Indian and Northern
Affairs Canada

Final Report
Arsenic Trioxide Management Alternatives

GIANT MINE

Prepared for:

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GIANT MINE
ARSENIC TRIOXIDE MANAGEMENT ALTERNATIVES
FINAL REPORT

Prepared for:

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EXECUTIVE SUMMARY

In late 1999, the Department of Indian Affairs and Northern Development (DIAND) assumed responsibility for pre-existing environmental liabilities at the Giant Mine. A decision was made to appoint an independent Technical Advisor to assist DIAND in developing a plan for the long-term management of arsenic trioxide dust stored underground at the mine. One of the key objectives set for the Technical Advisor was to analyze a wide range of options and recommend a limited number of alternatives for further consideration by DIAND and other stakeholders. This report and the supporting documents present the results of studies to achieve that objective.

BACKGROUND AND CURRENT CONDITIONS

The Giant Mine, located just north of Yellowknife, in the Northwest Territories, began producing gold in 1948. Gold in the Giant Mine ore is associated with an arsenic-bearing mineral, and the process used to liberate the gold also led to the production of arsenic trioxide dust. During the period from 1951 to 1999, the mine operators collected the arsenic trioxide dust and stored it underground in purpose-built "chambers" and mined-out ore "stopes". The operator of the Giant Mine went out of business in 1999, and the property was transferred to the control of DIAND. DIAND subsequently sold the property to a new operator, but retained responsibility for the arsenic trioxide dust.

Approximately 237,000 tonnes of arsenic trioxide dust is currently stored underground, contained in ten chambers and five mined-out stopes. The chambers have regular block-like shapes, while the stopes have irregular shapes. All of the chambers and stopes are located between depths of 20 to 75 metres below the ground surface. The dust storage areas are sealed off from the rest of the mine with concrete bulkheads.

The arsenic trioxide dust is approximately 60% arsenic, which is hazardous to both people and the environment. Currently, the dust is contained in the underground chambers and stopes, and any escaped arsenic is captured by a water collection system within the mine. The collected water is treated to remove arsenic before it is discharged to the environment.

The environment receiving arsenic releases from the Giant Mine, including Baker Creek, Back Bay and Yellowknife Bay, has been the subject of considerable scientific research since the early 1970's. Numerous studies provide useful data on environmental quality in that time frame, and indicate extensive arsenic contamination. The studies show that major improvements in water quality have occurred since the 1970's, as improved water treatment systems have been installed at the mine. However, lake and creek sediments still contain high levels of arsenic due to historical releases.

ASSESSMENT OF ECOLOGICAL AND HUMAN HEALTH RISKS

A risk assessment was completed to characterize possible human health and ecological risks associated with current and possible future arsenic releases from the Giant Mine and background sources upstream. A wide range of possible future releases was considered, varying from 950 kg/year to 16,000 kg/year. The low end of the range represents the level of arsenic releases expected if the management alternatives under consideration are successfully implemented, and is similar to the current arsenic loads in Baker Creek. The high end of the range represents the maximum releases that could occur if no management measures are in place when the mine is allowed to flood.

The results of the ecological risk assessment suggest that arsenic releases as high as 16,000 kg/year would result in no significant increase in the risk to aquatic plants and fish in Back Bay and Yellowknife Bay. In Baker Creek, even the current arsenic releases, and the lowest anticipated future releases, pose a potential risk to fish. Across the whole range of future arsenic releases considered, and at the level of current releases, there is potential risk to some terrestrial species that could inhabit Baker Creek. The primary source of this risk is the arsenic in Baker Creek sediments, which is linked to historical contamination from the mine.

The human health risk assessment suggests that arsenic release rates of about 4,000 kg/year can result in arsenic intakes that exceed the Health Canada “provisional daily tolerable intake”. At these release rates, the mean intakes would also exceed the typical range of intakes for the general Canadian population.

There are a number of uncertainties associated with the risk assessment methods used. Most of these are likely to overestimate the risks, but some may underestimate risks. Given these uncertainties, the Technical Advisor proposes the level of 2,000 kg/year as a target for maximum arsenic releases from the Giant Mine. That level of arsenic release will result in human health risks below the Health Canada threshold, and will keep the arsenic concentrations in Back Bay at or below the CCME criterion for freshwater aquatic life.

ASSESSMENT OF ALTERNATIVES

The initial efforts of the Technical Advisor identified over fifty technologies that were potentially applicable as part of complete alternatives for long term management of the arsenic trioxide dust. It was therefore decided that a first phase of review would consider a small number of ‘representative alternatives’ involving a limited number of these technologies. The results of the Phase 1 assessment were presented in June 2001. Subsequent dialogue with stakeholders led to modification of the original alternatives, and selection of new alternatives for further review in a second phase.

The Phase 2 assessment led to the development of seven alternatives, A through G, some of which have several variants:

- Alternative A and its variants would rely on long term collection and treatment of contaminated water from the area around the arsenic chambers and stopes.
- Alternative B and its variants would involve freezing of the ground around the arsenic chambers and stopes, then allowing the area to flood slowly so that ice would form around and/or within the chambers and stopes, preventing any further release of arsenic.
- Under Alternative C, the arsenic trioxide dust would be extracted from the chambers and stopes and deposited in specially prepared vaults much deeper in the mine, approximately 700 m below the ground surface.
- Under Alternative D, the arsenic trioxide dust would be extracted from the chambers and stopes, and then shipped off site to the nearest hazardous waste disposal site, assumed to be in Alberta.
- Under Alternative E, the dust would be extracted and put through a fuming process to recover high purity arsenic trioxide and gold. The high purity arsenic trioxide would be sold to American wood preservative manufacturers. This alternative was subsequently dropped from consideration because recent changes to U.S. regulations mean that the use of arsenic as a wood preservative will be severely restricted, and it is unlikely that a future market will exist for the Giant Mine arsenic trioxide.
- Under Alternative F, the dust would be extracted and processed to recover gold and convert the arsenic trioxide to a more stable chemical form known as “scorodite”. The “scorodite” residues would be stored on-site in a secure disposal facility.
- Under Alternative G, the dust would be extracted and then processed to encapsulate the dust in a more stable matrix, such as concrete or bitumen. The “encapsulated” waste would be stored on-site in a secure disposal facility.

All of the alternatives require that a water collection and treatment system be maintained at the site, and that a disposal facility for arsenic residues be constructed either on site or at some other location. As a result of the waste disposal and water treatment requirements, all alternatives will require continued management of the site over the long term (decades). Neither the arsenic itself nor the management problem can be made to "go away".

The costs and risks associated with each alternative have been assessed. Three categories of risk were considered: the risk of arsenic release in the short term, *i.e.* during the preparation or implementation phase of each alternative; the risk of arsenic release in the long term after implementation; and the worker health and safety risks that would be faced during preparation, implementation, and post-implementation activities. The cost estimates took into account capital costs, operating costs over 100 years, and revenue (from gold sales in Alternative F only).

Results of the assessments are summarized in the table below. The "overall risks" shown in the table reflect a combination of the various categories of risk. The approach was to assume that the overall risk for each alternative would be determined by the highest risk, in any category, associated with that alternative. That approach in effect places equal emphasis on the three categories of risk. It should be noted that stakeholders will have different opinions as to how to weight the various risk categories. The cost ranges shown in the table include a conversion of all future operating costs to a net present value.

Summary of Risks and Costs for Phase 2 Alternatives

Alternative	**Overall Risk**	**Dominant Risk Category**	**Net Cost Range ($Million)**
A1. Water Treatment with Minimum Control	High	Long term	30-70
A2. Water Treatment with Drawdown	Moderate	Long term	80-110
A3. Water Treatment with Seepage Control	Moderate	Long term	80-120
B2. Frozen Shell	Low	Long term	90-110
B3. Frozen Block	Low	Long term	90-120
C. Deep Disposal	Moderate	Worker H&S	190-230
D. Removal & Surface Disposal	High	Short term	600-1000
F. Removal, Gold Recovery & Arsenic Stabilization	Moderate	Worker H&S	400-500
G1. Removal & Cement Encapsulation	Moderate	Worker H&S	230-280

RECOMMENDATIONS

Given that segments of the local community have variously expressed reservations both about options that leave the dust in place and those that bring the dust to surface, the Technical Advisor recommends that at least two alternatives be taken through to public consultation. One of the alternatives carried forward should be the best *in situ* (“leave underground”) alternative, and one should be the best *ex situ* (“take it out”) alternative.

The Technical Advisor believes that the best *in situ* alternative is Alternative B3, isolating the arsenic trioxide dust in its current location by creating a frozen block, monitoring in perpetuity, and maintaining isolation by periodic re-freezing. The ground freezing alternatives are generally the lowest risk alternatives, and the frozen block approach has the advantage of being more robust than other variants.

The Technical Advisor believes that the best *ex situ* alternative is Alternative G, dust extraction and encapsulation. The data available to date suggest that using bitumen would better confine the arsenic, thereby resulting in lower long-term risks. However, to our knowledge, bitumen encapsulation has not been applied at this scale. Cement encapsulation, on the other hand, is a well proven technology. The Technical Advisor therefore recommends that DIAND carry forward encapsulation with cement as the preferred *ex situ* variant, but that the development of full scale bitumen encapsulation be further considered if an *ex situ* approach is ultimately selected.

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1. INTRODUCTION

1.1 The Arsenic Trioxide Dust

The Giant Mine, located just north of Yellowknife, NWT, has been producing gold since 1948. In the Giant Mine ore, the gold is associated with an arsenic-bearing mineral known as arsenopyrite. The processes used to liberate the gold from the arsenopyrite also led to production of arsenic-rich gases. During the period 1951 to 1999, operators of the Giant Mine captured the arsenic-rich gases in the form of an arsenic trioxide dust. The dust was then stored underground in mined-out stopes or purpose-built chambers.

Approximately 237,000 tonnes of the dust is currently stored underground, distributed among five mined-out stopes and ten purpose-built chambers. The dust is approximately 60% arsenic, which is hazardous to both people and the environment. Furthermore, the form of arsenic present in the dust is soluble, meaning that it could dissolve in the groundwater around the mine and then be transported to Baker Creek or Great Slave Lake. Development of a long term management plan for the Giant Mine arsenic trioxide dust is the primary subject of this report.

1.2 DIAND’s Role

The Department of Indian Affairs and Northern Development (DIAND) has taken an active interest in the arsenic trioxide dust for many years. In their role as regulator, DIAND staff were instrumental in seeing that the site Water License issued in 1993 included a requirement that Royal Oak Mines Inc., at that time owner of the property, prepare a “Project Description” for long term management of the dust. Since 1997, DIAND has supported workshops and scientific studies directed towards meeting that condition.

