Indian and Northern Affairs Canada
Affaires indiennes et du Nord Canada

Box 1500
Yellowknife NT X1A 2R3

Your file Votre reference

Our file Notre reference

January 29, 1998

0043

Vicki Losier
Administrative Coordinator
Northwest Territories Water Board

BRODIE CONSULTING LTD. - GIANT MINE CLOSURE COST ESTIMATE REPORT

Attached as requested at the public hearing yesterday, are copies of the Brodie Consulting Ltd. Giant Mine Closure Cost Estimate Report.

The report was prepared by Brodie Consulting Ltd. on contract to the Department of Indian and Northern Affairs Canada and represents the opinions and recommendations of Brodie Consulting Ltd.. The report is intended to provide an independent estimate of reclamation costs. It does not limit the responsibility of Royal Oak Mines Inc. for abandonment and restoration of the Giant Mine property as required by license N1L3-0043 and the *NWT Waters Act* and Regulations.

These estimates assume that a third party contractor will conduct the required work. As Mr. Brodie stated in his presentation, the conclusions and recommendations are subject to revision should any new or previously unavailable information be provided.

Neill Thompson
Pollution Control Specialist
Water Resources Division

Canada

REPORT ON

GIANT MINE
CLOSURE COST ESTIMATE

Submitted to:

Department of Indian Affairs and Northern Development
Water Resources Division
Box 1500
4914 - 50th Street
Yellowknife, NT, X1A 2R3

Prepared by:

Brodie Consulting Ltd.
572 St. Andrews Place
West Vancouver, B.C., V7S 1V8
604-922-2034 fax-922-9520

November 27, 1997

November 26, 1997

Department of Indian Affairs and Northern Development
Water Resources Division
Box 1500
4914 - 50th Street
Yellowknife, NT, X1A 2R3

Attention: Mr. Neill Thompson
Pollution Control Specialist

RE: GIANT MINE CLOSURE COST ESTIMATE

Dear Mr. Thompson,

We are pleased to present the attached report on our assessment of the decommissioning costs for the Giant Mine.

This report represents a preliminary assessment of the liabilities at the Giant Mine. As described in the report, several factors could result in different estimate of the mine closure costs. These include: a more detailed assessement of site conditions, additional data, favorable results from reclamation research, and input from other stakeholders.

I trust that this report addresses your current requirements. I would be pleased to revise this estimate of reclamation liability should additional information become available.

Please call if you have any questions.

Yours truly,
Brodie Consulting Ltd.

MJ Brodie

M.J. Brodie, P.Eng.

Brodie Consulting Ltd.
572 St. Andrews Place, West Vancouver, B.C., V7S 1V8
604-922-2034 fax-922-9520 Email: brodies@direct.ca

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1. INTRODUCTION

This report represents a preliminary assessment of the liabilities at the Giant Mine which is currently owned by Royal Oak Mines Inc. The mine has recovered gold nearly continuously since the late the 1940's. Primary impacts and disturbances from the operation include: the excavation of pits and underground workings, construction of tailings disposal facilities, and construction of underground chambers for the storage of arsenic trioxide dust. These and other aspects of the site have been addressed in order to characterize the financial liability associated with the ultimate closure of the mine.

The objectives of this project are to;

1. review the relevant information,
2. present our observations of the site,
3. evaluate the proposed abandonment and restoration plans, and,
4. prepare a first-order reclamation cost estimate for the site.

In this report, Section 2, Site Assessment, presents features relevant to site reclamation, for each principal mine component, as identified in the documentation and during the site inspection. The main objectives or plans in the A & R Plan are then summarized. These are followed by our comments regarding the viability or potential for success of the proposed measures. Section 3, Reclamation Activities, presents a description and the quantities of work for reclamation activities. These are used in developing the reclamation cost estimate which has been complied using the RECLAIM Model spreadsheet for estimation of the cost of mine reclamation. The output of the RECLAIM Model is presented in Appendix 1. A summary of the reclamation cost estimate is presented in Section 4, Conclusions & Summary.

The documents reviewed in conducting this work include;

- Type A Water License, dated June 1994,
- Submission in Support of 1994 Application for Water License, dated Sept. 1992,
- Abandonment and Restoration Plan (A & R Plan) dated 1994, with supporting appendices A through E,
- Emergency Spill Response and Contingency Plan, dated Aug. 1995,
- Golder Associates reports on Geotechnical Inspections of Giant Mine Tailings Dams, dated Sept. 1996 and Oct. 1997,
- Giant Mine monthly surveillance reports for the months of Jan. 1997 to Aug. 1997,
- Terms of reference for environmental study to assess covering of tailings,
- Terms of reference for environmental study to assess acid generation potential,
- Terms of reference for environmental study to assess potential surface contamination,
- Terms of reference for environmental study to assess control of till erosion in Trapper Creek diversion,
- Terms of reference for environmental study to assess permanent underground storage of arsenic trioxide dust,

- HBT Agra letter of Mar. 1994, comments regarding terms of reference for arsenic disposal study,
- meteorlogic data as measured by Environment Canada at the Yellowknife airport,
- assorted plans including; a general site plan, surface facilities plan, general mine site layout (Dec. 1992, 1"=800'), site plan showing surface geology, topography and location of arsenic trioxide chambers "preliminary" (Mar. 1996, 1"=100'), long section of underground workings showing location of arsenic trioxide chambers, and general mine site layout showing location of sampling points for surface contamination study,
- letter from NWT Water Board dated July 15, 1994, with comments and concerns re: A & R Plan,
- Surface Contamination Study, Aug. 1995,
- letter from NWT Water Board dated July 10, 1996, with comments and concerns re: Surface Contamination Study,
- letter from R.O.M., dated Aug. 18, 1997, re: Progress Report on Underground Storage of Arsenic Trioxide Dust Study,
- Arsenic Trioxide Management Feasibility Study (Report & Appendices) by Dillon Consulting Limited of Yellowknife, dated Oct. 6, 1997,
- 1996 Annual Report - Water License, dated Apr. 1997,
- ground based and aerial photographs taken by Water Resources personnel in June and Sept. 1997,
- site water quality data regarding tailings dam seepage and effluent treatment system performance,
- follow up information, dated Nov. 4 and 5, 1997, from the company on underground mine water quality, operating costs for the effluent treatment system, thermistor data from Dams 21D and 11, tailings pond and seepage water quality, mine ventilation power requirements and early tailings disposal practices, and,
- R.O.M. Application for Renewal of Water License, dated Aug. 8, 1997.

This report represents a preliminary assessment of the liabilities at the Giant Mine. A detailed audit of hazardous materials and contaminated soil is beyond the scope of work. The site was overlain by about 3 cm of snow at the time of the site inspection and some features of the site could have been overlooked. Most importantly, the company has prepared only a conceptual A & R Plan. A detailed plan, which could be shown to meet all closure objectives, has not been prepared. Specific reclamation measures and quantities of reclamation activities have not been developed.

The company has not completed some of the required research which was to aid in reclamation planning. The company has collected only the essential minimum site data in order to comply with the terms of the water license. Detailed water quality data for the mine components has not been collected. There has been virtually no progressive reclamation conducted at the site, despite the opportunity to do so, particularly at the tailings areas. A data base of information necessary to develop and substantiate mine reclamation plans has not been developed. Had the company done this they would have improved the confidence in any proposed reclamation measures and probably identified modifications to the mine plan which would have reduced the reclamation liability.

2. SITE ASSESSMENT

2.1 Site Setting

Relevant aspects of the site setting include the following;

- Precipitation at the site (as measured at the Yellowknife airport) is 265 mm/year, evaporation is 360 mm/year, sub-zero temperature prevails from October to April.
- The freezing index is 3750 degree-days, which places it in the zone predicted to be discontinuous permafrost.
- The site is located south of the southern limit of continuous permafrost and although permafrost occurs in the area of the mine, it is not continuous.
- The average annual temperature is -6^0 C.
- Based on average annual temperature, the site is located with the region of Canada where long-term permafrost stability is a concern due to the effects of global warming (inferred conclusion from the Environmental Assessment Panel of the BHP NWT Diamonds Project, Jan 26, 1996).
- The site is located in Zone 0 of the seismic zoning map of Canada, and the peak horizontal ground acceleration is estimated to be less than 0.04 times gravity with a 10% probability of exceedance in 50 years.
- The mine is situated on the shore of Yellowknife Bay, which is part of Great Slave Lake.
- The mine lease area is within the limits of the City of Yellowknife, but on Commissioner's Land.
- The Ingraham Trail (Highway 4) passes through the mine site. It provides access to several hundred cottages to the north and is the starting point for the winter road to access northern mines.

2.2 Open Pits

2.2.1 Observations

- There are 9 open pits.
- The largest open pit is the A-1 pit, which is about 800 feet by 2400 feet and about 150 feet deep.
- The smallest open pit is the B-4 pit, which is about 320 feet by 480 feet and about 50 feet deep.
- Slopes in all pits are in the range of 35 to 45 degrees.
- All pits are essentially dry and probably drain into the underground mine, except the C-1 pit from which water is pumped to the adjacent Baker Creek diversion channel.
- Underground mining removed the bottom of the A2 extension pit such that it now has nearly vertical sides to a depth of about 80 feet.

2.2.2 A & R Plan

- The pits will be allowed to flood naturally.
- As estimated in the 1994 A & R Plan, flooding up to the 200 level, which is about the bottom of the deepest pit, will take up to 78 years, based upon an initial infill rate of about 130 imperial gallons per minute (igpm). Overflow from the pits may not occur until about 450 years after mine closure.
- A berm will be constructed around portions of the pits for protection against inadvertent access.
- The ramps into the pits will be blocked with waste rock.
- Waste material which is to be placed in the B1 pit will be covered with a layer of waste rock.

2.2.3 Comments on A & R Plan and Recommended Closure Measures

- Presumably there is some arsenopyrite which has oxidized on the pit walls and floor such that some arsenic will go into solution upon flooding of the pits. Based on the distribution of rock types in the pits it is assumed that dissolution of arsenic will not result in exceedance of water quality limits as the pits fill with water. An exception to this is the C1 pit which received tailings for several months in the early 1980's. The company should sample the runoff which currently collects at the bottom of the pits to verify this assumption.
- Although the pit water may be of acceptable water quality at closure, the water in the underground mine has a high potential for elevated arsenic concentration as described in the underground section.
- From an environmental and public safety perspective it would be desirable if the pit water did not become contaminated with arsenic from the underground mine. Therefore, it is recommended that concrete bulkheads be constructed in all adits which are connected to the pits to minimize the flow of water from underground into the pits.

