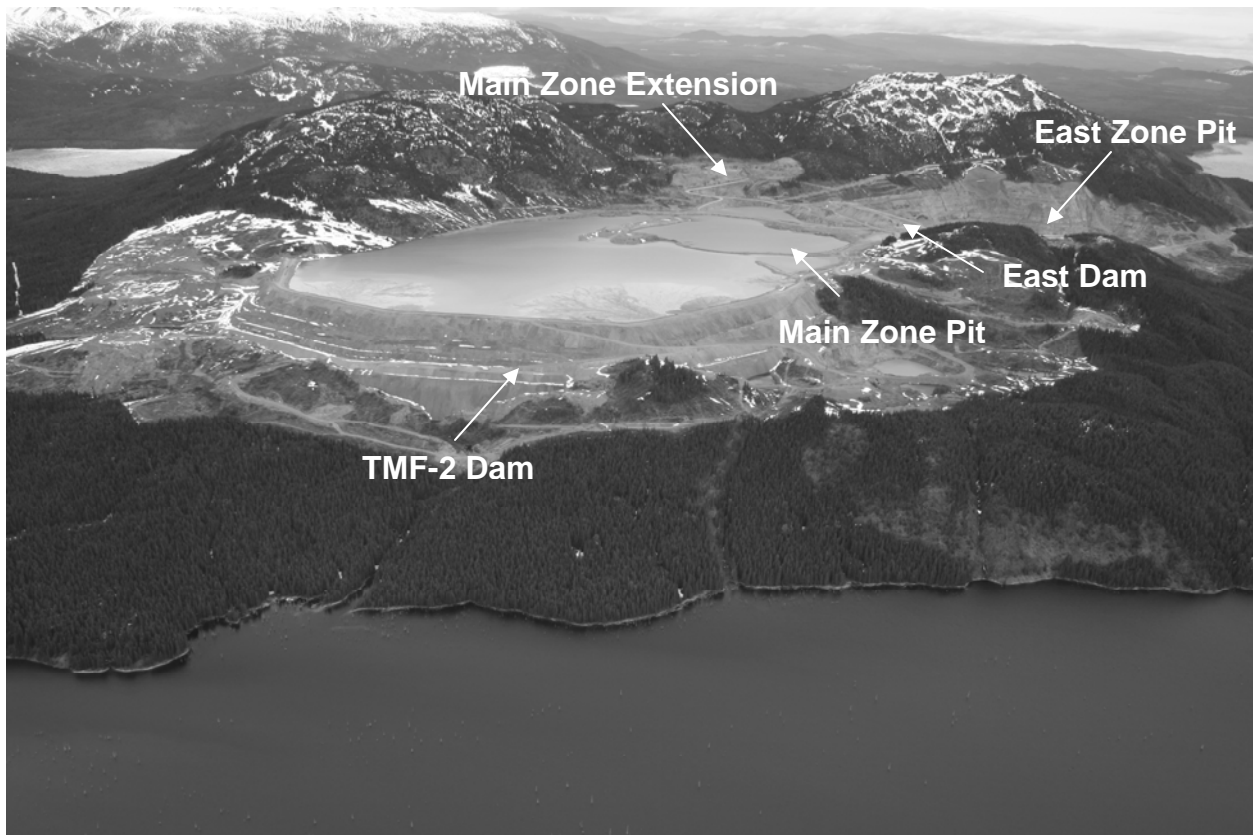


Photo 1: View of Huckleberry Mine site looking north across Tahtsa Reach

The following presents a chronology of significant steps in development and production through the Huckleberry mine life.

- **Pre-production 1996 and 1997.** Activities during this time included site clearing and road construction; development of mine infrastructure; construction of the water management and sediment control system; construction of the TMF-2 starter dam to 1016 m; and pre-production mining of the East Zone starter pit. The East Zone Pit was ideal as the starter pit in terms of the waste management strategy, as it had the largest volume of overburden removal, which facilitated construction of the TMF-2 tailings starter dam with glacial till.