Royal Oak Mines Inc. went out of business in 1999, and Giant Mine was conveyed to DIAND. DIAND subsequently sold the property to Miramar Giant Mine Ltd.

However, liability of the Miramar parent group for environmental conditions at the mine was limited to the assets of Miramar Giant Mine Ltd. That limitation means that the federal government effectively retained responsibility for pre-existing environmental liabilities on the property, including the arsenic trioxide dust. Among other things, DIAND assumed responsibly for preparation of the arsenic trioxide Project Description.

1.3 Technical Advisor's Role

In late 1999, when it became clear that DIAND would be responsible for long term management of the arsenic trioxide dust, a decision was made to contract an independent technical advisor. An international competition was initiated for the role

were a team of mining and environmental experts led by SRK Consulting Inc., an international firm with wide experience in mine waste management and mine closure. Other members of the team include three of Canada's top consultancies in these fields: SENES Consultants Ltd., Lakefield Research Ltd. and HG Engineering Ltd. The terms of the Technical Advisor contract specify that members of the team must provide independent technical advice to DIAND, and therefore must exclude themselves from participation in the implementation phase of the project.

One of the key objectives set for the Technical Advisor was to analyze a wide range of options for the arsenic trioxide dust and recommend a limited number of alternatives for further consideration by DIAND and other stakeholders. This report, "Study of Management Alternatives for Giant Mine Arsenic Trioxide Dust", represents a major milestone in that process. It compiles the results of scientific and engineering studies of various alternatives, and it recommends two alternatives that the Technical Advisor believes represent the most attractive options.

1.4 Role of this Report

It is expected that this report will provide the basis for a program of intensive public consultation that will assist DIAND in choosing a single preferred alternative for managing the arsenic trioxide dust. DIAND has been carrying out a public information program related to Giant Mine in general, and the arsenic trioxide dust in particular, since 1999. Representative management alternatives developed in an earlier study have been explained to various stakeholder groups, and supporting information has been provided through a public information video, workshops, a website, and a public registry of Giant Mine documents. The technical recommendations presented in this report will allow DIAND to proceed to the next step of intensive public consultation, which is expected to begin in early 2003.

Feedback from the public consultation will then be presented to senior federal officials, together with the technical reports. The current schedule is to have both the public consultation and technical inputs complete late in the first quarter of 2003. Allowing several months for policy and budgeting issue to be resolved within the federal system, it is hoped that DIAND will be in a position to announce its preferred alternative by mid-2003. That schedule will allow for the arsenic trioxide Project Description to be completed in late 2003.

The process of technical and public review will not end with the preparation of the Project Description. In fact, submission of the Project Description to the Mackenzie Valley Land and Water Board is expected to trigger a review by the Mackenzie Valley Environmental Impact Review Board. That review will include further, probably extensive, public and technical consultation. Should the project be approved by the Review Boards, it would then need to go through a regulatory and licensing process that would probably include further technical review, and possibly further public consultation.

Therefore, the recommendations put forward in this report should be viewed as the first step in a lengthy process. DIAND fully expects that the future public consultation and technical reviews will lead to refinement of the recommended alternatives, and looks forward to receiving input from the many other community groups with an interest in long term management of the Giant Mine arsenic trioxide dust.

1.5 Report Organization

The remainder of this report is organized as follows. Section 2 briefly summarizes the history of arsenic trioxide management at the Giant Mine. Section 3 describes the current situation. Section 4 examines the human health and ecological risks associated with current and possible future levels of arsenic release from the site. Section 5 describes the process used to identify and assess long term management alternatives, and then presents results of the technical assessments. Section 6 presents the Technical Advisor's recommendations. Much of the scientific and engineering detail developed in the study is presented in Supporting Documents 1 through 19. Individual supporting documents are referenced where appropriate in the main report.

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2. PROJECT BACKGROUND

2.1 Project Location and Site Layout

The Giant Mine is located five kilometres north of the city of Yellowknife, Northwest Territories, on the west side of Yellowknife Bay on Great Slave Lake. Figure 2.1 shows the location of the mine and its surroundings.

Yellowknife Bay stretches from the mouth of the Yellowknife River, just north of the site, to the main body of Great Slave Lake approximately 15 kilometres to the south. The portion of Yellowknife Bay known locally as Back Bay is located just southeast of the site, between the south end of the mine property, the City of Yellowknife, and Latham Island.

Figure 2.2 shows surface features of the site. The topography is undulating, with extensive areas of exposed bedrock on the higher ground, and deposits of glacial till and peat in low lying areas. Baker Creek passes through the mine site before discharging into Back Bay. Trapper Creek enters the mine area from the north and flows into Baker Creek. The Ingraham Trail (Highway 4) runs directly through the length of the site. A second public road, known locally as Vee Lake Road, runs through the northern portion of the site.

2.2 Mine Infrastructure

Figure 2.2 also shows major surface infrastructure related to the Giant Mine. The infrastructure covers a footprint of about 500 hectares, dominated by four tailings disposal areas and two water treatment ponds. Smaller but important mine features include the seven open pits, the buildings in the mill area, and the Giant Townsite located on the shore of Back Bay.

The mine workings extend to a depth of about 610 metres (2000 feet) below the ground surface. Figure 2.3 shows a longitudinal section through the underground workings, and Figure 2.4 shows a projection of the underground workings onto a surface map. The thin lines on both figures indicate only the major shafts and tunnels (ramps, drifts, cross-cuts, etc.) that provided access to the ore. The much larger excavations associated with ore removal, called stopes, are generally not shown. Only the mined-out stopes and purpose-built chambers that contain the arsenic trioxide dust are shown. They are highlighted in red.

2.3 Mine History

2.3.1 Overview

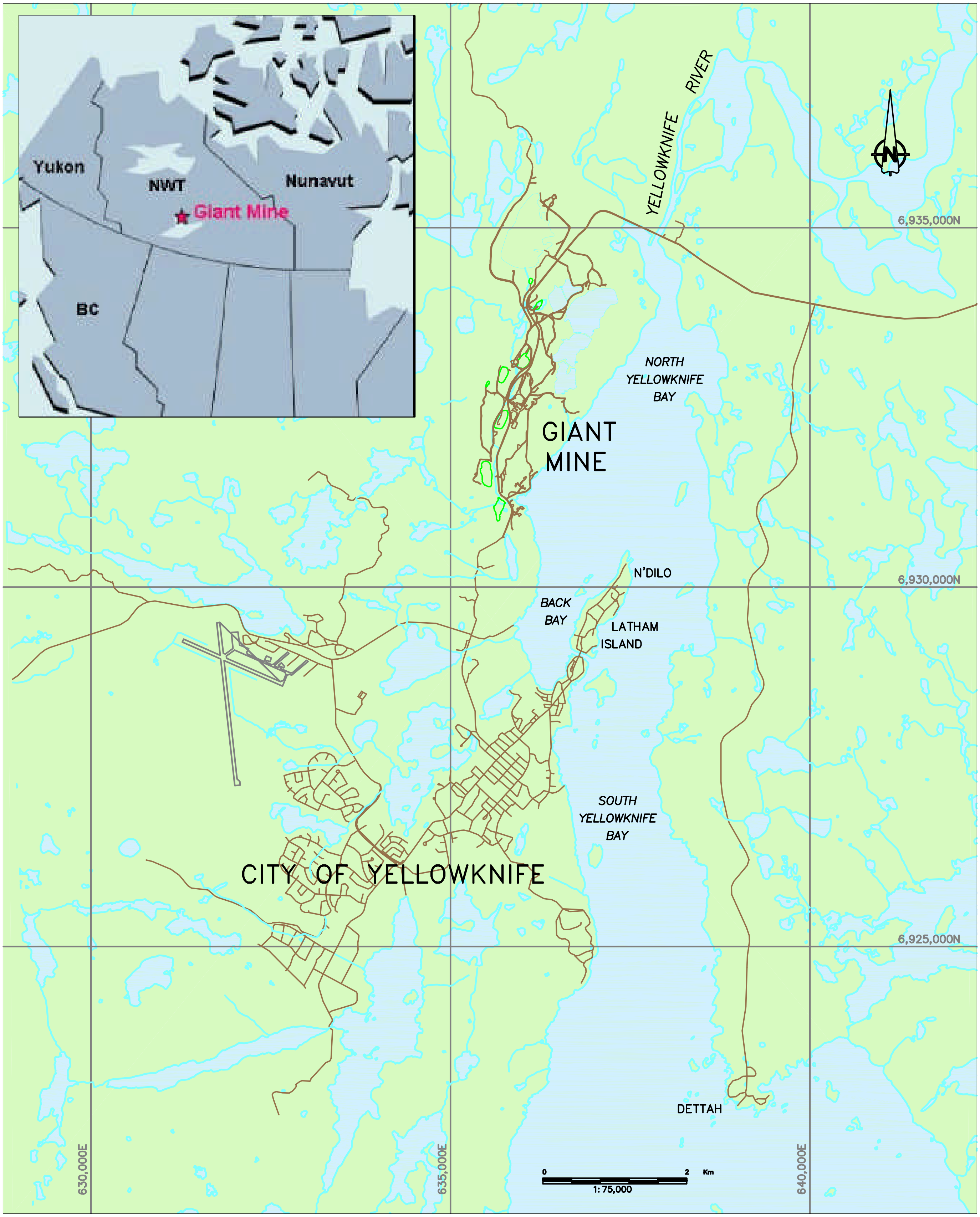
Before the development of mines in the area and the settlement of what is now known as the City of Yellowknife, the land was used by Dene groups, including the Yellowknives and the Dogrib. These people traveled and camped in the area, while harvesting food from the land and the lake. The earliest written records of the area make reference to a semi-permanent Dogrib fishing camp located across Yellowknife Bay, in the area now known as Dettah.

Many histories of the area state that gold colors were first discovered in the Great Slave Lake region in 1896, by miners on their way to the Klondike gold rush. There is concrete evidence that gold was found by prospectors in the Great Slave Lake area at least as early as 1900. In any case, it was not until the 1930’s, with the advent of aircraft travel in the far north, that significant mineral development began. The first mine to open in the present-day Northwest Territories was the Port Radium mine, on Great Bear Lake. It opened in 1933.

The Port Radium development stimulated mineral exploration throughout the area. An interesting historical fact is that the first non-native use of the Yellowknife area appears to have been as a semi-permanent float plane base to serve airborne explorers prospecting the surrounding area. However, it wasn’t long before gold discoveries were made in the immediate vicinity. Numerous claims were staked around Yellowknife in the 1930’s, leading to the opening of the Con Mine in 1938, and the first large-scale gold production in the area. The Yellowknife Administration District was created in 1939.