2.3 Underground Mine

2.3.1 Observations

- There are a total of 24 openings to surface at the mine, which include the following;
- 4 portals which are located in the pits, the Brock adit which only intersects the bottom of the Brock shaft, and the B3 adit which is located between the Ingraham Trail and the B3 pit,
- 5 shafts, identified as "A", "B", "C", "Akaitcho" and "Brock",
- 7 raises which have been used for ventilation, conveying of arsenic trioxide, fuel supply and ore handling.
- Other openings include 5 points where there is breakthrough between the underground and the pit walls, and the bottom of the A2 Extension pit which was removed by underground mining.

- Most of the underground workings have been developed using waste rock and/or local gravel as backfill. Some backfilling with uncemented cycloned flotation tailings was conducted in the 1950's and 1960's.
- Underground water quality varies throughout the mine and with time, from a low of 6.5 ppm arsenic to a high of 63.5 ppm arsenic based on sampling at stations on the 950,1300 and 2000 levels in 1996 (ref.: Nov. 4, 1997 follow up correspondence from Royal Oak).

2.3.2 A & R Plan

- All equipment which has the potential to contaminate groundwater will be removed from the mine.
- The mine will be allowed to flood naturally.
- All vertical openings are to be sealed with a reinforced concrete cap.
- All adits will be sealed with a rock plug.

2.3.3 Comments on A & R Plan and Recommended Closure Measures

- The 5 points where there is breakthrough between the underground and the pit walls is not addressed in the A & R Plan. As described above for protecting water quality in the pits these openings should be sealed with a concrete bulkhead.
- The A2 Extension pit (approximate dimensions 10m x 25m x 25 m deep) should be backfilled with waste rock.
- There are three potential sources of arsenic which could contaminate the mine water upon filling of the mine; tailings backfill, minor spills and leakages of arsenic trioxide dust around the bulkheads to the chambers, and products of oxidation of arsenopyrite in the stope walls. Collection and treatment of the initial flooding of the mine could be required; it is assumed at this stage that collection and treatment will be required for at least several decades after the mine begins to overflow.
- Overflow of mine water could occur between 78 and 450 years after mine closure, depending upon the connections to the pits.
- If there are benefits, mine flooding could be accelerated by discharging the polishing pond overflow or other site runoff into the mine.
- The company should sample the mine water which is currently pumped from the mine to estimate the expected water quality of the eventual overflow.

2.4 Quarries and Till Borrow Areas

2.4.1 Observations

- Many quarries are located around the mine site, the largest being in the Northwest Tailings area.
- All quarries appear to have been excavated in rock which is similar to the wall rock in the open pits.

- Although there is no confirming data, ARD and leaching of metals from the quarries is assumed to not be a problem.
- Highwall slopes in the quarries are generally less than 10 m high and are consistent with surrounding topographic hazards.

2.4.2 A & R Plan

- No reclamation measures are proposed for the quarries.
- The surface of till borrow areas will be scarified to allow natural revegetation.

2.4.3 Comments on A & R Plan and Recommended Closure Measures

- Revegetation of the bottom of the quarries and till borrow areas should be conducted.
- This revegetation could consist of hand-cast grass seed and fertilizer.

2.5 Waste Dumps

2.5.1 Observations

- The B2 waste dump is located on the west side of the B2 pit.
- This dump appears to have impounded a section of Baker Creek.
- Natural revegetation has started on the top of the dump.
- The dump is probably constructed of till or rock which is similar to the wall rock in the open pits.
- Although there is no confirming data, ARD and leaching of metals from the dump is assumed to not be a problem.

2.5.2 A & R Plan

- No reclamation measures are proposed for the dump.

2.5.3 Comments on A & R Plan and Recommended Closure Measures

- No reclamation measures are required for the dump.

2.6 Tailings Impoundments

2.6.1 Old Tailings System

2.6.1.1 Observations

- The old tailings system is made up of three adjacent ponds called the South, Central and North ponds. The collective system consists of 13 dams which are identified as dams 2, 3, 3C, 3D, 4, 5, 6, 7, 8, 9, 10, 11, and 12.
- Dams 4, 5, and 6 no longer function as dams as they have tailings at or near the crest on both sides of the dam.
- Dams 3C, 3D and 7 are seepage collection dams and do not contain tailings.
- All dams have been inspected annually by Golder Associates Ltd. (Golder).
- Golder has recommended repairs to dams 6 and 8, and installation of monitoring devices on dams 7 and 11.
- Golder has concluded "that all dams are performing acceptably in terms of their current function".
- There is a concrete decant tower, with a wooden stop-log wall to contain any tailings and the maintain the water level, through Dam 2.
- Dams 2 and 11 have a downstream slope at or near to the angle of repose and up to 50 feet high.
- The tailings are not potentially acid generating.
- Several trial plots were constructed to evaluate the potential for inducing permafrost into the tailings as a closure stabilization method.
- A conclusion of this work was that even the thickest rock cover could not induce permanently frozen conditions and that such a cover even if effective would be prohibitively costly to construct.
- Golder has noted that seepage from the dams is above discharge limits and must be collected for treatment prior to release.
- In sampling of seepage water in June 1995, arsenic was found at 0.39 ppm at Dam 7 and 2.4 ppm at Dam 3C. The seepage volume was reported as "very little" in the 1997 geotechnical inspection by Golder.
- In general the volume of seepage is very small with little or no seepage collected at Dams 3C and 3D.
- Runoff from within the Old Tailings area drains from the South Pond through the Central Pond and collects against Dam 2 in the North Pond. Consequently most of the seepage from the three ponds is likely to report to the settling pond and polishing pond below Dam 2. The quantity of this seepage is not known.
- A pond forms in the south end of the South pond and presumably contributes to the seepage which reports to Dam 7.
- Attempts to mine the tailings in the early 1980's by hydraulic methods has left a gully across the Central Pond which is up to 5 m deep and 25 m wide.
- Dam 2 was mined to provide construction materials for the Northwest Tailings area. The dam has an irregular shape; however there appears to be sufficient freeboard.

Golder has recommended that additional material be placed to prevent further erosion of the dam.

- Complaints have been registered with the Water Board regarding wind erosion of the tailings during the summer months.
- Some natural revegetation has occurred on the rock fill of the tailings dams.
- There is virtually no natural revegetation of the tailings surface although a few tuffs of grass are growing adjacent to Dam 3 in the North Pond.

2.6.1.2 A & R Plan

- No specific closure plan is in place for the tailings impoundment although the company had proposed several options in the 1994 A & R Plan.
- A spillway is proposed for Dam 2 to allow release of excess runoff from extreme precipitation events.
- Test work to date has only served to eliminate one reclamation option.

2.6.1.3 Comments on A & R Plan and Recommended Closure Measures

- No specific measures for closure have been proposed and assessment of long-term stability of the dams has not been conducted.
- Based on reported seepage monitoring, long-term seepage of contaminated water is likely to emerge from the tailings.
- Assessment of the tailings and pore water regarding the total metals content and mineralogical make up has not been conducted. It is believed that some arsenopyrite will be present in the tailings as recovery in the mill is only 95%. In addition, there may be trace amounts of arsenic trioxide in the tailings as well as free arsenic in the frozen and un-frozen pore water.
- Measures such as inducing permafrost are not currently seen as economically viable to immobilize the tailings pore water.
- Without measures to induce and maintain permafrost, thawing of frozen tailings is likely to occur in at least the upper 5 to 10 m, and possibly more due to the downward migration of water which will collect in the tailings containment area.
- Based on the excess of evaporation over precipitation, the only discharge on an average annual basis from the tailings containment area should be seepage. A water balance for the closure scenario (based upon the final pond capacity and including extreme precipitation events) should be prepared to verify this prediction.
- Seepage collection at Dams 3C, 3D and 7 may be negligible if the tailings ponds are contoured to enhance the current runoff into the pond against Dam 2. Ongoing treatment of the water or seepage at this location could then be conducted.
- A channel for flow of the runoff from the South Pond to the North Pond should be constructed and would require some rip rap for erosion protection.
- The concrete decant tower in Dam 2 should be filled with concrete.
- Elevated arsenic in the ponded water or seepage from Dam 2 is likely to require treatment for at least several decades as the pore water along the seepage throughout the three tailings areas paths melts and is flushed out.

- The company should assess the quantity and quality of seepage and propose a method to mitigate environmental impact.
- For the purpose of this assessment it is assumed that collection and treatment of the ponded water and seepage from Dam 2 will be required.
- The gully in the Central Pond should be contoured to stabilize against water and wind erosion.
- Measures to stabilize the tailings against erosion by wind will be required. Based on the very limited natural revegetation which has occurred in the inactive tailings areas it is expected that while grasses may be able to control wind erosion, it will be difficult to establish an effective cover. Vegetation growth will be retarded by arsenic toxicity. Over time, as the arsenic if flushed out the viability of the vegetation will improve. Provision for high fertilization rates and multiple seeding is recommended. Alternatively, some other stabilization could be used, such as a rock cover.
- If control of wind erosion is based on establishment of vegetation then it will be necessary to restrict access such that the vegetation is not destroyed by motorcycles and off-road vehicles. All access roads onto the tailings surfaces should be removed or blocked with steep-sided berms.
- Measures to improve the long-term stability of dams 3 and 11 will be required and should consist of placement of additional rock against the downstream face to flatten the slopes.

2.6.2 Northwest Tailings System

2.6.2.1 Observations

- The Northwest Tailings system consists of a single pond which is defined by dams 21A, 21B, 21C, 21D, 22A and 22B.
- There are no internal dams.
- An unnamed seepage collection dam is located below Dam 22B and does not contain tailings.
- All dams have been inspected annually by Golder Associates Ltd. (Golder).
- Golder has recommended raising the tailings beach against dams 21A, 21B, 21C and 21D to reduce seepage loses and installation of monitoring devices on Dam 21D.
- Three sinkholes located in the crest of Dam 21D should be backfilled with a soil/bentonite mixture.
- Golder has concluded "that all dams appear to be performing safely".
- Overall slopes are approximately 2H:1V.
- The tailings are not potentially acid generating.
- In sampling of seepage water in June 1995, arsenic was found at 2.6 ppm below Dam 21A, 0.96 ppm below Dam 22A, and 4.8 ppm at the sump below Dam 22B.
- Seepage water at Dam 22B has ranged up to 14.8 mg/l (June 13, 1994).
- The quantity of seepage was estimated by Golder to be:
    - 5 to 10 l/min. total from Dam 21B,
    - less than 1/2 l/min. at Dam 21C,

  - uncertain but possibly up to 30 l/min. at Dam 21D,
  - less than 1/2 l/min. at Dam 22A,
  - about 100 l/min. at Dam 22B.
- The total seepage from the Northwest Tailings area is about 140 l/min.
- Only one measurement of tailings pond water has been reported. On August 19, 1997 the pond in the Northwest Tailings area had an arsenic concentration of 25.8 mg/l.
- Thermistor monitoring of temperature in Dam 21C at depths of 45 and 55 feet has shown consistent values of 0.5 to 1.0^0 c.
- Complaints have been registered with the Water Board regarding wind erosion of the tailings during the summer months.
- Some natural revegetation has occurred on the rock fill of the tailings dams.
- There is no natural revegetation of the tailings surface.