- **East Zone (Phase 1) starter pit mid-1997 to late 1999:** This was the period during which the East Zone (Phase 1) starter pit was mined to access the high grade / lower strip portion of the pit. All tailings and waste rock was co-disposed in the initial TMF-2 impoundment during this time.
- **Main Zone Pit (Phase 2) November 1999 through April 2002:** Mining activities began in the Main Zone Pit (Phase 2) in November 1999 and continued until pit completion in April 2002. During this period, PAG waste was placed in the active TMF-2 impoundment area or used in the upstream (of the till core) construction of the TMF-2 and East Dams. As planned, this area will be encompassed in the ultimate flooded area of the combined TMF-2 / MZP impoundment area
- **East Zone (Phase 3) Pit April 2002 to June 2007:** Development of the final East Zone (Phase 3) Pit began in April 2002, at approximately the same time as mining ceased in the Main Zone Pit. Flooding of the Main Zone Pit began in May 2002. Initial water inputs were limited to groundwater infiltration, precipitation, and runoff. In June 2003, tailings deposition began within the MZP, and shortly thereafter the reclaim barge was relocated to the MZP. Mining of the East Zone Pit continued until terminated somewhat earlier than planned, when a failure of the overburden slope in the north wall forced an early shutdown of mining. About 1 month of ore production were lost due to this slope failure, during which time milling operations were continued by milling some low grade ore stockpiles.
- **Main Zone Extension (Phase 4). February 2007 to end of mine life 2009:** Minesite exploration work in 2005 identified a significant extension of the Main Zone orebody to the north, that was outside of the flooded mine area. With the favourable copper price regime, this extension has provided the opportunity to profitably extend the mine life for over 2 years. To accommodate some of the additional waste rock and tailings from the Main Zone Extension, the crest of the TMF-2 tailings impoundment is being raised an additional 2 m. The ability to raise the TMF-2 impoundment is limited, however, as any further raising would require a major extension of the downstream slopes, requiring a large amount of rockfill. The final waste rock and tailings volumes will be stored in the East Zone Pit.

At the conclusion of the last phase of operations, the Huckleberry Mine will be decommissioned and reclaimed.

TAILINGS MANAGEMENT FACILITY

The Tailings Management Facility (TMF) is central to the Huckleberry operations. The impoundment fulfils the following functions:

- provides permanent storage for all of the mill tailings produced
- provides storage and permanent submergence of the potentially acid generating (PAG) waste rock
- serves as the central water management facility, providing storage for process and runoff waters and as the source of reclaim process water.

The TMF (AGRA Earth & Environmental Ltd., 1997) was initially formed by the TMF-2 Dam enclosing the west and south sides of the tailings area. As the impoundment level rose, the South Saddle Dam was constructed to retain the tailings and water from entering the Main Zone Pit. On completion of the Main Zone Pit, tailings and waste rock disposal into the pit was started. The South Saddle Dam was allowed to be inundated as the water level in the Main Zone Pit reached the level of the main TMF, and the two areas merged. The TMF now incorporates the TMF-2 impoundment and the adjacent mined out Main Zone Pit. The East Dam, constructed on the east side of the Main Zone Pit, provides the eastern containment of the merged TMF area. The current configuration of the TMF is illustrated on Photo 2.



Photo 2: View of site looking southwest, showing TMF-2 Tailings Impoundment in background

The final volumes of waste rock and tailings from the Main Zone Extension Pit that cannot be accommodated in the TMF will be disposed in the East Zone Pit. The volume of materials, plus the water pond that will be required to operate the pit as a tailings impoundment, would raise the level of the impoundment above the level of the present outlet of the pit on the east side of the pit. Hence, a dam will be constructed to raise the level of the pit. This dam, called the East Pit Plug Dam, is currently being designed and will be constructed in 2008.

To meet ongoing tailings and water storage requirements, the dams have been raised annually. The initial elevation of the Starter Dam was 1016 m. The final elevation of the TMF dam crests, being completed 2007, is 1080.5 m. The height of the dam at the highest section is about 120 m.

The TMF was operated until 2006 as a closed system. As predicted by initial water balance modeling, a surplus in water developed in later years of mine life, as the catchment area of the merged TMF increased. A provision was made in the initial mine permitting for eventual water release, subject to meeting water quality criteria. That provision was triggered, and after extensive consultation, permission was confirmed to release excess water and that discharge began in late 2006.

AMEC Earth & Environmental Ltd (and its predecessor firm AGRA Earth & Environmental) has been the geotechnical engineer of record for the TMF and has been responsible for the detailed design of the TMF-2 Starter Dam and all subsequent raises. In addition, AMEC has provided QA/QC construction and performance monitoring since construction of the starter dam in 1996 through all subsequent dam construction through 2007. The tailings starter dam was constructed of glacial till overburden, from initial East Zone Pit stripping and from a glacial till borrow pit. The dam is raised with a centerline configuration, with a central glacial till core and a downstream shell of quarried NAG rockfill. Basal till for containment structures is sourced primarily from a borrow pit located west of the TMF-2 Dam. Processed filter zones are used to separate the glacial till core from the NAG rockfill. PAG rockfill is placed upstream of the till core to provide support for the core.