The original twenty-one mineral claims on which the Giant Mine is located were staked in 1935. Exploration of the property continued until 1944, at which time the decision was made to develop a mine. The first shaft was sunk in 1945, and mine production began on June 1, 1948. Since 1935, the property has seen several ownership and operational changes. Major milestones in the mine history are shown on a timeline in Figure 2.5.

The following summary of the mine history is based primarily on information obtained from a review of the monthly operational reports, written by the Mine Manager, Chief Engineer and Mill Superintendent to the company Board of Directors,



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Giant Mine			
GIANT MINE LOCATION AND LAYOUT			
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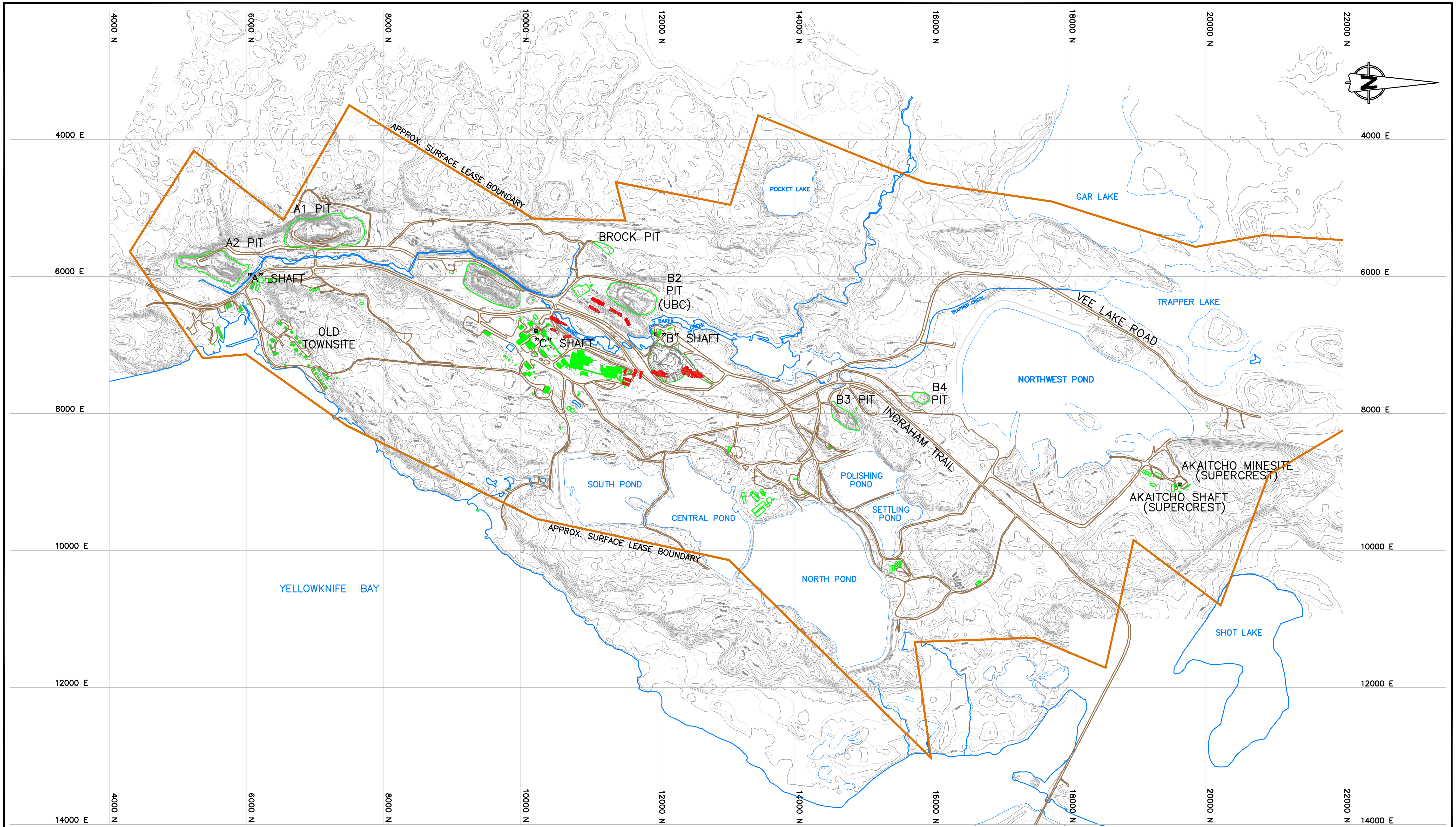

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Giant Mine

GIANT MINE SURFACE FEATURES

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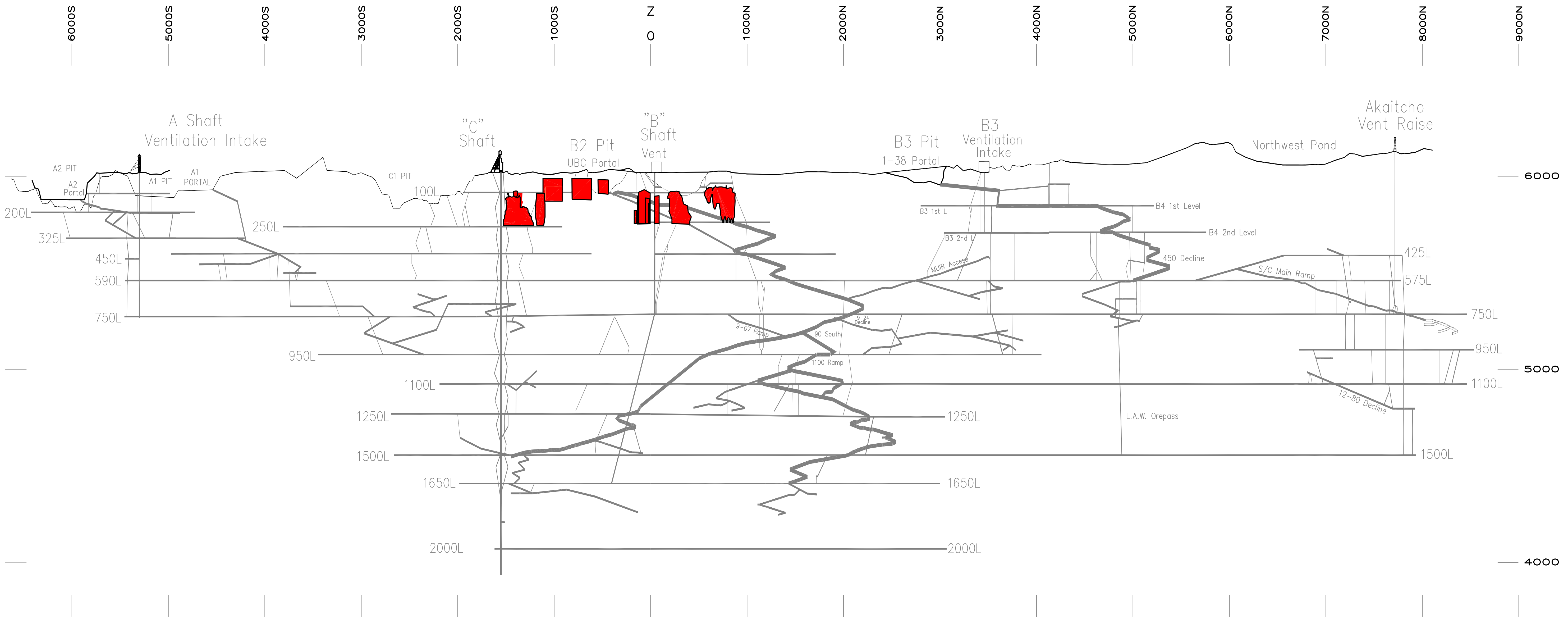

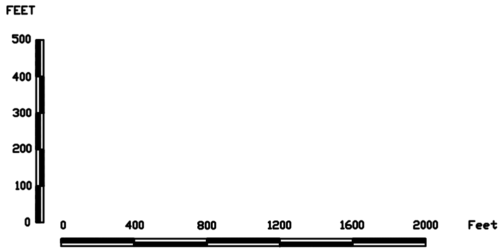

SCALE

NOTE: 2:1 VERTICAL EXAGERATION

LEGEND:

🟥 – LOCATION OF ARSENIC CHAMBERS

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Giant Mine

LONG SECTION THROUGH
GIANT MINE UNDERGROUND

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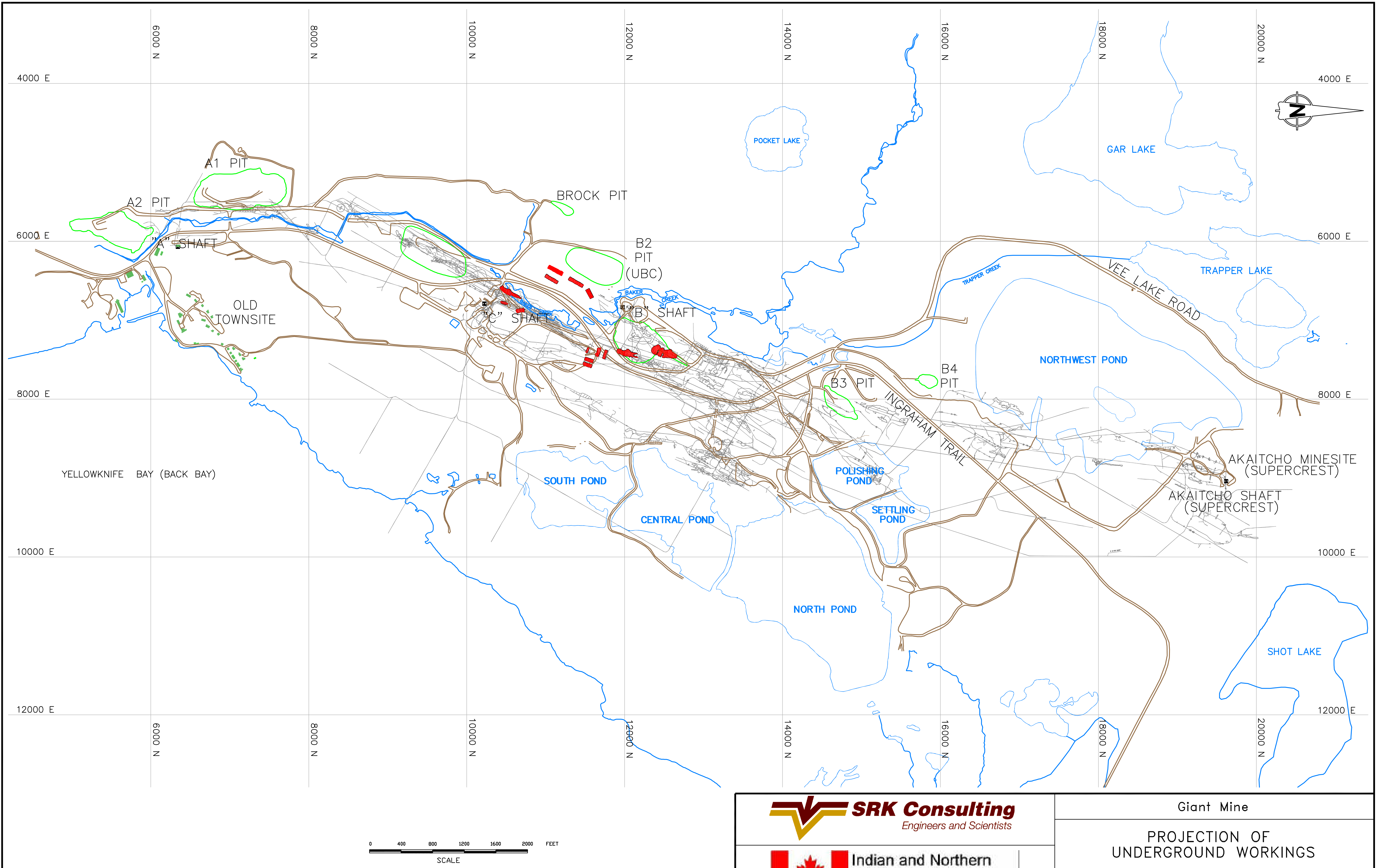