2.6.2.2 A & R Plan

- No specific closure plan is in place for the tailings impoundment although the company had proposed several options in the 1994 A & R Plan.
- Test work to date has only served to eliminate one reclamation option.
- A spillway for runoff is proposed at the north end of Dam 22B.
- The final tailings surface will be either seeded or a granular fill cover will be placed over the tailings.

2.6.2.3 Comments on A & R Plan and Recommended Closure Measures

- No specific measures for closure have been proposed and assessment of long-term stability of the dams has not been conducted.
- Based on reported seepage monitoring, long-term seepage of contaminated water is likely to emerge from the tailings.
- Assessment of the tailings and pore water regarding the total metals content and mineralogical make up has not been conducted. It is believed that some arsenopyrite will be present in the tailings as recovery in the mill is only 95%. In addition, there may be trace amounts of arsenic trioxide in the tailings as well as free arsenic in the frozen and un-frozen pore water.
- Measures such as inducing permafrost are not currently seen as economically viable to immobilize the tailings pore water.
- Without measures to induce and maintain permafrost, thawing of frozen tailings is likely to occur in at least the upper 5 to 10 m, and possibly more due to the downward migration of water which will collect in the tailings containment area.
- Based on the excess of evaporation over precipitation, the only discharge on an average annual basis from the tailings containment area should be seepage. A water balance for the closure scenario (based upon the final pond capacity and including extreme precipitation events) should be prepared to verify this prediction.
- Elevated arsenic in this seepage is likely to require treatment for at least several decades as the pore water along the seepage paths melts and is flushed out.

- The company should assess the quantity and quality of seepage and propose a method to mitigate environmental impact.
- For the purpose of this assessment, it is assumed that collection and treatment of the seepage from Dams 21B, 21D and 22B will be required.
- Seepage control dams should be constructed below Dams 21B and 21C.
- Collection of the seepage and pumping to the effluent treatment plant will be required, treatment of 140 l/min. results in an annual volume of 73,500 m^3/yr. Over time this may decrease once process water is no longer added to the system.
- Measures to stabilize the tailings against erosion by wind will be required. Based on the very limited natural revegetation which has occurred in the Old Tailings area it is suggested that while grasses may be able to control wind erosion, it will be difficult to establish an effective cover. Provision for high fertilization rates and multiple seeding is recommended.
- If control of wind erosion is based on establishment of vegetation, then it will be necessary to restrict access such that the vegetation is not destroyed by motorcycles and off-road vehicles. All access roads on to the tailings surfaces should be removed or blocked with steep-sided berms.

2.6.3 Yellowknife Bay Tailings

2.6.3.1 Observations

- Tailings were deposited below Dam 7.
- A beach of these tailings is currently being eroded in Yellowknife Bay. The eroding face of the tailings is about 2 m high and 150 m long.
- These tailings are not potentially acid generating.
- A layer of dark material about 20 cm thick is visible in the exposed face of the tailings. This material may be arsenic-rich calcine dust.
- Natural revegetation has established on these tailings.

2.6.3.2 A & R Plan

- No reclamation measures are proposed for these tailings.

2.6.3.3 Comments on A & R Plan and Recommended Closure Measures

- Assessment of the tailings and pore water regarding the total metals content and mineralogical make up has not been conducted. It is believed that some arsenopyrite will be present in the tailings as recovery in the mill is only 95%. In addition, there may be trace amounts of arsenic trioxide in the tailings as well as free arsenic in the pore water,
- Release of dissolved arsenic and/or arsenic bearing material into the lake is occurring and should be prevented.

- Reduction of arsenic release could be achieved by reducing the erosion of this material. Control of erosion could consist of placing a rip rap barrier against the tailings.

2.6.4 Baker Creek Tailings

2.6.4.1 Observations

- Tailings were deposited below Dam 1.
- These tailings are not potentially acid generating.

2.6.4.2 A & R Plan

- No reclamation measures are proposed for these tailings.

2.6.4.3 Comments on A & R Plan and Recommended Closure Measures

- Assessment of the tailings and pore water regarding the total metals content and mineralogical make up has not been conducted. It is believed that some arsenopyrite will be present in the tailings as recovery in the mill is only 95%. In addition, there may be trace amounts of arsenic trioxide in the tailings as well as free arsenic in the pore water.
- Release of dissolved arsenic and/or arsenic bearing material into Baker Creek is occurring and should be prevented.
- Control of erosion could consist of placing a rip rap cover over the tailings.

2.6.5 Underground Tailings

2.6.5.1 Observations

- It is reported that tailings were used in mine backfill up to the early 1980's.
- Information regarding location, cement content or the type of bulkheads used for containment of this tailings was not available during the preparation of this report.

2.6.5.2 A & R Plan

- No closure measures are presented in the A & R Plan.

2.6.5.3 Comments on A & R Plan and Recommended Closure Measures

- The tailings presumably have a similar potential for long-term leaching of arsenic as does the tailings on surface.

- It is assumed that leaching of arsenic from these tailings will contribute to arsenic release from the mine and that collection and treatment of the underground water will be required.

2.7 Mill and Surface Facilities

2.7.1 Observations

- The surface facilities consists of many buildings including; the mill, roaster, dry, warehouses, and offices.
- Many of these buildings have asbestos-based tar paper siding.
- Several buildings have asbestos cement cladding.
- The kiln, roaster, AC roaster, cottrell and bag-house buildings have friable asbestos insulation on the walls.
- The roasters, bag filters and various piping have friable asbestos insulation.
- The Akaitcho surface plant consists of a head frame and seven buildings most of which have asbestos-based tar paper siding.
- The former tailings re-treatment plant (TRP) consists of the treatment plant, clarifier, and seven concrete leach silos.
- Mine air heaters are located by the B shaft and the portal in the B3 pit.
- A propane tank farm is located below Dam 21C,
- The explosives plant consists of two buildings and is located north of Dam 2.
- The old power house and power house tank farm are located by the A shaft.
- Five more tanks are located by the mill site.
- There are numerous ultilidors, pipelines, pipe-boxes around the mill area.

2.7.2 A & R Plan

- After removal of salvageable equipment, all remaining buildings will be demolished and the non-hazardous debris disposed of in the B1 pit under a cover of waste rock.
- Concrete slabs will be left exposed.

2.7.3 Comments on A & R Plan and Recommended Closure Measures

- There is a significant quantity of asbestos material on the site. The brief site assessment upon which this report is based is not sufficient to characterize this liability. A detailed audit of these materials should be conducted.
- As proposed by the company, a hazardous materials survey should be conducted to identify all materials which should be removed before demolition.
- Concrete slabs should be cracked to prevent ponding of water and covered with soil to allow revegetation.

2.8 Town Site

2.8.1 Observations

- The townsite consists primarily of homes, several of which have asbestos-based tar paper siding.
- There is a boiler house which provides steam heating to the townsite and the mine offices via a surface pipe system.
- It is believed that a fuel tank was located adjacent to the boiler house.

2.8.2 A & R Plan

- No reclamation measures are proposed for the townsite.

2.8.3 Comments on A & R Plan and Recommended Closure Measures

- The townsite could be sold as residential property. However, such a sale would be complicated by the common heat supply from the boiler house. There is potential for arsenic contamination in the soil above the CCME guidelines for residential use which will further limit the potential for sale. One soil sample taken near the townsite had over 2000 ppm arsenic and the CCME guideline is 30 ppm.
- Due to the above complications to a potential sale, it is assumed here that the townsite would be vacated and the buildings removed.
- Potential for oil contamination around the boiler house and fuel storage areas was not addressed in the Surface Contamination Study, the company should conduct sampling in this area.

2.9 Roads

2.9.1 Observations

- Roads throughout the mine area have been constructed with either waste rock or quarried rock.
- Test work suggests that there is no concern for ARD or metal leaching from the rock.

2.9.2 A & R Plan

- All roads will be graded to allow controlled runoff.
- Culverts and bridges will be removed.
- Roads will be scarified to allow natural revegetation.
- Existing fencing around the site will be removed.

2.9.3 Comments on A & R Plan and Recommended Closure Measures

- The proposed reclamation measures are in general acceptable.
- Due to the proximity to Yellowknife and the need to restrict access to the site, berms should be constructed at entrance ways to the property and roads should be revegetated with trees to make future use of the roads and access to the site more difficult (than if the revegetation consisted of grasses).

2.10 Water Management System

2.10.1 Observations

- The effluent treatment system currently treats mine water for removal of arsenic and destruction of cyanide.
- The annual process rate is 1.8 x 10^6 m^3 per year, which is processed in about 5 months between May and September.
- The average arsenic concentration in the influent from the three sources was 5.6 mg/l on June 2, 1997.
- Treatment efficiency is acceptable all metals are generally well below discharge limits.
- Over the five year period the total discharge of arsenic is as follows:

YEAR	TOTAL DISCHARGE STN 43-1, m^3	AVERAGE ARSENIC CONCENTRATION, mg/l	ARSENIC DISCHARGE, kilograms/year
1993	2,165,637	.652	1,411
1994	1,945,088	.313	609
1995	1,810,502	.248	449
1996	1,949,217	.264	515
1997(to end Aug.)	1,226,088	.262	321 + ?

- Despite the acceptable treatment efficiency, the arsenic concentration in Baker Creek over the period of 1993 to 1997 has ranged from 0.02 mg/l to 0.76 mg/l. The average of 56 measurements over this period is 0.20 mg/l (the average for 1996/97 is 0.154 mg/l from 27 samples). A concentration of 0.20 mg/l exceeds the guideline of 0.05 mg/l for protection of aquatic life by 4 times.
- Influent water is runoff from the old and new tailings areas plus about 137 igpm from the underground mine.
- The current costs of water treatment are $210,000/yr. for hydrogen peroxide, $365,000/yr. for ferric sulphate and other reagents, $25,000 per year for a part time operator and $85,000 for power. These costs are applied to 1950,000 m^3/yr. of water for a unit treatment cost of $0.35/$m^3$.
- Site runoff from outside the tailings areas is released directly to the environment.
- A concrete decant tower, with a wooden stop-log wall to contain the tailings, passes through Dam 1.