The main tailings stream, produced from the bulk rougher circuit, is pumped by one of two 800 horsepower pumps through a 26 inch tailings line to the TMF-2 impoundment, where they are spigotted from the dams to form a beach. Tailings produced by the bulk cleaner scavenger circuit, which contain high levels of pyrite, are pumped in a separate pipeline to be disposed in a central part of the pond where they will be permanently submerged.

The bulk rougher tailings do not meet NPAG criteria for aerial exposure, and for closure will be permanently submerged. For long term dam safety, AMEC did not favour an entirely flooded impoundment. Hence, the strategy developed for closure of the TMF is to place a final cap of (NAG) tailings over the surface of the impoundment. In 2006, the Huckleberry mill commissioned a new additional flotation circuit to de-pyritize the rougher tailings. This final tailings cap will allow the pond to be closed with a wide above-water beach of NAG tailings. Tailings to be exposed for final beach construction are planned to meet a NPR criterion of 2:1. The depth of NAG tailings will exceed the depth to the long term phreatic level, so that the already-deposited PAG tailings will be permanently submerged.

For TMF closure, an open channel spillway will provide for water release from the TMF. The critical event governing the spillway design is based on the flow from a 4-day duration PMF event combined with a 1 in 100-year snowmelt is the design. The PMF is estimated to be 750 mm. The location proposed for the permanent closure spillway is between the east abutment of the TMF-2 Dam and the submerged South Saddle Dam. This location affords the following advantages:

- It is located in a natural saddle and so excavation volumes will be minimized.

- The spillway would discharge into an existing natural drainage channel, carrying the discharge well away from the TMF-2 Dam. The extent of excavation therefore required to construct the spillway will be minimal. The spillway will be inlet-controlled and can be constructed to have a very high discharge capacity, minimizing the rise in pond level that would occur during extreme flood inflow events.

EAST ZONE PIT WALLS AT CLOSURE AND PROJECTED POST-MINE WATER QUALITY

The exposed walls and benches of the East Zone Pit remaining post-closure will be PAG. A number of potential prevention / mitigation strategies to prevent off-spec drainage from the pit have been discussed with MEMPR and Ministry of Environment. Stephen Day (Principal Geochemist, SRK Consulting) has been consulting to Huckleberry on the geochemical and water quality modeling to assess potential post-mine water quality of the East Zone Pit.

Key points from hydrogeochemical evaluations are as follows.

- ARD generation from exposed PAG material on the pit walls is expected to begin in about 12 years.
- Inflows from the average annual rainfall will not fully counteract the low pH
- The model indicates that the final water quality is very sensitive to groundwater inflows. At 31 l/s, the 2004 modeling predicts a pH of 3.9 and Cu of 3 mg/l, yet 87 l/s predicts a pH of 7 and Cu of 0.2 mg/l
- The model was based developed prior to the plan to use the East Zone Pit for tailings and waste rock disposal. With the pit outlet being raised to a higher level, the pit walls will be submerged to a higher level, which is expected to have a positive benefit on the amount of exposed PAG rock.
- Although selenium has been detected in leachate from a column test, predicted selenium concentrations in the pit lake are expected to be very low (0.002 mg/L)

The actual long term discharge water quality from the East Zone Pit will not be known for a number of years. A contingency measure that Huckleberry could implement would be diversion of discharge flows from the TMF, to provide additional mitigation of water quality.

RECLAMATION PROGRAM

Huckleberry has submitted in its 2004 Closure Plan a thorough reclamation program. Because much of the site remains in active use, most of the major reclamation work must be performed following mine shutdown. Vegetation grows readily in the high precipitation climate at Huckleberry, so that reclamation programs are expected to experience good success. This section presents a brief overview of the reclamation strategy and program for Huckleberry Mine. Additional details are available in the mine closure plan.

A detailed soils handling plan for the Huckleberry Mine was developed in conjunction with an overall materials handling plan for the mine site, based on a prior intensive pre-mine soil survey and soil salvage assessment carried out in 1996 by Terra-Silva Environmental Services. The pre-mine soil survey

provided a pre-mine soil inventory and land capability assessment of areas that would be affected by project development; determined the locations and quantities of salvageable soils; and made recommendations regarding the salvage and stockpiling of soils for eventual site reclamation.