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PROJECTION OF
UNDERGROUND WORKINGS

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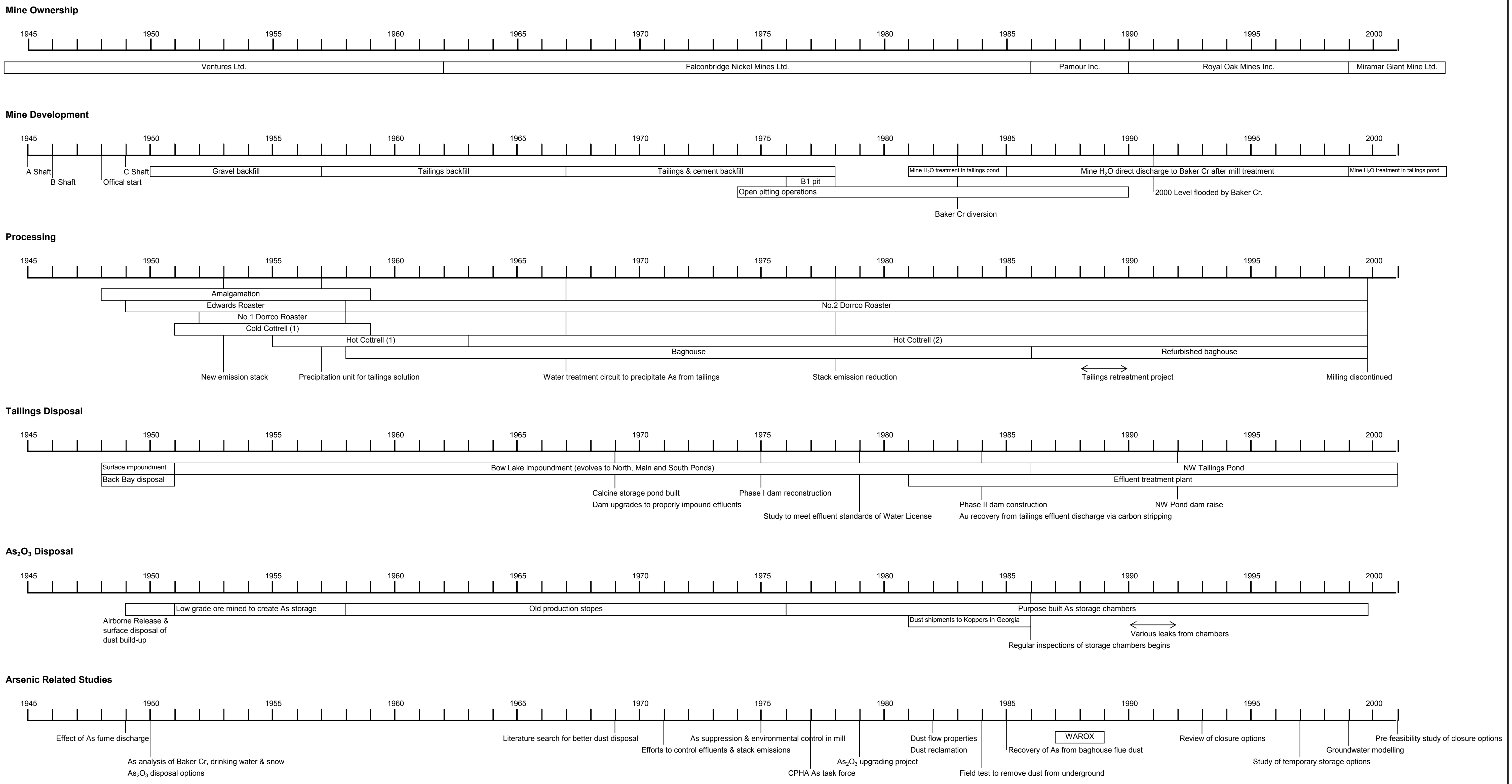

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TIMELINES OF GIANT MINE HISTORY

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and stored in the archives of the Prince of Wales Northern Heritage Center. Additional information was obtained from published papers (Pitcher 1952, Grogan 1953, McDonald 1953, Mortimer and Tait 1959, Foster 1963), from Royal Oak Mines Inc (1998), and from selected correspondence in files located at the Giant Mine.

2.3.2 Mine Ownership

The original claims were staked by Burwash Yellowknife Mines Ltd. in 1935. Giant Yellowknife Gold Mines Ltd. (GYML) was incorporated in August 1937, as a joint subsidiary of Bear Exploration and Radium Ltd. and Yellowknife Gold Mines Ltd., after the latter acquired the assets of Burwash.

During the early 1940's, GYML and Frobisher Exploration Company Ltd. examined the possible geological relationship between the Con and Giant ground via the West Bay fault offset. As a result of this work, Frobisher, which was owned by a company called Ventures Ltd., optioned the remaining treasury shares of GYML in July 1943, and took over management control. Ventures Ltd. remained the property owner until 1962, when it merged with Falconbridge Nickel Mines Ltd..

Ownership changed again in 1986 when Pamour Inc., controlled by Giant Resources Ltd. of Sydney, Australia, bought Giant Yellowknife Gold Mines. Pamour was subsequently bought out by Royal Oak Resources in 1990. In the following year, Royal Oak Mines Inc. was formed to consolidate the assets of Pamour and Royal Oak Resources.

Royal Oak Mines Inc. continued operations at Giant Mine until 1999 when it went into receivership. Control of the property was transferred through a court-appointed receiver to the Department of Indian Affairs and Northern Development (DIAND) in December 1999. In that same month, Miramar Giant Mine Ltd. (a subsidiary of Miramar Mining Corporation) purchased the Giant Mine from DIAND. Under the terms of the purchase agreement, DIAND retained responsibility for all pre-existing environmental liabilities at the site, including the arsenic trioxide dust stored underground.

Currently, Miramar Giant Mine Ltd. (MGML) is continuing to mine ore from the Giant Mine. The ore is being trucked to the Miramar Con Mine, located on the southern edge of Yellowknife, for processing.2.3.3 Mine Development

Underground mine development began in 1945 with the sinking of A-Shaft. A-Shaft was developed to provide access for exploration drilling and to allow development of the East Zone ore body. While the shaft was being developed, surface drilling identified high-grade ore further up the Baker Creek valley. The decision was made to develop the high-grade ore body first and B-Shaft was sunk in 1946 for this purpose. At the same time, the nearby C-Shaft collar was excavated and stabilized prior to mill construction, in anticipation of future development of the South and Central ore zones.

C-Shaft was sunk in 1949 and was connected to A- and B-Shafts via the 750 level by 1952. Once C-Shaft was connected to the major workings, it became the production shaft through which ore was hoisted to surface, and A- and B-Shafts were used primarily as service and ventilation openings.

Three mining methods were initially employed, including cut and fill, shrinkage, and open stoping. The selection of mining method for a particular stope was largely dictated by the shape, size and angle of the ore block. Shrinkage and open stoping were used exclusively until October 1950, at which time cut and fill methods became the preferred choice to develop shallow-dipping ore bodies. In addition to development waste rock, natural gravel excavated on surface was used as stope fill until 1957, at which time mill tailings became the main backfill material. A new tailings backfill preparation plant was commissioned in 1967, and tailings backfilling operations continued until 1978.

Economic ore reserves were practically depleted by the early 1970's. In order to keep the operation going while additional reserves were found, open pit mining began in 1974, with the excavation of A-1 pit, and continued through the 1970's with the development of the A-2, B-2 and B-1 pits. The B-1 pit, which lies close to several of the arsenic storage stopes, was worked from 1976 to 1978. Baker Creek was diverted in 1983 to allow the excavation of the C-1 pit. A total of seven pits were developed until open pit mining ceased in 1990. Since then, ore has been extracted only from underground workings.

2.3.4 Ore Processing

The Giant Mine ore has a complex mineralogy. Most of the gold occurs as extremely fine-grained particles that are "refractory", *i.e.* encased within larger grains of sulphide minerals, principally arsenopyrite and pyrite. An oxidation process is required to convert the dense sulphide grains into porous structures and expose the gold to cyanide leaching solutions. Roasting was the only efficient oxidation process available when the Giant Mine was developed. The ore processing system was therefore designed to concentrate the gold-bearing sulphide minerals using froth flotation, and then to roast the sulphide concentrate in preparation for cyanide leaching.

Ore processing operations began on May 12, 1948, with circuits for ore crushing, grinding, froth flotation, and mercury amalgamation. Initially, the flotation concentrates were stockpiled to await the completion of the roaster facility. Some free gold (gold not encased within sulphides) was recovered by mercury amalgamation in this period.

An Edwards type multiple-hearth roaster, built by Allis-Chalmers, began operation in January 1949. The roaster calcine (oxidized product) was leached with cyanide solution. The gold was recovered from solution by precipitation onto zinc, and the zinc-gold product was smelted in a furnace to produce gold bullion. Gold was recovered using both mercury amalgamation and cyanidation methods until 1959, at which time amalgamation was discontinued.

The Allis-Chalmers roaster had a low capacity and was difficult to operate. Variability in feed rate and sulphide concentration caused major problems, and frequently required the roaster to be shut down and cleaned out. Additional difficulties were experienced with the calcine cyclone collectors. The temperatures at the exit point from the roaster were low enough that arsenic gases condensed, forming arsenic trioxide deposits that tended to plug the collector. Arsenic trioxide condensation also created difficulties in the roaster emission stack, where dust build-up caused operating problems.