2.10.2 A & R Plan

- No reclamation activities are proposed for the water management facilities.
- Return of Baker Creek to a fish habitat is proposed in the A & R Plan.
- Upon completion of post-closure water treatment the effluent treatment plant should be removed.

2.10.3 Comments on A & R Plan and Recommended Closure Measures

- There is potential for post closure erosion and dissolution of the ferric arsenate contained in the settling pond. Ferric arsenate can be redissolved in a reducing environment such as may exist at depth in the settling pond. Placement of a soil cover over the settled precipitate could reduce erosion and flushing of any dissolved arsenic.
- Baker Creek may not become a fish habitat without a significant reduction in the total arsenic released from the effluent treatment system in the post closure discharge of water. Either the performance of the treatment system should be improved and the volume of water significantly reduced, or the A & R objective should be modified. An alternative discharge point, such as into the underground mine or directly into Yellowknife Bay, could be considered.
- The concrete decant tower in Dam 1 should be filled with concrete.
- Should there be any discharge from the Old Tailings system via the spillway it would flow into the polishing pond, consequently a spillway for Dam 1 is also required.

2.11 Wastes, Chemicals, Contaminated Soil

2.11.1 Observations

- Waste refuse is located at many locations around the site including; various collections around the mill, along the road to the town site, by Dam 1, and in Northwest Tailings pond by Dam 22B.
- Arsenic trioxide is stored in about 1000 drums at the hazardous waste area in Northwest Tailings pond. Other materials at this location include batteries and 10 pallets of ammonia sulphate. Runoff from this area reports to the Northwest Tailings area.
- Batteries from trucks and underground equipment are located in numerous collection sites around property.
- All waste oil has been removed from the site.
- Contaminated soil is present at the waste oil storage area, by the mill, boiler house, around fuel storage tanks at both tank farms, and below the heavy equipment repair shop.
- The extent of hazardous materials in the underground mine is not known.
- Junk vehicles have been placed in the B2 pit. It is not known if they have been decontaminated such that they can be buried at this location.

- A site assessment of soil contamination has been initiated by the company and is described in the 1995 report "Surface Contamination Study" and an addendum dated Aug. 1995. Although the report is presented as final, several concerns were identified by the Water Board. Subsequent work on background arsenic in soils indicates occasional natural levels of arsenic above CCME criteria. Further work is required to develop site specific reclamation objectives.

2.11.2 A & R Plan

- Non-hazardous solid waste except for demolition waste is to be disposed of under a cover of waste rock in the Northwest Tailings area.
- Scrap metal and demolition debris is to be disposed of in the B1 open pit.
- Petroleum contaminated soil may be burnt, buried or bio-remediated.
- Arsenic contaminated soil is to be placed in the tailings impoundment.

2.11.3 Comments on A & R Plan and Recommended Closure Measures

- The company has not met the Water Board's request (July 10, 1996) to provide actual remediation options and maps depicting areas of contamination. Quantities of potentially contaminated soils have not been identified.
- The non-hazardous solid waste could be buried in the tailings impoundment, however burial in the B1 pit may be less costly. Rock for the cover over the waste in the B1 pit could be taken from the access roads which are to be removed from around the tailings areas.
- Cleaning of sludge accumulation in fuel storage tanks will be required before they are demolished.
- Removal of soluble arsenic contaminated soil to the tailings impoundment should be conducted.
- Petroleum contaminated soil from around fuel storage and machine service areas should be bio-remediated and then used for re-establishment of vegetation.

2.12 Arsenic Trioxide Chambers

2.12.1 Observations

- Only three arsenic trioxide chambers were inspected, B208, #12 and #14.
- Impure arsenic trioxide is a by-product from the roasting of gold bearing arsenopyrite.
- The arsenic trioxide bearing dust has been stored in underground chambers since 1951.
- It is not known where the arsenic trioxide dust from roasting of ore between 1948 and 1951 is located. Some may have been discharged in the stack exhaust and is dispersed around the mine area. Presumably most of it is contained in the original tailings deposits; either behind Dam 1 or in the deposits in Baker Creek or on land and in Yellowknife Bay south of Dam 8.

- Currently there is about 260,000 tons of arsenic trioxide dust in the underground chambers. The early material placed underground is reported to be about 40 to 45 % arsenic trioxide and contains up to 2 ounces per ton of gold. The dust which is currently being placed is up to 85% arsenic trioxide and contains up to 0.5 ounces per ton of gold. The 1994 terms of reference study reported a total of 141,000 ounces of gold in 236,000 tonnes of dust, for an average content of 0.6 ounces per ton.
- The arsenic trioxide dust is located in 15 chambers, 5 of which are mined out stopes and 10 are chambers excavated specifically for storage of the dust. A sixteenth chamber is currently being constructed, but filling has not commenced.
- The distance from the top of the chambers to surface varies from a low of 30 feet to a high of 188 feet, and the average is 81 feet.
- All of the chambers are sealed with concrete bulkheads which are reported to be reinforced concrete at least 2 feet thick.
- Bulkheads at the bottom of the chambers have no perforations. The bulkheads at the top of the chambers have a 1/2 inch thick steel door bolted onto the bulkhead and numerous pipes (up to 8 at one bulkhead) for pumping the dust in and returning the exhaust air back to the bag-house in the mill. Leakage around the steel door is controlled with a rubber gasket, although not all of the steel doors have a gasket.
- The pipes are 4 or 6 inch diameter steel, and those that are no longer in service have been filled with concrete.
- All of the pipes and inspection doors are made of mild steel. Stainless steel has not been used.
- Most of the chambers have a fill pipe directly to surface which was used when the underground lines were being maintained.
- It is understood that upon completion of bulkhead construction for the more recent chambers that the mine compressed air system was used to pressure test the chamber. Leakage's points and drill holes were identified by mine personnel and sealed with concrete. It is not known if this was conducted for the earlier chambers.
- Leakage of water containing some dust from the chambers has occurred. Grouting of the rock was conducted to stop the leakage. Leakage of about 0.1 l/min. of water with up to 10,000 mg/l arsenic was observed at Chamber 14 As noted above, not all chambers were inspected. It is possible that there is some unchecked leakage occurring at the other chambers.
- Attempts to market the dust in the 1980's were unsuccessful because the dust was not of high enough purity.
- Test work has shown that it may be possible to upgrade the dust to a marketable product. However market conditions are such that this is not economically attractive, as described below in the evaluation of removal options.

2.12.2 A & R Plan

- A number of studies pertaining to containment of the arsenic trioxide were to be conducted by the end of 1997 as part of the conditions of the 1994 Water License.
- It is understood that little of this work has been completed.

- The primary objective of the studies was to demonstrate that the dust could be permanently immobilized by permafrost. Options to enhance this objective were also to be studied, these included:
  1) use of forced ventilation of winter air to enhance re-establishment of permafrost,
  2) use of additional bulkheads to isolate the storage chambers from the groundwater regime,
  3) use of grout curtains to isolate the storage chambers from the groundwater regime, and,
  4) creation of artificial ice plugs behind the bulkheads to enhance isolation of the storage chambers from the groundwater regime.
- Additional options which are identified in the 1997 Water License application include;
  5) pumping water from the underground mine such that groundwater does not enter the chambers,
  6) develop preferential pathways for groundwater to flow around the chambers (called hydraulic isolation), and,
  7) removal of the dust for permanent on-land storage,
  8) removal of the dust for conversion into chemically more stable ferric arsenate,
  9) removal of the dust for upgrading to a preservative grade arsenic product.

2.12.3 Comments on A & R Plan and Potential Closure Measures

Unlike other sections of this report which contain recommended closure measures, this section does not recommend a closure option. It presents an evaluation of the options listed above and one concept proposed by Brodie Consulting Ltd. Determination of the final solution for the arsenic trioxide will involve assessment of scientific data, detailed engineering design, risk assessment, cost, and concerns of land owners and the general public. Addressing all of these issues is beyond the scope of this report. However, our scope of work does require providing a cost estimate for a practical solution to the problem.

In our evaluation which follows we have numerically characterized the potential problem and then assessed each of the potential solutions. Those solutions which are not expected to provide sufficient environmental protection are rejected. The least costly of the remaining potentially effective solutions has been used in the reclamation cost estimate for the mine.

A more detailed assessment may find that one of the rejected options is in fact viable. Furthermore, as this assessment has considered only the technical and financial aspects of the problem, it should not be viewed as a recommendation for the least costly option. Consideration of other factors may result in a different "preferred" solution.

2.12.3.1 Assessment of "Do-Nothing" Option

In order to gain a sense of the level of control which is required and evaluate the closure options it is worthwhile to identify the potential consequences of the "do nothing" option. This is roughly assessed as follows.

- The solubility of arsenic trioxide in water with a pH of 7 at 0° c is about 12,100 ppm (Perry's Chemical Engineer's Handbook, 16th Edition). At a pH of 8 the solubility could rise to about 25,000 ppm. The solubility also increases with temperature.
- The apparent insolubility of the dust in water is probably due to the hydrophobic properties of elemental sulphur in the dust. The presence of this sulphur will not reduce the long-term dissolution of the arsenic trioxide. Seepage water from the #14 chamber had an arsenic concentration of about 10,000 ppm, which appears to confirm the potential for high dissolved arsenic in solution. That sampled seepage may have had only a brief contact with the dust, may not have reached equilibrium or could have been diluted with other groundwater. A higher concentration could occur in the chambers if they are flooded.
- The mine water has a pH in the range of 7 to 8 (verbal communication, S. Schultz, Superintendent, Environmental Services) and is expected to remain in this range due to the alkaline nature of the rocks if flooding of the mine occurs.
- Current mine dewatering involves discharge of 137 igpm.
- If post-closure discharge is 10% of this rate and contains only 0.1 mg/l arsenic (before contribution from the chambers) then the total seepage from the chambers would have to be less than 9.9×10^{-7} m^3/m at 25,000 ppm arsenic in order that the discharge does not exceed the 0.5 mg/l limit. Note that this is based on 0.1 mg/l arsenic in the mine water which is significantly below the current level of 6 to 63 mg/l. A higher arsenic concentration in the mine water would require an even lower seepage rate from the chambers.
- We can roughly estimate the hydraulic conductivity of the rock around the chambers required to achieve this low level of seepage as illustrated in Figure 1 and as follows; assume the hydraulic gradient into the chambers is 0.05 (1 m head loss in 20 m, which is less than topographic slopes), assume the cross-section area of the chambers is 46 m high by a cumulative length of 533 m, using the formula $Q=-k \times i \times A$ ($Q=$ flow, $-k =$ hydraulic conductivity, $i=$ hydraulic gradient, and $A =$ cross section area through which the flow passes), we find that the hydraulic conductivity of the rock and bulkheads around the arsenic trioxide would have to be 1.35×10^{-11} m/s,
- Eventual oxidation of the steel pipes and doors would result in increased flow through the chambers.
- It is unlikely that the rock around the chambers has a hydraulic conductivity in this range (the lower limit of hydraulic conductivity of fractured igneous and metamorphic rocks as reported in text Groundwater, by Freeze and Cherry, 1979, is 1×10^{-8} m/s).
- Based on the above crude assessment, release of arsenic from the storage chambers would occur at an initial rate which is three orders of magnitude greater than permissible levels. Eventual corrosion of the steel pipes and doors would increase the impacts. Consequently measures to isolate or immobilize the arsenic trioxide dust or collect and treat the mine water discharge will be required.