During mine development, soil was salvaged in general accordance with these soils and materials handling plans. Soil was salvaged as one unit consisting of A and B horizons. Some modifications to the planned soil handling were necessary during implementation and subsequent mine operations as a result of logistics, lack of storage space and other constraints.

Some of the key reclamation areas include:

- Soils placement on the coarse tailings beach sands is the highest priority due to anticipated susceptibility to wind erosion and difficulties in vegetation establishment if left uncovered. Wind erosion is particularly undesirable because the exposed tailings beaches are an important and integral part of the final dam configuration. It is expected that successful revegetation of the tailings can be achieved with placement of less than 50 cm of soil. Depending on trafficability, HML will place 30 to 40 cm of soil on the upper beach areas, and up to 40 cm on the lower beaches (average of 25 cm).
- The millsite and on NPAG Haul Roads Soils will be covered with depths of 4cm to 50cm of soil. The deepest soils placement is targeted for these areas because they are considered to have the best potential to support productive tree cover.
- Soils placement will be variable on the TMF dam faces, depending on geotechnical considerations; at-surface materials exposure; and equipment constraints. No soil placement is permitted on the free-draining toe area (1.5:1 slopes). Reduced soils placement (maximum 15 cm) is planned for the dam crests, as these areas must remain free of woody species for dam inspection purposes. Soils will not be placed on portions of the dam faces where void spaces between rocks at surface are sufficiently large that soil would simply fall or be washed into the dam materials. Placement will instead be focused on those portions of the dam where there are sufficient fines at surface to prevent this problem. Soils will be placed to a depth of 40 to 50 cm in a continuous zone from 20 to approximately 50 m below the dam crests. Soils will be placed in irregularly shaped 'islands' wherever feasible over the remainder of the dam faces to enhance diversity.
- Placement depth on the Till Borrow Area will average 30 cm. It is expected that the depth of the rooting zone in this area can be increased by decompacting the pit floor.
- 120 ha of area logged in initial development have been reforested with a mixture of Pine, spruce and Balsam fir

Other reclamation areas include:

- The TMF Pond will occupy an area of approximately 156 ha at closure. It will remain in place to maintain submergence of PAG wastes. Most of it will be relatively shallow, ranging in depth from 0 to 5 m. In part because the pond will be relatively shallow, there is potential for it to gradually develop into a moderately nutrient-rich aquatic ecosystem.
- The ex-Pit NPAG Quarry will flood to form a small lake on closure, and the surrounding area will be seeded

- Sediment Control Ponds will be removed and reclaimed following revegetation of the TMF Main Dam, when discharge quality is acceptable and stable.

CONCLUSIONS

Huckleberry Mine has demonstrated that a well planned waste management plan can be executed over the life of a mine, to achieve the objectives of long term prevention of acid rock drainage. Huckleberry's plan provided for use of all non potential acid generating materials, both NAG rock and glacial till overburden, to construct an impoundment for co-disposal of tailings and PAG waste rock. The plan also staged pit developments to both optimize cash flow and to provide for use of the mined-out pits for tailings and PAG waste disposal. The waste management plan had sufficient flexibility to be able to accommodate changes in ore reserves through the mine life while still maintaining the integrity of the waste management strategy. It is anticipated that the TMF-2 tailings impoundment will provide for long term prevention of acid generation, and the site will be reclaimed to productive wildlife and forest habitat. There will be some exposed PAG rock on the walls of the East Zone Pit. The long term quality of water discharging from the East Zone Pit is uncertain at this stage and will be monitored in the post closure period.

REFERENCES

AGRA Earth & Environmental Ltd. 1997. Huckleberry Project Design Report: Tailings and Waste Rock Management Facilities. Report submitted to Huckleberry Mines Limited.

Huckleberry Mines Limited. 1997. Acid Rock Drainage and Metal Leaching Prevention and Prediction Plan. Submitted to the B.C. Ministry of Energy, Mines and Petroleum Resources.

Huckleberry Mines Limited. 2004. Huckleberry Closure Plan. Submitted to the B.C. Ministry of Energy, Mines and Petroleum Resources.

Price, William A. and John C. Errington. 1998. Guidelines For Metal Leaching and Acid Rock Drainage at Minesites in British Columbia. Ministry of Energy Mines and Petroleum Resources.

<http://www.em.gov.bc.ca/Subwebs/mining/Project_Approvals/guidelines.htm>.