Soon after roasting operations began, fluo-solids roasters were introduced to the market. Testing of Giant ore with the new roaster technology demonstrated that the best gold recovery could be achieved using a two-stage roast, where arsenic is eliminated in the first stage under reducing conditions, followed by an oxidation stage at a higher temperature. A two-stage fluo-solids roaster (known as the No. 1 Dorrco) was commissioned and put into operation in May 1952, when mill tonnage was increased from 425 tons per day to 700 tons per day. The No. 1 Dorrco initially operated in parallel with the Allis-Chalmers roaster. The company experimented with operating parameters for the No. 1 Dorrco for a couple of years in an effort to obtain a good compromise between gold extraction and electrostatic precipitator efficiency. This experimentation ended in 1954, when the roaster was operated to optimize extraction, and arsenic dust collection was addressed as a separate issue (see Section 2.4.1 for further information on arsenic fume management).

Mill tonnage was increased again in 1958, to 1000 tons per day. At the same time, the ore being mined became increasingly refractory. To cope with both of these changes, a new fluo-solids roaster (known as the No. 2 Dorrco) went into operation in November 1958, replacing the two other roasters. After an initial optimization period, the No. 2 Dorrco proved to be a much more efficient and reliable roaster. The No. 2 Dorrco roaster remained in operation until ore processing ceased at the end of 1999.

2.3.5 Tailings and Water Management

Tailings disposal began in 1948 with discharge directly into Back Bay. Beginning in February 1951, calcine and flotation tailings were deposited in Bow Lake, located in the approximate area of the current North Pond. Dam construction appears to have begun in 1955 with Dam 1. In 1957, this dam was raised and Dam 2 was constructed. The construction date of the dams creating the North, Central and South ponds was not well documented in the monthly operation reports. However, it is known that Dams 3 through 11 were constructed and improved from 1958 through 1986. These dams were generally numbered in the chronological order of their construction.

A storage pond was built in 1969 to store calcine tailings for summer re-processing in a kiln plant. The site of this storage pond is located northwest of the B-1 pit, in an area now covered with overburden soils removed from the pit.

The Northwest Pond was commissioned in 1987 to serve as an impoundment for tailings recovered from the North and Central Ponds, and processed in the Tailings Retreatment Plant (TRP), as well as new tailings from conventional ore processing. The relocation of tailings from the old storage area was discontinued in 1990 when the TRP shut down, while the deposition of new tailings in the Northwest Pond continued until milling operations ceased in 1999.

Arsenic removal from the tailings effluent apparently began in 1957, when mine records indicate that a precipitation circuit was put into service. A new water treatment circuit was commissioned in June 1967, using lime to precipitate arsenic from the mill tailings stream before it was discharged to the active tailings pond. The precipitated arsenic was co-disposed with the mill tailings in the active tailings pond.

In 1978, as a condition of a new Water License, the mine owner was committed to improving the quality of effluent released to the environment. After conducting pilot testing in collaboration with Environment Canada, a new tailings effluent treatment plant started operating in August 1981. The new plant destroyed cyanide by alkaline chlorination, precipitated arsenic through the addition of ferric iron, and precipitated heavy metals with lime. Gold recovery from tailings effluent with carbon adsorption began in 1984. The chlorination stage of the treatment process was replaced by hydrogen peroxide oxidation in 1990.

Up until 1981, water pumped from the mine was discharged directly to Baker Creek near C-Shaft. Minewater was not used in the mill process, since the water quality had a negative effect on froth flotation efficiency. A 1981 requirement to treat minewater in the tailings effluent treatment plant led to the practice of storing minewater in the tailings ponds prior to treatment. The addition of mine water to the tailings ponds significantly reduced the available tailings storage capacity. To help avoid this problem, in 1985 the Water Board approved the treatment and discharge of mine water directly to Baker Creek via the mill, but this option was never implemented. In 1997, a minewater treatment circuit was installed in the mill, allowing the treated water to be used in the mill process, and reducing the consumption of fresh water. Since 1999, when the processing of ore at the site was discontinued, minewater has been pumped to the Northwest Pond for storage, and then treated in the existing water treatment plant prior to discharge to Baker Creek during the summer months.

2.4 Arsenic Trioxide Management History

As previously described, most of the gold in the Giant Mine ore is encased within larger grains of sulphide minerals, principally arsenopyrite and pyrite. The roasting process, used to oxidize the sulphide minerals and expose the gold prior to cyanide leaching, produced two major off-gases; sulphur dioxide and arsenic vapor. Initially, the roaster off-gases were vented directly to the atmosphere, with no recovery of arsenic, but since 1951 several generations of gas cleaning technology have been applied, leading to the production and disposal of arsenic trioxide dust as a waste by-product. Sulphur dioxide emissions were not reduced by any of the gas cleaning circuits installed. Major developments in the management of roaster off-gas and arsenic trioxide are summarized in Figure 2.5, and discussed in the following sub-sections.

2.4.1 Arsenic Fume Management

At the start of roasting operations in 1949, off-gas management was limited to the provision of a stack for release of gases and particulate to the atmosphere, where it was dispersed. The operation initially had regular problems handling the fumes. Fumes entered the roaster building, and numerous worker health problems were reported.

The first study of the effects of arsenic pollution in the Yellowknife area was initiated in May 1949. The results of this study, along with occupational health concerns and roaster operating problems associated with arsenic trioxide condensation, led mine management to the conclusion that arsenic fume emissions needed to be controlled. For this purpose, an electrostatic precipitator (an ESP, known as the “Cottrell Precipitator”) was commissioned in October 1951, and the first large-scale arsenic trioxide production began. The ESP initially operated as a “cold” unit, in which the inlet gas temperature was low enough that the arsenic was present as particulate arsenic trioxide, and was recovered from the gas by attraction to charged electrodes, along with very fine calcine dust carried over from the roaster.

The efficiency of the cold ESP dropped dramatically when the first fluo-solids roaster (the No. 1 Dorrco) was installed in May 1952. The fumes from the new roaster had an acid deficiency, which reduced the electrostatic charge on the dust particles and reduced the ESP collection efficiency. The new roaster also produced a greater load of fine calcine dust in the off-gas. The calcine dust not only overloaded the ESP, leading to higher arsenic trioxide emissions, but also resulted in significant loss of gold.

In an effort to recover the calcine dust separately from the arsenic trioxide, a second ESP was installed in February 1955. This “hot” unit operated above the temperature at which arsenic trioxide would condense, and was placed in front of the cold ESP. The system of passing roaster off-gas through the hot ESP, where calcine dust was recovered, and then the cold ESP, where condensed arsenic trioxide was recovered, worked quite well. However, the collection efficiency of the cold ESP decreased further due to the additional removal of acid in the hot ESP. Sulphuric acid and water vapour were added to the roaster off-gas in an attempt to increase the acidity in the fumes entering the cold ESP, with limited success. Eventually both ESP's were operated as cold units to improve the arsenic collection efficiency while additional research was undertaken.

When the second fluo-solids roaster (the No. 2 Dorrco) was commissioned in 1958, and the mill feed was increased to 1000 tons per day, a baghouse (known as the "Dracco Baghouse") was installed to handle the added arsenic trioxide burden. The baghouse began operating in November 1958, as the sole dust collection device in the system. Once the new roaster was operating efficiently, one ESP was put on-stream as a hot unit, to remove fine calcine dust in advance of the baghouse. After much experimentation aimed at optimizing the operation of the roaster and dust collection system, which was finally completed in 1963, the original cold ESP was converted to a hot unit and was put on-stream in parallel with the other hot ESP. This system, consisting of two hot ESP's operating in parallel, followed by a baghouse, was used until roasting operations ceased in 1999. The final configuration of the roaster and gas cleaning circuits is shown in Figure 2.6.

2.4.2 Arsenic Trioxide Dust Disposal

Arsenic trioxide dust formation was not anticipated during the initial development of the mine. When dust build-up in the stack became a problem, the material was periodically cleaned out and, according to mine records, was disposed of "in a suitable area in the north of the property". According to the records, surface disposal of arsenic trioxide dust occurred in July 1949 and February 1950, but the disposal locations are not recorded in any of the documents reviewed for this project.

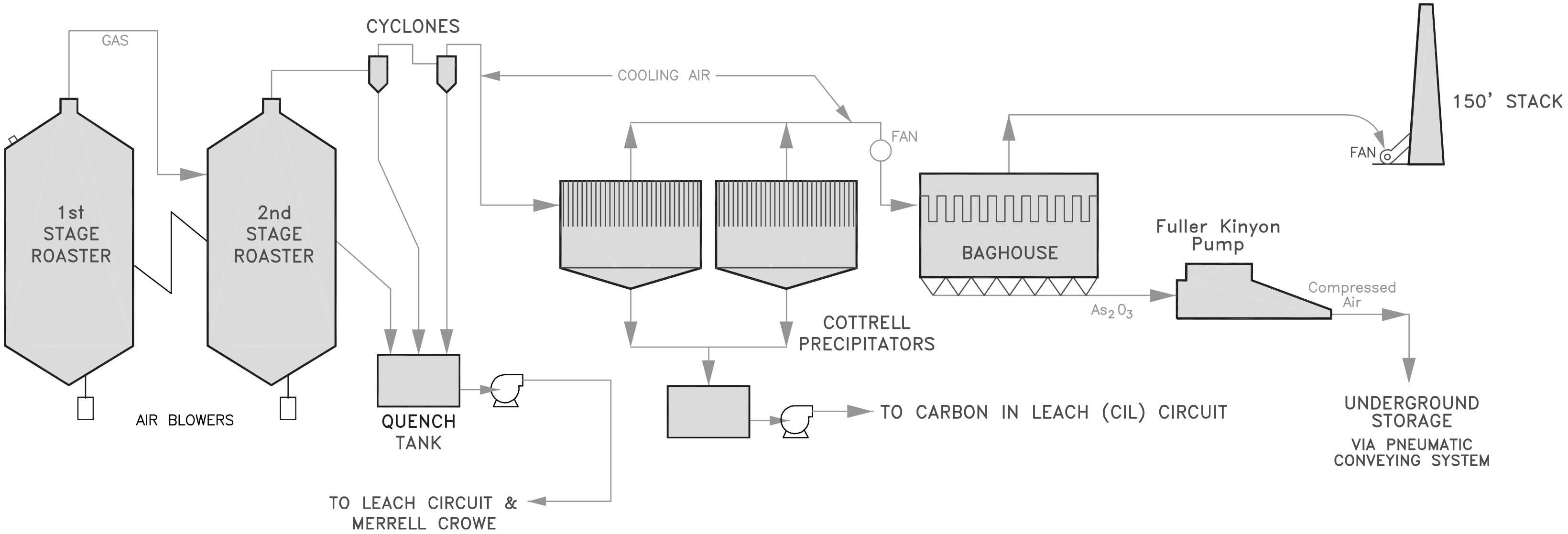
With the first arsenic trioxide dust collection equipment scheduled to be on-line in 1951, the mine operators looked at options for storing the dust. Initial investigations focused on the sand plain west of the Yellowknife airport, and on Veronica Lake (now known as Pocket Lake), northwest of the process plant. The sand plain option was abandoned due to a high water table, and the Department of National Health and Welfare would not consider the Veronica Lake option until much more information was available. The time restrictions were such that sufficient environmental data for the proposed disposal area could not be collected before the arsenic trioxide recovery plant went into operation.