- Dissolution of arsenic in a flow of 9.9×10^{-7} m^3/min. at a concentration of 25,000 mg/l, gives a removal rate of arsenic trioxide of 24.8 mg/min. Dissolution of all of the arsenic trioxide at this rate would take about 10 million years.

As assessed above, it is certain that measures will be required to prevent environmental impact. Control measures can be loosely classified as;

i) contain in place,
ii) remove from the mine, or
iii) collect and treat the drainage from the mine.

The potential options are discussed below under these three headings.

2.12.3.2 Contain In-Place Options

- The contain in place options include immobilization with permafrost, ice plugs or additional bulkheads, grout curtains and hydraulic isolation.
- The 1997 Water License application reports that underground mining has disturbed the existence and discontinuous pattern of permafrost in the rock and that below 70 feet depth the temperature of the rock is between +0.3 and 3.7° c.
- The natural re-establishment and maintenance of discontinuous permafrost may be very slow.
- As described in the site setting section, there is concern that permafrost may not survive in the long-term due to global warming.
- Consequently it is probable that any closure option which relies upon sub-zero temperature to prevent migration of arsenic will require perpetual intervention.
- Maintaining perpetual freezing is no longer considered as an option using the mine ventilation system. It is unlikely that this approach would be effective in freezing the chambers and rock around them. This approach may only freeze the rock in the drift walls. If this option could be shown to be effective it would require running the fans for about six months a year. As only a portion of the mine would be ventilated using this approach the power supply may be only 30% of the current power demand (350 HP x1/3 = 115 hp = 85 kW), based on $0.0772/kW-hr this would cost about $28,740/yr., labour would be $100,000/yr., annual maintenance and periodic replacement of equipment may be $25,000/yr., for a total annual cost of $154,000 /yr.
- Development of additional drifts around the chambers would be required to allow the cooling air to contact the chambers. Up to 4000 feet of drifting may be required to provide air flow around the chambers. Based on $1550/ft, the drifting would cost about $6,200,000.
- Maintaining freezing conditions with the mine ventilation system would require that the mine does not flood above about the two hundred level. Assuming an inflow of about 30 igpm (about 60,000 m^3/yr.) and pumping up 55 m to the discharge point, this would cost about $8500/yr. Labour would be included in the ventilation cost above, annual maintenance and periodic replacement of equipment may be $25,000/yr., for a

total annual cost of $33,500 /yr. Infiltration of groundwater from above the chambers would require treatment of the water before discharge.

- The total cost of running the fans and pumps would be $187,000/yr.
- Financing this cost in perpetuity could be achieved with a fund which provides sufficient return on investment to maintain the fund and pay the annual operating costs. The portion of the interest which would be applied to the annual operating costs is called the real rate of return. The long-term real rate of return is between 2.5 and 3.5% of the original fund amount. Based on a real rate of return from an investment of 3%, the net present value of this option is about $6,250,000. This amount would be required in cash so that the fund for perpetual operations could be established.
- The total of capital cost for drifting plus perpetual operations is estimated at $12,450,000.
- Based on the "do-nothing" assessment above, it is unlikely that simply constructing additional bulkheads would do much to reduce the rate of release of arsenic unless some of the existing bulkheads are leaking. If corrosion studies indicate that the mild steel pipes and doors on the bulkheads are not durable then it may be necessary to construct a second bulkhead over all of the existing bulkheads with these components.
- The use of grout curtains may be of benefit however, a grout curtain would have to be extremely effective to be a stand alone option for closure. Achieving a permeability reduction of two to three orders of magnitude is an optimistic objective for grouting. It is likely that other measures would be required in addition to grout curtains.
- The use of ice plugs may be of benefit however, ice plugs would have to be extremely effective to be a stand alone option for closure. It is likely that other measures would be required in addition to ice plugs.
- In addition to the company's concept of freezing the mine with winter air forced in with the mine ventilation system, freezing of the rock around the arsenic trioxide chambers could be achieved with thermosiphons such as have been used at BHP Diamonds and installed at Colomac.
- Thermosiphons could be used to create a frozen perimeter around the chambers and in the ground above them. In this approach, flooding of the chambers would be allowed but release of arsenic would be prevented by a barrier of ice above and around the chambers. Movement of arsenic by dispersion through the unfrozen ground below the chambers would occur, however this process would be extremely slow. This concept is illustrated in Figure 2.
- For cost estimating purposes, it is assumed that thermosiphons may be needed on 15 foot centers around the perimeter of chambers. The total length around the chambers at 30 feet out from the wall of the chambers is 6710 feet and would require 99,755 feet of drilling, based on an average drill depth of 223 feet. The area within the perimeter holes would require an additional 32,040 feet of drilling based on an average thermosiphon length of 40 feet and 15 foot centres. Using 6 inch diameter holes, the drilling would cost about $14/ft. The total drill length would be 131,975 feet, which would cost $1,845,000. Installation of the thermosiphons would be approximately $33/ft for a cost of $4,349,000.
- Installation of the thermosiphons over the C 2-12 chamber, which is located directly under Baker Creek, will require confining the creek to a discrete channel. A ditch

about 750 feet long would permit drainage of the ponded area above the C 2-12 chamber and minimize infiltration. It is not clear how much material would have to be excavated as this ditch would connect several low points along the creek and pass under the highway. For the purpose of this assessment it is assumed that construction of this ditch would involve excavation of an average of 65 cubic feet of rock per foot of ditch. The total volume would be 48,750 cubic feet or 1380 m^3. The cost would be $16,500.

- The capital cost of the thermosiphon approach is $6,211,000.
- Annual maintenance and periodic replacement of gases or the thermosiphon equipment may be $25,000/yr.
- Financing this cost in perpetuity could be achieved with a fund which provides sufficient return on investment to maintain the fund and pay the annual operating costs. The portion of the interest which would be applied to the annual operating costs is called the real rate of return. The long-term real rate of return is between 2.5 and 3.5% of the original fund amount. Based on a real rate of return from an investment of 3%, the net present value of this option is about $833,000. This amount would be required in cash so that the fund for perpetual operations could be established.
- The a total cost of the thermosiphon approach is estimated at $7,044,000.
- Hydraulic isolation is a proven approach to preventing flushing of contaminants and is currently in use at the Rabbit Lake Mine in Saskatchewan for containment of radioactive tailings. In the above formula, $Q= -K \times i \times a$, the flow becomes zero when the hydraulic gradient, i, becomes zero. This occurs when the water level is the same on both sides of the material to be contained. In order to develop this situation where regional gradients are not zero it is necessary to create a pathway of less resistance for water to flow around the zone to be isolated. . This concept is illustrated in Figure 3.
- It is possible to create this condition around the chambers by increasing the permeability of an envelope of rock about 100 ft beyond the wall of the chambers. A method to construct this would involve underground drilling of drain holes around the chambers. Some drifting would be required as the access around the base of the chambers is not complete. Some grouting of any faults which connect the permeable envelope to the chambers would be required. It should be noted that even if the hydraulic gradient is exactly zero there would still be some release of arsenic due to dispersion.
- For cost estimating purposes of the hydraulic isolation option, it is assumed that 2 inch diameter drillholes may be needed on 10 foot centers around the chambers. A total of about 1000 holes with an average length of 200 feet would be required. The total drill length is 200,000 feet, which would cost $1,000,000, based on $5/ft using an underground longhole drill. Up to 3000 feet of drifting may be required to provide access for the drilling and ensure that the hydraulic isolation is effective. Based on $1550/ft, the drifting would cost about $4,650,000. Additional measures to prevent short-circuiting through the chambers would include grouting fracture zones and construction of new bulkheads in front of those with steel pipes and doors.
- Reduction of infiltration from incident precipitation would likely be beneficial and could be achieved with a compacted soil cover. Additional measures will be required to control infiltration into the C 2-12 Chamber, which is located directly under Baker

Creek. A ditch about 750 feet long would permit drainage of the ponded area above the C 2-12 chamber and minimize infiltration. It is not clear how much material would have to be excavated as this ditch would connect several low points along the creek and pass under the highway. For the purpose of this assessment it is assumed that construction of this ditch would involve excavation of an average of 65 cubic feet of rock per foot of ditch. The total volume would be 48,750 cubic feet or 1380 m^3. The cost would be $16,500.

- If we allow $500,000 for grouting, $1,000,000 for additional bulkheads and $1,000,000 for covers, then the total cost of this option is estimated at $8,167,000.

2.12.3.3 Removal From The Mine Options

- Several options exist for removal of the arsenic trioxide from the mine and either processing it into a product, converting it into a stable material or placing it in a secure storage facility which is specifically constructed for the material.
- Removal of the arsenic trioxide would require entering the storage chambers and excavating the material which may be loose, settled into a dense (i.e.; non-flowing) condition or a wet paste.
- Removal of all of the arsenic trioxide would likely require washing of the walls of the chambers as well as manual excavation of the material from the corners of the chambers.
- Due to the solubility of arsenic trioxide, attention to water management would be essential to ensure that the water treatment system could handle the load and to prevent release of high arsenic water into the mine workings.
- It will be extremely difficult to remove a sufficiently high percentage of the arsenic trioxide such that there is no requirement for closure measures for the remaining quantity which is left in the chambers. The arsenic trioxide is contained in chambers excavated by drill and blast methods in rock. These are not smooth walled chambers, they have the texture of broken rock and pockets and cracks associated with natural fissures in the rock and holes where loose rock fell out during mining. Due to the high solubility of the material, removal of more than 99% would be necessary in order to not exceed water quality objectives.
- Based on the assessment in the "do-nothing" option, we can assume that release of arsenic may occur at up to three orders of magnitude above permissible levels, or at about 500 mg/l in the water overflowing from the mine (if there were no control measures for the remaining 1%). If only 1% of the arsenic trioxide were left in the chambers and the bulkheads were re-established to achieve a permeability equivalent to the surrounding rock, it would take about 300,000 years to remove the residual dust at 500 mg/l. *It can be concluded from this that; even if a removal option was selected, it would still be necessary to employ one of the options for containment in-place for the residual 1%.*
- The report by Dillon Consulting Ltd. (Dillon) presents an evaluation of the potential for removal of the arsenic trioxide to be upgraded into a high purity product for sale into the pesticide market.

- The Dillon report suggests that the marketable value of the material (sale of arsenic trioxide and recovery of gold) could gross about $202 million (gold = $40 million & arsenic trioxide = $162 million). This is based on the average import price into the USA in 1996. The potential revenue indicated in the Dillon report appears to be based upon recovery of 100% of the metals, which is optimistic.
- The Dillon report appears to be optimistic in the rate at which arsenic trioxide could be recovered and sold. The inventory at the Giant Mine is roughly 10 times the annual consumption in the USA (28,000 tons/yr.) and about 7 times the world consumption. Processing of the 260,000 ton inventory over the suggested twenty years would result in nearly a 100% increase in the market supply of the material and presumably a significant reduction in the market price. Consequently the revenue from sales would be much less than indicated above. Alternatively, sale of the material at a rate equal to 10% of the current demand (such that a high price could be obtained) might require nearly 100 years to remove all of the material.
- The Dillon report estimates that the cost of treatment and transport of high purity arsenic trioxide is $214 to 270 million, depending upon truck or rail transport, as some combination of these would likely be required the final cost may be $242 million. The cost of removal of the material from the chambers, maintaining the underground mine (ventilation, dewatering, mine rescue, etc.) and disposal of the arsenic rich residue (22% of 260,000 tons = 57,000 tons) would be in addition to these costs.
- The net cost of removal and recovery of the arsenic trioxide would be at least $40 million, and with other costs (removal @ $25/ton, on land disposal of 57,000 tons @ $750/ton, and mine maintenance at $10/ton) added in, the total cost could be possibly as much as $90 million.
- Other options for removal of arsenic trioxide dust from the mine were identified by Dillon. All of the feasible technologies cost more than $200 million except for cement stabilization.
- The cement stabilization cost is typical of the cost for stabilization of heavy metal contaminated material such as fly ash. The application of this technology and the associated cost should be reviewed in detail as the technology may not be applicable to the conditions at the Giant Mine. It should be noted that arsenic solubility increases with pH and cement stabilization without other containment measures may not fully address the problem.
- In US EPA report "Best Demonstrated Available Technology Background Document", 1988 (as referenced by J. Conner in Chemical Fixation and Solidification of Hazardous Wastes, 1990) leaching rates of 2 to 3 mg/l were obtained in laboratory tests on cement stabilized waste containing up to 11,500 ppm arsenic trioxide. The arsenic trioxide at Giant is in the range of 550,000 ppm arsenic.
- Based on the above points, it is our opinion that while laudable, none of the above options for removal of the arsenic trioxide dust for secure storage or recovery are economically viable and all of the options will require significant measures for long-term control of residual arsenic which will leach from the emptied chambers.
- In the event that the company develops or proposes an alternative removal and recovery technology which is environmentally and economically attractive its viability should be based upon the range of arsenic trioxide and gold concentration which exists

in the current chambers. Any assessment should be based upon conservative market values for these materials as economically induced reclamation of the arsenic trioxide may take up to 100 years. Potential for leaching of residual arsenic trioxide should also be evaluated.

2.12.3.4 Long Term Water Treatment

- Perpetual collection and treatment of the arsenic rich mine water could be employed to provide environmental protection.
- The volume of water may be about 14 igpm and without other measures to reduce the flushing of arsenic from the chambers may have a concentration of at least several ppm.
- Collection, treatment, monitoring, sludge disposal annual maintenance and periodic replacement of equipment may cost about $250,000/yr.
- Financing this cost in perpetuity could be achieved with a fund which provides sufficient return on investment to maintain the fund and pay the annual operating costs. The portion of the interest which would be applied to the annual operating costs is called the real rate of return. The long-term real rate of return is between 2.5 and 3.5% of the original fund amount. Based on a real rate of return from an investment of 3%, the net present value of this option is about $8,300,000. This amount would be required in cash so that the fund for perpetual operations could be established.
- Sludge disposal will be in addition to this cost and would require construction of a dedicated facility.

A summary of the closure options for the arsenic trioxide, and order of magnitude cost estimate for viable options is presented in Table 1.

TABLE 1
SUMMARY OF CLOSURE OPTIONS FOR ARSENIC TRIOXIDE

OPTION	DESCRIPTION	COMMENTS	ORDER OF MAGNITUDE COST
1	"Do nothing"	not acceptable, excessive release of arsenic	nil
2	Cooling with winter air	unlikely to be effective, would require perpetual effort to maintain ventilation system and mine dewatering	$12,450,000
3	Additional bulkheads	beneficial if existing bulkheads leak, will be difficult to significantly reduce gross permeability around chambers	not effective
4	Grout curtains	beneficial if existing fracture zones intersect chambers, will be difficult to significantly reduce gross permeability around chambers to be a stand-alone option	not effective
5	Ice plugs	unlikely to be effective as a stand-alone option, would require perpetual effort to maintain ventilation system and mine dewatering.	not effective
6	Thermosiphons to induce permafrost	high capital cost, passive long-term solution, periodic maintenance required.	$7,044,000
7	Perpetual mine dewatering	probably insufficient as a single control measure, would be required in perpetuity, cost included in option 2.	not effective
8	Hydraulic isolation	proven concept, could be achieved with drain system around chambers, may require additional bulkheads, no perpetual maintenance, caps on ground surface over chambers may be required to reduce infiltration	$8,150,000
9	Removal, on land storage	very costly, would require significant improvement over secure underground containment to justify risk of removal, would be difficult to remove all arsenic trioxide.	> $200 million (ref. Dillon Consulting Ltd.)
10	Removal, conversion to ferric arsenate	prohibitively costly	>$700 million (ref. Dillon Consulting Ltd.)
11	Removal, gold recovery & preservative product	beneficial in that the liability is completely removed, based on past experience and current gold prices this option seems unlikely to viable, would be difficult to remove all arsenic trioxide.	$40 to $90 million (ref. Dillon Consulting Ltd.)
12	Long-term water treatment	conceptually viable, primary concern is sludge disposal. (not included in this cost)	$8,300,000 + sludge disposal

3. RECLAMATION ACTIVITIES

In addition to the quantities and unit costs of reclamation activities presented in the attached RECLAIM estimate, the following sub-sections present the rational and supporting quantities of work for key items.

3.1 Open Pits

- allow 37,270 m^3 for access control berm, based on 2.5 m high berm with 1 m crest width over a length of 2485 m.,
- block ramps into pits, based on 2.5 m high berm with 1 m crest width over a length of 1140 m.,
- backfill A2 Extension pit, volume is 6250 m^3,

3.2 Quarries & Till Borrow Areas

- revegetation, allow 2.95 ha,

3.3 Underground Mine

- bulkheads in adits and drifts to prevent contamination of pit water, 11 bulkheads required, allow $25,000 each,
- construct cap of reinforced concrete over 4 shafts and 6 raises,
- backfill Brock shaft (76 m^3) and raise by B3 pit (71 m^3),
- remove hazardous and petroleum waste materials from underground,
- cost of water collection and treatment is covered in Water Management section.

3.4 Waste Dumps

- no reclamation activities required, natural revegetation already established,

3.5 Tailings Areas - Old Tailings

It is assumed that maintenance to dams 3 and 8 as recommended by Golder Associates will be conducted as part of the ongoing operation and will not be outstanding at closure.

- Central Pond recontouring of the gully, assuming final slopes of 3H:1V, the volume to be dozed is 520 m length times 9.4 m^3/m on both sides of the gully is 9775 m^3,
- contour South Pond for runoff, allow 8000 m^3,
- construct runoff channel in each pond, allow 366 m^3 rip rap in South Pond, 439 m^3 in Central Pond, and 180 m^3 in North Pond,
- establish vegetation, area to be seeded in each pond is; South - 9.15 ha, Central - 13.26 ha, and North - 29.04 ha, vegetation work is assumed to consist of 300 kg/ha of seed

and 600 kg/ha of fertilizer, and conducted over 3 growing seasons, revegetation of dams is not required,

- flatten slopes on Dams 3 and 11, assume rock is placed along 400 m of dam at 35 m^3 per metre, total volume of rock is 14,000 m^3,
- construct a spillway at Dam 2; this consists of a 100 m long channel in the left abutment, the channel is excavated 3 m deep and with a 5 m base width and then backfilled with a 1 m depth of rip rap, excavation volume is 4200 m^3 and rip rap volume is 1100 m^3,
- the concrete decant in Dam 2 should be filled with concrete, concrete volume is 1.5 x 1.5 x 37 m = 83 m^3, complete filling will require use of tremmie pipe to fill the horizontal section,
- cost of water collection and treatment is covered in Water Management section.

3.6 Tailings Areas - Northwest Tailings

It is assumed that maintenance to Dam 21D, and beach development as recommended by Golder Associates will be conducted as part of the ongoing operation and will not be outstanding at closure.

- establish vegetation, area to be seeded is 45.9 ha, vegetation work is assumed to consist of 300 kg/ha of seed and 600 kg/ha of fertilizer, and conducted over 3 growing seasons, revegetation of dams is not required,
- construct seepage collection dams below dams 21B and 21C, each dam is assumed to be 4 m high with 3H:1V slopes and have a crest width of 3 m, the total crest length of both dams is 30 m,
- construct a seepage collection ditch running into each collection pond, each ditch is assumed to be 1 m deep with 2H:1V slopes and have a base width of 0.5 m, the total length of both ditches is 200 m,
- install pump houses for pump back of seepage water into NW tailings pond for pumping back to the effluent treatment plant,
- construct a spillway at Dam 22B; this consists of a 50 m long channel in the right abutment, the channel is excavated in rock 2.5 m deep and with a 5 m base,
- cost of water collection and treatment is covered in Water Management section.