Other options being explored at the time included surface storage tanks and underground storage. In a letter dated July 21, 1950, the Department of National Health and Welfare stated that they regarded the use of concrete vats on surface as the safest method of storage. They also stated, however, they did not want to put mining companies to unnecessary expense and therefore would agree to other storage proposals provided certain criteria were met. The criteria were that the storage would last indefinitely and that a large capacity could be obtained at an economic cost.

Surface storage methods that were considered included wood, steel and concrete tanks. Wood and steel failed to meet the requirement of an indefinite life span. Concrete tanks were long lasting but the required storage capacity was such that a continuous construction program would be required to keep up with the anticipated dust production. It was felt that the amount of form lumber, steel and cement would be an excessively high cost.

An area of ground near the new arsenic recovery plant was selected as a potential underground arsenic disposal area, and was tested for stability and the presence of permafrost. Although not stated explicitly at that time, it is clear that permafrost was to be the principal means by which the arsenic storage areas were to be kept dry, and prevent the dissolution of arsenic in groundwater. Testing of the ground was conducted by drilling exploratory holes from the 250 Level and from surface. From this drilling, it was determined that permafrost was present from above the 100 Level to below the 250 Level, that is, from 100 feet below surface to more than 250 feet below surface. Temperatures in two holes at the 250 Level were -0.5 and -0.4 ^{o}C. The drilling program also showed that there was not excessive fracturing in the rock.

In a February 1951 letter from the Mine Manager to the Department of Resources and Development, in which all the storage options were reviewed and permission was requested to use underground storage for the arsenic trioxide dust, the Manager stated that the proposed storage area was located in permafrost. In addition, he stated that active mining tended to thaw the surrounding walls, but frozen conditions returned within a few hours after work was completed. Ice conditions in the closest working stope (B208) were presented as supporting evidence.



SRK Consulting
Engineers and Scientists

Indian and Northern Affairs Canada

Giant Mine

ROASTER AND GAS CLEANING CIRCUITS

PROJECT NO.	DATE	APPROVED	FIGURE
1CI001.10	December 2002		2.6

FILE REF: Fig 2.6_ROASTGAS.DWG

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The first arsenic storage chambers were located close to the arsenic recovery plant, in the horizon from 100 feet through 250 feet below surface, identified as the permafrost zone. This area contained low-grade ore and was mined for gold recovery. Arsenic trioxide disposal began in this area in October 1951 and continued until 1962, by which time five storage chambers had been excavated and there was little space left for new excavations located close to the baghouse, in permafrost ground.

Arsenic trioxide disposal then switched to the early ore production stopes that met the storage criteria, and were now empty, beginning with the B208 stope. Mined-out stopes had the advantage of requiring less preparation time than purpose-built dust storage chambers, and therefore had a lower development cost. In applying for approval to use the mined-out stopes, B208 and B212, B213 and B214, the mine company emphasized that these areas were dry and located in the same horizon as the existing disposal stopes. Ice crystals were observed in B208, but not in B212. To counter the argument that the warm dust would make any permafrost recede, freezing air was to be circulated in all arsenic storage stopes during the winter months to maintain permafrost in the surface crown pillar, thereby preventing water inflows to the stopes.

In 1966, while considering a proposal for the development of new storage capacity, DIAND recognized that permafrost receded in mine areas that were well ventilated. DIAND questioned whether permafrost was still present at the upper stope level, noting that the proposed new storage area close to C-Shaft was located under Baker Creek, and some of the insulating material had been removed by earlier development. DIAND agreed that the mined-out C212 stope appeared to be a suitable area for arsenic trioxide disposal (it was within the permafrost zone), but requested that rock temperature data be collected to verify that the stope was in permafrost. DIAND objected to the disposal of the dust in stopes located below the lower level of the permafrost zone. Although the mine claimed that these stopes were dry, DIAND questioned whether they would remain dry, if the permafrost in the surface bedrock and overburden became fragmented.

In an internal memorandum of May 1973, the Mining Inspector expressed concern regarding the potential for arsenic pollution from the Giant Mine, if it were to be flooded after a shut-down proposed for 1975, and permafrost was not present. The Inspector presented evidence of permafrost thawing in other mine workings to depths of at least 50 feet, and clearly questioned the continued presence of a permafrost zone at the Giant Mine. He recommended that the mine should not be allowed to flood until the extent and permanency of the permafrost was established through a long-term rock temperature monitoring program. Such a program was not established until the mid-1990's, when temperature measurement devices were installed in several new drillholes.

By the end of the 1970's, there was strong observational evidence that permafrost in the arsenic storage areas was receding and the movement of groundwater in these areas was increasing. The loss of originally present permafrost may have been caused by the progressive development of mine workings near the storage areas and the movement of warm ventilation air. This would have been accelerated by the development of open pits in the area, which removed insulating overburden from the surface.

All former production stopes suitable for arsenic trioxide disposal were filled by 1976. During the 1970's greater emphasis was placed on maximizing the amount of dust storage in existing stopes, to avoid developing new storage areas. Older storage stopes were "topped up" as the dust compacted over time. The possibility of mechanically compacting the material before it was placed in the stopes was investigated. It was also anticipated that future production of dust could be sold, and the mine investigated the purification of arsenic trioxide for sale. In fact, the sale of dust did not begin until 1981. More efficient use of existing storage space did not stop the development of new storage. A new purpose-built chamber, C9, had to be rapidly excavated in 1976 to keep up with dust production.

Raw arsenic trioxide dust from the baghouse was sold to Koppers, a manufacturer of pesticides located in Georgia, USA, from 1981 to 1986. The amount of dust sold was less than the ongoing dust production and underground storage continued throughout the 1980's, with the development of chamber C10, near C-Shaft, and later chambers B11 and B12 in a new area adjacent to the B2 Pit. A downturn in the arsenic trioxide market, and introduction of stricter waste disposal regulations in the USA in the mid-1980's, led to the termination of sales of low-grade arsenic trioxide dust produced by the baghouse.

At this point, it became clear that the arsenic trioxide baghouse dust could only be sold in the future if it was purified, which would require a new process. This option was actively pursued and investigated by the mine owner in the late 1980's, culminating in the detailed feasibility study of an upgrading project, known as the WAROX Project (acronym for the registered trade-name White ARsenic OXide). Interest in implementing the project was lost when the property was sold to Royal Oak Resources in 1990. Chambers B14 and B15 were excavated for arsenic trioxide disposal in the 1990's. Chamber B15 had not been commissioned by the time on-site ore processing ceased in October 1999, and remains empty.

Until the 1980's, standard procedure in the development of dust storage areas was to cut off ventilation of warm air, and to blow cold air through the chamber or stope during the winter prior to first use, to re-establish the permafrost. It was concluded that permafrost was in place if ice or frost was visible on the walls. From the mid 1980's onward, the criteria for selecting suitable areas for development of storage chambers no longer included the presence of permafrost. An area was considered suitable if the rock was competent, the area could be effectively sealed off from other mine workings, and the excavation was generally dry before dust storage commenced. The last four chambers (B11, B12, B14 and B15) were excavated partially above the elevation of the original permafrost zone. In the minutes of a meeting held in December 1995, the Mine Captain noted that in the regular inspections he conducted since 1986, ice was never observed in any of the arsenic chambers or stopes.

All of the underground excavations used for storage of arsenic trioxide dust are listed in Table 2.1, along with the year of their commissioning. The excavations are identified either as purpose-built chambers or mined-out stopes.

TABLE 2.1

Underground Arsenic Trioxide Dust Storage Excavations

Excavation Identification	Excavation Type	Year of Commissioning
B230	Chamber	1951
B233	Chamber	1952
B234	Chamber	1956
B235 / 236	Chambers	1958
B208	Stope	1962
B212 / 213 / 214	Stopes	1965
C212	Stope	1973
C9	Chamber	1976
C10	Chamber	1982
B11	Chamber	1986
B12	Chamber	1988
B14	Chamber	1995

2.5 Previous Arsenic-Related Studies

Numerous arsenic-related studies have been carried out in the Yellowknife area since the Giant Mine started operating. Major studies relating to the arsenic trioxide dust are shown on the timeline in Figure 2.5 and are briefly summarized in the following subsections.

2.5.1 Early Studies

The first arsenic-related study was initiated in May 1949, in partnership with the Con Mine, to look at the effect of roaster fume emissions from the two mines on the Yellowknife district. This study was followed up in March 1950, with the collection and analysis of arsenic in water samples from Baker Creek, the mine domestic water supply, and mine site snow. Partly as a result of these studies, the mine company began assessing various arsenic trioxide emission controls and disposal options in 1950.

The issue of dust storage was revisited several times throughout the 1950's and 1960's, in conjunction with the developments described above. A comprehensive literature search for better arsenic trioxide dust disposal alternatives was conducted in 1969. The federal government stated at that time that they considered Giant Mine personnel to be the experts on this topic.

In 1971, the mine underwent a program to control tailings pond effluents and stack emissions. Physical works began with the upgrading of the tailings dams to properly impound effluents. Work completed in 1975 concentrated on arsenic emissions suppression and environmental control in the mill.

2.5.2 Canadian Public Health Association Task Force

In 1977, a task force was established to assess the effects of arsenic emissions on the population of Yellowknife. The Canadian Public Health Association (CPHA) Task Force on Arsenic consisted of three individuals with backgrounds in medicine, environmental health, and occupational health. The Task Force was charged with examining the issue of “whether or not there is a serious health hazard to the community of Yellowknife as a result of possible arsenic poisoning”. The terms of reference for the Task Force included the review of existing data, the identification of any additional data required, and the task of ensuring that such data were obtained. The Task Force was to recommend any remedial action required to address the issue.

In December 1977, the CPHA Task Force published its report. The report looked at the potential effects in the Yellowknife population of arsenic exposure from soil, water, food and air, as well as occupational exposure. The report made recommendations on issues ranging from food hygiene practices to industrial emissions control measures. With respect to arsenic trioxide management, the report recommended that underground storage of the arsenic trioxide dust at the Giant Mine should continue, pursuant to the requirements specified by the Mining Inspection Branch.

2.5.3 Giant Yellowknife Mines Projects

Between 1979 and 1990, several studies were undertaken by Falconbridge and Pamour, investigating processes to produce purified arsenic trioxide that could be sold into the pesticide manufacturing market. Although a portion of the crude baghouse dust production (about 88% arsenic trioxide) was successfully marketed in the early 1980's, it became clear that a reliable market for the Giant Mine by-product could only be established if the arsenic trioxide content was increased to 95%, or greater. The trade name "WAROX" was registered for the proposed high-grade product.

The processes investigated included hot water leaching and re-fuming of the dust. Hot water leaching had been applied at the Con Mine in the mid-1980's, to upgrade that mine's stockpile of arsenic trioxide roaster residue, with limited success. The re-fuming process was similar to the existing roaster and off-gas cleaning circuit, but would use improved technology and control. By the late 1980's, the fuming process had been selected and extensive pilot plant studies were being conducted.

Although upgrading and finding a market for the ongoing by-production of arsenic trioxide dust was a primary objective of these studies, thereby avoiding the need for additional underground storage, the existing underground dust inventory was also viewed as a potentially valuable asset. In addition to the arsenic, the underground dust contained gold, which could be recovered in the proposed process and sold along with the purified arsenic trioxide. Additional studies were undertaken to assess methods to remove arsenic trioxide dust from the underground storage stopes and chambers, to feed the purification process.

The WAROX project studies were discontinued in 1990, when Royal Oak Resources took control of the mine.

2.5.4 Royal Oak Mines Inc. Projects

Royal Oak Mines Inc. completed an internal review of closure options for the Giant Mine in 1993, the results of which were presented to the Northwest Territories Water Board at a public hearing for the renewal of the mine Water License in that year. Royal Oak proposed to leave the arsenic trioxide dust underground, and to implement measures to limit the contact of groundwater with the dust. The use of permafrost, either naturally or artificially established, was proposed as a means of achieving this objective.

The Water Board renewed the Water License, for a term of five years, but required Royal Oak to develop terms of reference for a detailed study of the proposed arsenic trioxide management measures for mine closure, to implement the study according to the terms of reference approved by the Board, and to provide a comprehensive report to the Board by the end of the License term, in March 1998. Royal Oak developed terms of reference for the study, which were approved by the Board.

From 1994 through 1997, the company made efforts to study the arsenic trioxide management issue. These included a detailed review of the mine records on underground arsenic disposal, the drilling and instrumentation of six holes to monitor rock temperatures in the arsenic storage areas, and assessment of the conditions of bulkheads and access workings in the arsenic storage areas. However, the original terms of reference for the study were only partially addressed. A summary report on the work completed was submitted to the Water Board in March 1998.

In 1997, Royal Oak advised the Water Board of an interest in the potential to produce a high-grade arsenic trioxide product for sale, as a means of disposing of both the ongoing production of baghouse dust, and the underground dust inventory. Royal Oak engineers conducted laboratory studies of the hot water leach process from late 1997 to mid 1998.

2.5.5 DIAND Projects

In 1997, anticipating Royal Oak's failure to comply with the original terms of reference for the Water License study by the March 1998 deadline, DIAND became more directly involved with the company in addressing the issue. This direct involvement commenced with a workshop held in October 1997, organized jointly by DIAND and Royal Oak, which attempted to develop a common understanding of the problem and potential solutions. The workshop was attended by company personnel, government regulators and invited technical consultants.

DIAND's involvement with the project continued in 1998, with the sponsorship of hydrogeological studies by FracFlow Consultants, studies at CANMET on material properties, leaching and crystallization, and studies at the University of British Columbia on stabilization of the dust using cement and bitumen.

In April 1999, Royal Oak Mines Inc. was placed in receivership. Now working with the Interim Receiver for Royal Oak, but taking a leadership role, DIAND convened a second technical workshop in Yellowknife in June 1999. For this meeting, technical experts were asked to present assessments of potential solutions to the arsenic trioxide management problem, including the establishment of permafrost in the mine by artificial means, the production and sale of a high-grade arsenic trioxide product, the conversion of arsenic to a stable chemical form by pressure oxidation in an autoclave, and the encapsulation of the dust in various stable materials, such as cement, bitumen and glass.

Several studies were commissioned from Royal Oak personnel by DIAND in 1999, including a review of mining methods applicable to the removal of the arsenic dust from the underground chambers and stopes, a review of the arsenic trioxide market, and plans for underground rehabilitation to improve access to the dust storage areas. Studies at CANMET and UBC continued in 1999, and final reports on their work were received in 2000.

In January 2000, DIAND appointed an arsenic trioxide Technical Advisor, consisting of a team of technical experts in all of the major disciplines relating to arsenic trioxide management, led by SRK Consulting Inc. A meeting of senior technical experts from the Technical Advisor team, representatives of DIAND, and the new mine owner, Miramar Giant Mine Ltd., was convened in March 2000. A work plan was developed by the group to obtain additional information required to assess and compare the numerous management alternatives. The Technical Advisor team then carried out or supervised the scientific and engineering assessments described in the work plan. The results of those studies were compiled in a major report issued in May 2001 (SRK 2001a). That report was subsequently presented at a public workshop held in Yellowknife in June 2001.

DIAND set up a hydrogeology experts committee in February 2000, to review the results of earlier studies and prepare recommendations for further work. A second meeting of the hydrogeology experts was held in June 2001, to review the results of the Technical Advisor's studies in that area. Members of the group continue to advise DIAND and the Technical Advisor on the direction of further work.

Since June 2001, DIAND and the Technical Advisor have commissioned a number of additional scientific and engineering studies. A major program to install wells for monitoring groundwater in the mine area was initiated in late 2001. Field testing of a device that could be used to freeze the ground around the arsenic storage areas was initiated in January 2002. An investigation of the stability of bulkheads sealing the dust chambers and stopes was also initiated in early 2002. Other tasks included the continuation of minewater monitoring programs, testing of mine backfill materials for arsenic release, laboratory testing of dust properties and stabilization methods, and completion of a Tier 2 risk assessment to define the human health and ecological risks associated with possible arsenic releases from the site. Many of the products of the 2001-2002 studies are compiled as Supporting Documents to this report.

In addition to the June 2001 workshop, DIAND took several public information initiatives in 2001. These included public focus group studies, open house sessions, and mine tours for members of government and the media. In February and March 2002, DIAND held a series of six community meetings to present the results of the Technical Advisor's work and receive feedback from the community. Public information open house sessions were held at the same time. DIAND is planning to continue public information sessions and to initiate an intensive public consultation program on the basis of the findings presented in this report.

3. CURRENT ARSENIC TRIOXIDE AND WATER MANAGEMENT

3.1 Dust Inventory

The estimated inventory of arsenic trioxide dust stored in each of the purpose-built chambers and mined-out stopes is shown in Table 3.1. These estimates were compiled by the mine operators throughout the period of dust production, from 1951 through 1999. The inventory of dust stored in chambers B230, B233 and B234, up to 1958, was estimated based on the volume of the storage space and the estimated bulk density of the settled dust. After 1958, dust production was calculated on a daily basis, using mass balance methods. Mass balance calculations are usually an accurate means of estimating the weight of process products, and the data are considered to be sufficiently accurate for the purpose of this study.

The inventory shown in Table 3.1 was summarized to the end of 1997 by Royal Oak Mines Inc. (1998), and updated to current conditions by the Technical Advisor. Dust production from 1998 and 1999 was taken from mine records.

TABLE 3.1
Inventory of Arsenic Trioxide Dust Stored Underground at Giant Mine

Chamber / Stope	Dust Inventory (dry tonnes)
B230	2,835
B233	11,426
B234	12,048
B235 / 236	33,112
B208	29,364
B212 / 213 / 214	59,289
C212	16,946
C9	18,394
C10	9,569
B11	5,860
B12	26,243
B14	12,257
Total	237,343

Prepared by: SRS

3.2 Dust Properties

3.2.1 Data Sources

The physical and chemical properties of the arsenic trioxide dust have been assessed in several studies conducted over the past twenty years. The most important of these studies are:

- Routine gold and arsenic assays by the mine staff;
- Geocon Inc. (1981) – Sampling of underground dust and testing of geotechnical properties;
- Giant Yellowknife Mines Ltd. (1981) – Analysis of arsenic and gold content of Geocon (1981) samples;
- Jenike & Johanson (1982) – Testing of flow properties on Geocon (1981) samples;
- New Brunswick RPC (1988) – Chemical and particle size analysis of current dust production;
- Royal Oak Mines Inc. (1998) – Chemical analysis of current dust production;
- CANMET (2000) – Chemical properties and mineralogy of recent dust production and underground dust samples; and,
- Lakefield Research (2002) – Physical and chemical properties of later dust production.

The results of these studies are presented in Supporting Document 5 and briefly summarized in the remainder of this section.

3.2.2 Physical Properties

The physical properties of the dust have been characterized in the studies by Geocon (1981), Jenike and Johanson (1982), and Lakefield Research (2002). Table 3.2 provides a summary of physical properties reported in these studies.

TABLE 3.2
Physical Properties of Arsenic Trioxide Dust

Parameter	Range
Grain Size	90.8% - 100% <0.045mm
Dry Density	
Maximum	69.1 – 91.1 lbs/ft^3
Minimum	39.7 – 55.6 lbs/ft^3
In-situ	83.7 – 101.3 lbs/ft^3
Specific Gravity	2.59 – 3.79
Atterberg Limits	
Liquid limit	inconclusive
Plastic limit	19% - 24%
Angle of Repose	46° - 58°
Angle of Internal Friction	33° - 35°
Hydraulic Conductivity (at 71.8 lbs/ft^3)	6.7 x 10^{-5} cm/s
Thermal Conductivity	
at 0% moisture	0.093 W/m-k
at 1% moisture	0.100 W/m-k
Freezing point of saturated solution	-0.7°C

Prepared by: SRS
Checked by: DBM

3.2.3 Arsenic and Gold Content

The arsenic trioxide dust product from the plant was assayed for arsenic and gold on a routine basis, generally daily, throughout the production period from 1951 through 1999. The weighted averages of these assays for the inventory of each chamber and stope are shown in Table 3.3. The averages are based on the same sources as were used for Table 3.1.

As described in Section 2.4, the roaster and gas cleaning circuits saw a number of changes during the production period, the most significant of which were changes to the electrostatic precipitator circuits (Cottrells) and the installation of a baghouse. The last major modification was made in 1963, after the B235 and B236 chambers had been filled. The assays show significantly lower arsenic concentrations and higher gold concentrations in the dust produced before this change was made. The estimated total inventory of gold in the dust is 138,500 troy ounces. About 60% is contained in the five oldest chambers, which hold just 25% of the total dust inventory.