3.7 Yellowknife Bay Tailings

- construct a rip rap barrier against the tailings, it is assumed to be 2 m high and have a slope of 3H:1V, volume is 450 m^3,

3.8 Baker Creek Tailings

- place a cover of rip rap over the exposed tailings, area to be covered is assumed to be 50 m by 20 and rock is placed 0.5 thick, volume is 500 m^3,

3.9 Mill/Camp/Chemical Storage Areas

- allowance for removal of asbestos cladding and insulation is $400,000,
- concrete quantity in building areas includes 5% of wood or steel area to allow for removal of pony walls, stairs and cracking of basement slabs,
- scarify compact soil around all buildings, 13.5 ha,
- place soil cover over concrete slabs, area is 27,000 m^2 and cover is 0.45 m thick, total volume is 12,590 m^3,
- demolish all buildings and dispose in open pit; building areas area as follow;

COMPOSITION OF BUILDINGS IN SQUARE METRES

AREA	WOOD	STEEL	CONCRETE
MILL & C SHAFT BUILDINGS	6240	2040	307
ROASTER	9096	762	480
A SHAFT	2017	595	102
ICI EXPLOSIVES		595	30
EFFLUENT TREATMENT		678	394
TAILINGS RE-TREATMENT		1487	1227
AKAITCHO	1222	558	60

- it is assumed that the propane tanks will be removed by the owner and that revegetation of this area is covered under the scarify and revegetation allowance in the roads section,
- revegetate scarified and covered areas, total area is 14.8 ha,
- a rock cover over the debris placed in the B1 pit is required, assume area is 7084 m^2 and cover is 1.5 m, total volume is 10,626 m^3,

3.10 Town Site

- remove 25 wooden buildings, average area is about 111 m^2,
- sampling for potentially contaminated soil, allow $1000,

3.11 Roads

- assume that fill for dams, pit backfilling and blocking roads is taken from existing roads, no cost for removal and reclamation,
- scarify and revegetate roads and areas where road fill has been removed, 16.9 ha
- removal of fencing along Highway #4, estimate 4600 m and allow $1/linear metre,
- berms to restrict access into site and tailings impoundments, based on 2.5 m high berm with 1 m crest width over a length of 10 m., 11 berms required for total volume of 1650 m^3.

3.12 Chemicals, Wastes & Contaminated Soils

- waste at NW tailings by Dam 22B is 7190 m^3, assume that burial in B1 pit is less costly than excavation of tailings and burial with the excavated tailings,
- other debris and refuse around site is estimated at 20,000 m^3, assume burial in B1 pit,
- hazardous materials audit, allow $10,000,
- 1000 barrels of arsenic trioxide at NW tailings area should be placed in underground storage chamber, allow $20/barrel for loading, hauling and placement in storage chamber,
- disposal of hazardous chemicals, 10 pallets from underground, 10 pallets of batteries, 60 pallets of chemicals & waste oils from mill and roaster,
- decontaminate mobile and stationary equipment; allow $35,000
- bio-remediate petroleum contaminated soil, allow 5000 m^3,
- remove arsenic contaminated soil to tailings impoundment, allow 135,000 m^2 by 0.3 m thick.

3.13 Water Management & Treatment

- assume that the quantity of water which must be treated before discharge is 50% of annual precipitation on tailings areas and 10% of current underground discharge, volumes to be treated are:
- NW Tailings, 45.9 ha times 0.5 times .265 m/yr. = 60,800 m^3/yr.,
- Old Tailings, 51.45 ha times 0.5 times .265 m/yr. = 68,200 m^3/yr.,
- underground water, 10% of 137 igpm = 13.7 igpm = 27,900 m^3/yr.,
- total volume for treatment is 156,900 m^3/yr. (approximately 8% of current treatment volume),
- Post-closure water treatment would likely require 10% or less of the current hydrogen peroxide supply per m^3 of water. Based on figures supplied by the company our estimated reagent consumption is $0.20/$m^3$ and power is $0.04/$m^3$. Annual labour would be $100,000 and maintenance and replacement of equipment would be $25,000. Based on 156,900 m^3/yr., the annual water treatment cost be $163,000.
- construct a spillway at Dam 1; this would consist of a 100 m long channel in the left abutment, the channel is excavated 3 m deep and with a 5 m base width and then backfilled with a 1 m depth of rip rap, excavation volume is 4200 m^3 and rip rap volume is 1100 m^3,
- the concrete decant in Dam 1 should be filled with concrete, concrete volume is 1.5 x 1.5 x 27.5 m = 62 m^3, complete filling will require use of tremmie pipe to fill the horizontal section,
- upon completion of water treatment a cover should be placed over the precipitate sludges to prevent inadvertent contact with the material and control the rate of release of any arsenic which is eroded or goes into solution, area to be covered is 33,260 m^2, assume cover is 1.5 m depth of rock placed over geo-synthetic (to aid the placement of rock), geo-synthetic is $2.50/$m^2$ F.O.B. Yellowknife, volume of rock is 50,000 m^3,

4. CONCLUSIONS & SUMMARY

The most important aspects of reclamation of the Giant Mine are the long-term seepage from the tailings and the potential for release of arsenic from the arsenic trioxide chambers.

Sulphide reducing bacteria may offer an alternative treatment system for removal of arsenic from mine waters. Arsenic was removed to below detection limits when the pH was between 7 and 8 in laboratory tests (Diaz, M, Consecutive Hydroxide-Sulphide Precipitation Treatment of ARD, June 1997, Fourth Int.'l Conference on ARD). If the company could develop and demonstrate this technology (using the underground workings as a reactor and repository for the arsenic sulphides) and associated costs at the Giant Mine they may be able to reduce the reclamation liability.

Royal Oak Mines Inc. should submit an interim A & R Plan, in accordance with the Water Board's "Guidelines for Abandonment and Restoration Planning for Mines in the NWT" and the Water Board publication "Mine Reclamation in Northwest Territories and Yukon".

There is a significant liability on site regarding the inventory of asbestos insulation and cladding. Royal Oak Mines Inc. should conduct an audit of these materials and submit a plan and a contractor's estimate of costs for removal and disposal of these materials.

Machinery and equipment disposed of on site have the potential for environmental impact if not properly decontaminated. A quality assurance/quality control plan for the decontamination of equipment should be approved prior to starting this work.

It is important for Water Resources, other regulatory agencies, and Royal Oak Mines Inc. to recognize that this report presents a conservative estimate of mine closure costs. It is based upon a single site visit and review of available information. Royal Oak Mines Inc.'s A& R Plan is conceptual only. They may be able to demonstrate that some of the closure measures suggested here are not required or can be reduced in scope, such that the closure cost may be less than estimated here.

There may be reclamation requirements which were not identified or some of the reclamation activities described here may be impractical. Any failure here to identify necessary work or practical measures does not relieve the company of its obligation to the terms of the Water License. This report presents an assessment of the closure liability. It is not a presentation of minimum or recommended reclamation work.

It is Royal Oak Mines Inc.'s responsibility to assess their mine site and then prepare a closure plan which best meets the requirements of the NWT Guidelines for Abandonment and Restoration as well as their corporate needs. Such a plan requires accepted engineering analysis and/or on-site demonstration of the proposed reclamation measures.

The estimated closure cost presented here should be the basis for reclamation security until such time as the company's plan has been submitted and approved.

A summary of the reclamation cost estimate is presented in Table 2. Note that the amount for monitoring and maintenance would be required in cash as part of the reclamation security so that the fund for perpetual operations could be established.

TABLE 2
RECLAMATION COST SUMMARY GIANT MINE

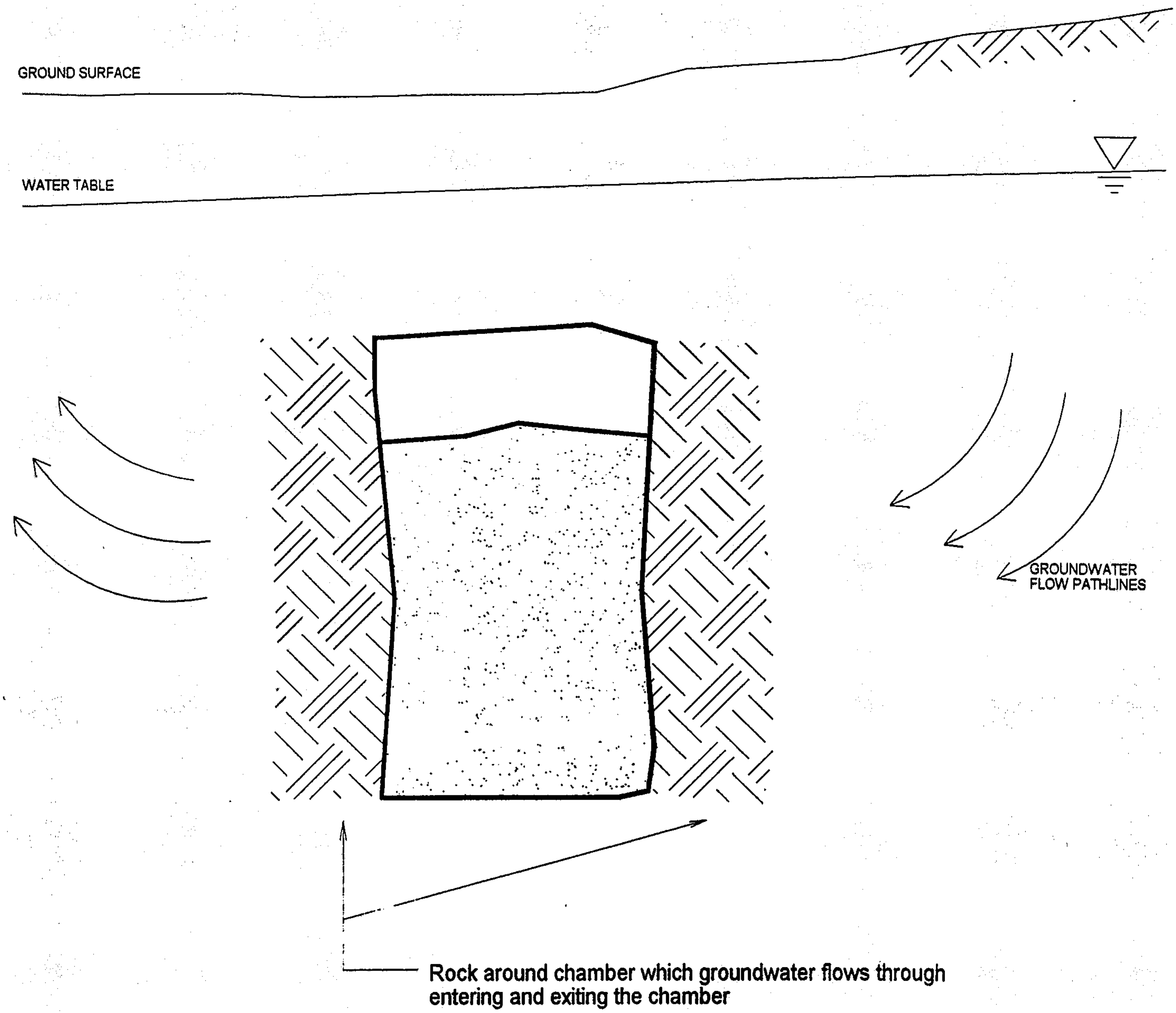
MINE COMPONENTS	ESTIMATED COST
Open Pits	$215,196
Quarries	$3,245
Underground Mine	$365,356
Waste Dumps	$0
Old Tailings Impoundment	$323,015
Northwest Tailings Impoundment	$196,400
Yellowknife Bay & Baker Creek Tailings	$4,864
Mill & Surface Facilities, includes townsite & roads	$1,040,658
Wastes, Chemical & Contaminated Soil	$630,856
Water Management & Treatment	$365,098
Contractor's Mob/Demob	$50,000
Arsenic Trioxide Chambers	$7,044,000
Sub-Total	$10,238,688
Project Management, @ 3%	$307,161
Engineering @ 3%	$307,161
Contingency @ 20%	$2,047,738
Reclamation Research	$250,000
TOTAL - CAPITAL COSTS	**$11,103,009**
Monitoring & Maintenance, annual cost	$300,176
Monitoring & Maintenance, Net Present Value annual payment of $300,176 every year for 20 years; interest =5%, plus 20% contingency	**$4,789,224**
TOTAL RECLAMATION LIABILITY	**$15,892,233**

I trust that this report addresses your current requirements. Should you have any questions please call. I would be pleased to revise this estimate of reclamation liability should additional information become available.

Yours truly,
Brodie Consulting Ltd.

M J Brodie

M.J. Brodie, P.Eng.

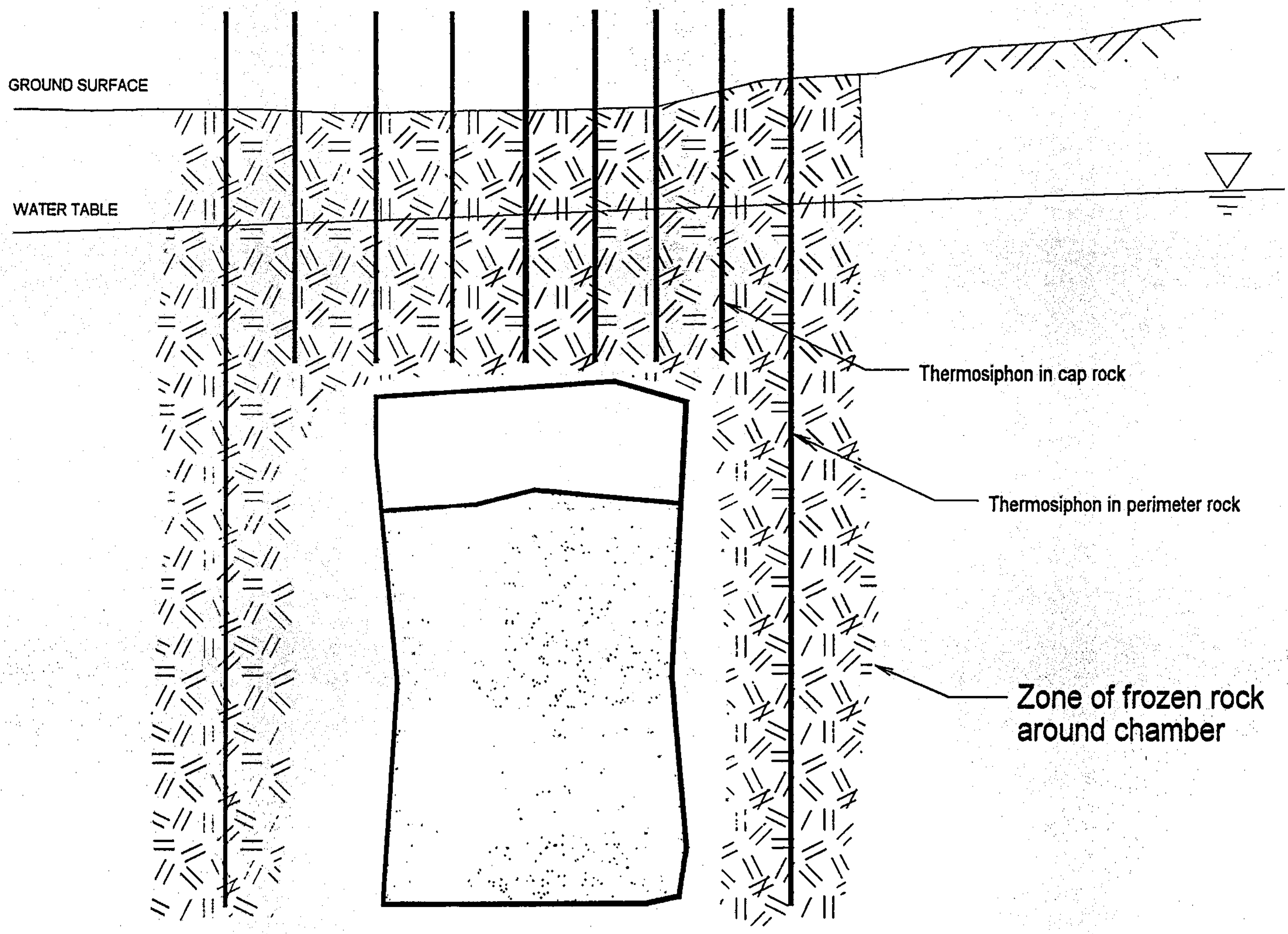


VOLUME OF FLOW, $Q = K \times i \times A$
K = hydraulic conductivity
i = hydraulic gradient or slope of groundwater table
A = area which flow passes through = length (into page) x height

GIANT MINE CLOSURE COST ESTIMATE

GROUNDWATER FLOW IN "DO-NOTHING" OPTION

BRODIE CONSULTING LTD. Figure 1

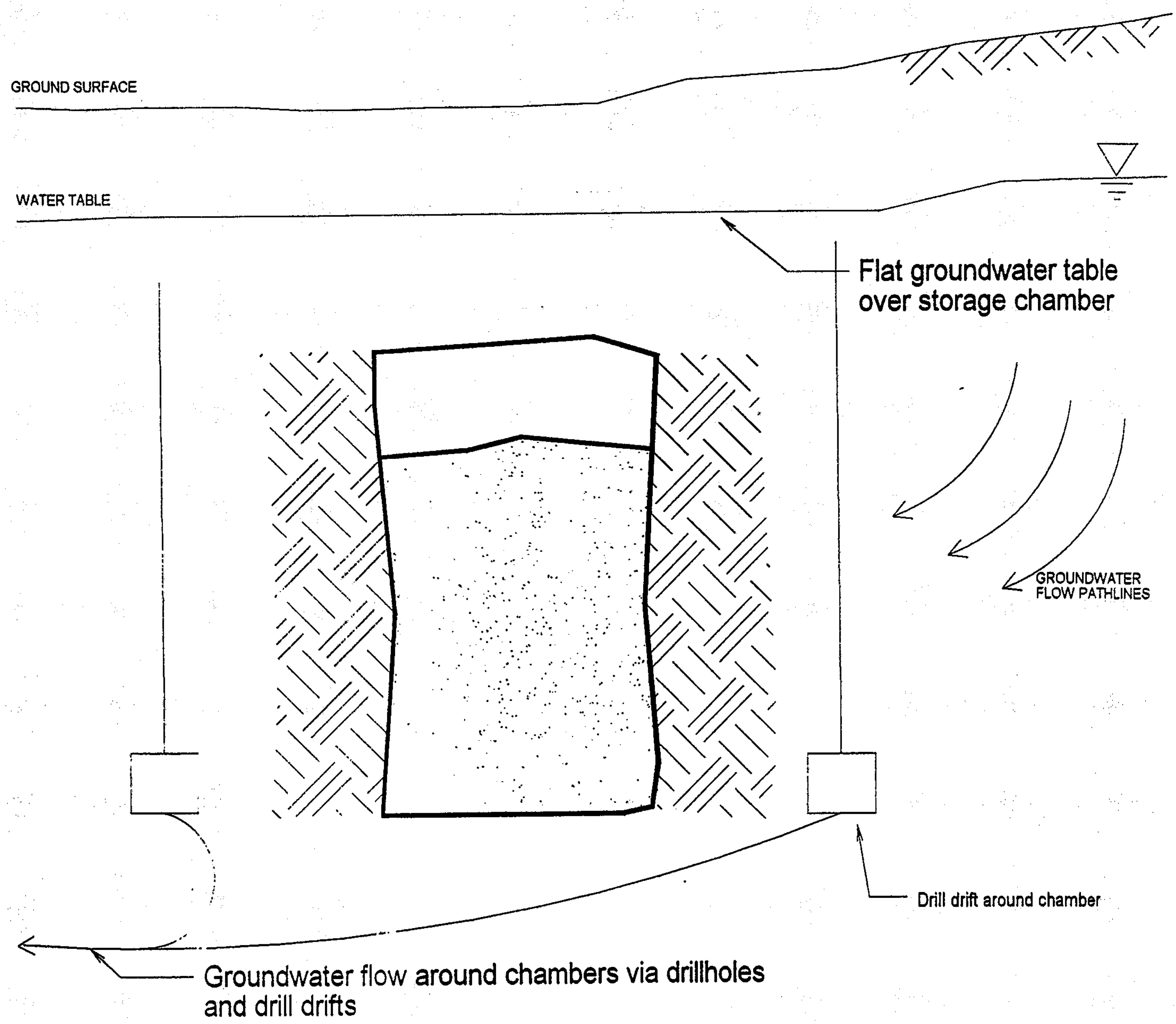


GIANT MINE CLOSURE COST ESTIMATE

GROUND FREEZING WITH THERMOSIPHONS

BRODIE CONSULTING LTD.

Figure 2



GIANT MINE CLOSURE COST ESTIMATE

GROUNDWATER FLOW IN "HYDRAULIC ISOLATION" OPTION

BRODIE CONSULTING LTD.

Figure 3