TABLE 3.3
Arsenic and Gold Content of Arsenic Trioxide Dust
(Production Assays 1951-1999)

Chamber / Stope	**Arsenic (%)**	**Gold (g/t)**
B230	45.3	24.8
B233	36.9	57.3
B234	36.1	80.0
B235 / 236	53.7	26.3
B208	65.7	12.1
B212 / 213 / 214	61.7	15.5
C212	65.6	5.9
C9	67.5	4.3
C10	66.8	4.6
B11	67.4	4.8
B12	65.9	5.9
B14	65.5	5.5
Inventory Averages	60.1	18.1

Prepared by: SRS

3.2.4 Other Chemical Components

The distinction between “old” and “new” dust is also reflected in the other components, as shown in Table 3.4. “Old” dust in the table is material produced before 1963 and stored in Chambers B230, B233, B234, B235 and B236. “New” dust is material produced after 1963 and stored in the other chambers and stopes.

The analyses confirm that the older dust has a lower arsenic content, but a higher gold content, than the new dust. The concentrations of other elements are also somewhat higher in the old dust, notably antimony, aluminum, calcium, magnesium and silicon.

3.2.5 Arsenic Solubility

Table 3.5 summarizes the solubility of arsenic from the dust in water, at temperatures typical of the present mine waters. The ranges in the table indicate the variability in arsenic solubility, which appears to be at least partially dependant on the antimony content of the samples. Samples with a higher antimony content, which is generally typical of the “old” material, tend to show a lower arsenic solubility.

TABLE 3.4
Chemical Composition of "Old" and "New" Arsenic Trioxide Dust

Parameter	Unit	"Old" Dust	"New" Dust
As	%	46.42	65.31
Au	opt	1.07	0.094
Sb*	ppm	12200	11078
Fe*	ppm	21400	22889
Al*	ppm	9900	7180
Ca*	ppm	6100	4718
Mg	ppm	3600	2078
Si	ppm	19400	6806
Ba	ppm	-	8.5
Be	ppm	-	<0.5
Cd	ppm	-	1.1
Cr	ppm	-	12.6
Co	ppm	-	18.6
Cu	ppm	-	246
Pb	ppm	-	472
Mn	ppm	-	87
Hg	ppm	-	14
Mo	ppm	-	1.9
Ni	ppm	-	43
P	ppm	-	52
K	ppm	-	889
Se	ppm	-	<1
Ag	ppm	-	3.1
Na	ppm	-	288
Sn	ppm	-	<20
Zn	ppm	-	154

* Includes Lakefield (2002) results

Prepared by: SRS
Checked by: DBM

TABLE 3.5
Solubility of Arsenic Trioxide Dust

Solution Concentration	**5°C**	**10°C**
g As_2O_3/L	6.2 - 11.9	7.4 - 12.7
g As/L	4.7 – 9.0	5.6 – 9.6

Prepared by: SRS
Checked by: DBM

3.3 Storage Chambers and Stopes

3.3.1 Locations

The locations of the underground arsenic trioxide storage areas are shown in relation to surface features in the central mine area in Figure 3.1. As discussed in Section 2.4, the dust is stored in both purpose-built chambers and mined-out stopes. For ease of discussion, the chambers and stopes are often referred to as being in four areas, referred to as AR1 through AR4, and also shown on Figure 3.1.

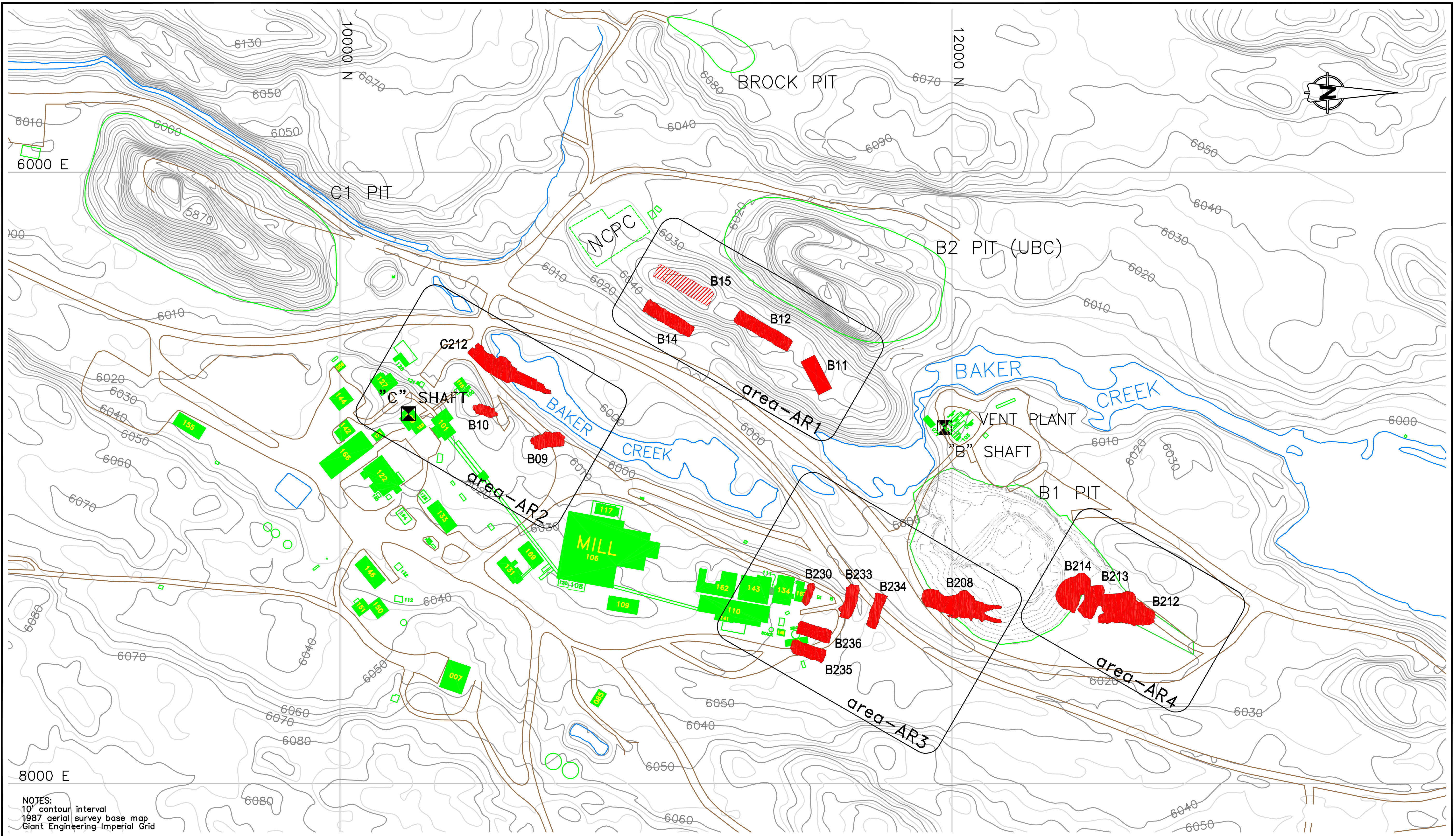
A total of ten purpose-built chambers and five mined-out stopes were used to store the dust, although the stopes B212, B213 and B214 are joined together and can be considered as one excavation. All of the chambers and stopes are located in the central area of the mine, close to the processing plant where the dust was produced. The chambers and stopes are relatively close to the surface, with most of the excavations extending from about 20 metres to about 75 metres below the ground surface.

3.3.2 Geology of the Storage Areas

Supporting Document 1 provides an overview of the structural geology of the mine area in general, and the dust storage areas in particular. In brief, the chambers and stopes used for dust storage are located in a volume of rock that is bounded by three major faults. The major faults do not intersect any of the arsenic storage chambers or stopes, with the possible exception of Chamber B15, which is empty.

The background rock, away from the major faults, is of two types, known as sericite schist and chlorite schist. The sericite schist rocks have particularly well-developed small scale fractures, leading to increased hydraulic conductivity and stability problems. The chlorite schist appears to be more ductile, and therefore is not as fractured.

The B212, B213 and B214 stopes occupy a hinge in a major fold in the sericite schists. The combination of intense fracturing with horizontal orientations mean that this area is prone to instability, as evidenced by the presence of several wall failures. The rock surrounding the other stopes and chambers is generally either chlorite schist or sericite schist where the fractures are oriented close to vertical. These areas are expected to be more stable.



NOTES:
10' contour interval
1987 aerial survey base map
Giant Engineering Imperial Grid

0 200 400 600 800 1000 FEET

SCALE

LEGEND

🟥 CHAMBER OR STOPE CONTAINING ARSENIC TRIOXIDE DUST

▨ CHAMBER EMPTY

File Ref: Site Plan 2002.dwg

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LOCATIONS OF DUST STORAGE CHAMBERS AND STOPES

PROJECT NO.	DATE	APPROVED	FIGURE
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3.3.3 Chamber and Stope Geometry

Three-dimensional views of the chambers and stopes are presented in Figures 3.2 to 3.6, and summary dimensions are shown in Table 3.1. The chambers and stopes vary considerably in dimensions, shape and volume. The chambers, which were excavated for the purpose of storing arsenic dust, are generally shaped like a regular block with vertical walls. Figures 3.2 and 3.3 show the purpose-built chambers in areas AR1 and AR3 respectively.

In contrast, the stopes were originally excavated to follow the ore body and are quite irregular in shape. They are generally narrower than the chambers and have inclined walls. Figures 3.4 and 3.5 show the mined-out stopes in areas AR2 and AR4 respectively. Figure 3.6 shows B208, which is also a mined-out stope, although it is typically grouped with the nearby chambers in AR3. The irregular nature of the stopes means that extensive access workings were developed to allow efficient removal of ore. As a result, there are numerous openings from the stopes into ore chutes, raises and drifts.

TABLE 3.6
Chamber and Stope Geometry

Identification	Excavation Type	Excavation Volume (cubic metres)	Minimum Crown Pillar Thickness (metres)
B230	Chamber	2,294	57
B233	Chamber	12,307	35
B234	Chamber	12,035	22
B235	Chamber	17,896	25
B236	Chamber	15,178	31
B208	Stope	22,847	11
B212	Stope	25,740	9
B213	Stope	9,401	8
B214	Stope	12,403	9
C212	Stope	18,070	9
C9	Chamber	13,337	21
C10	Chamber	5,663	21
B11	Chamber	9,833	21
B12	Chamber	25,485	23
B14	Chamber	12,006	32

Prepared by: SRS
Checked by: DBM

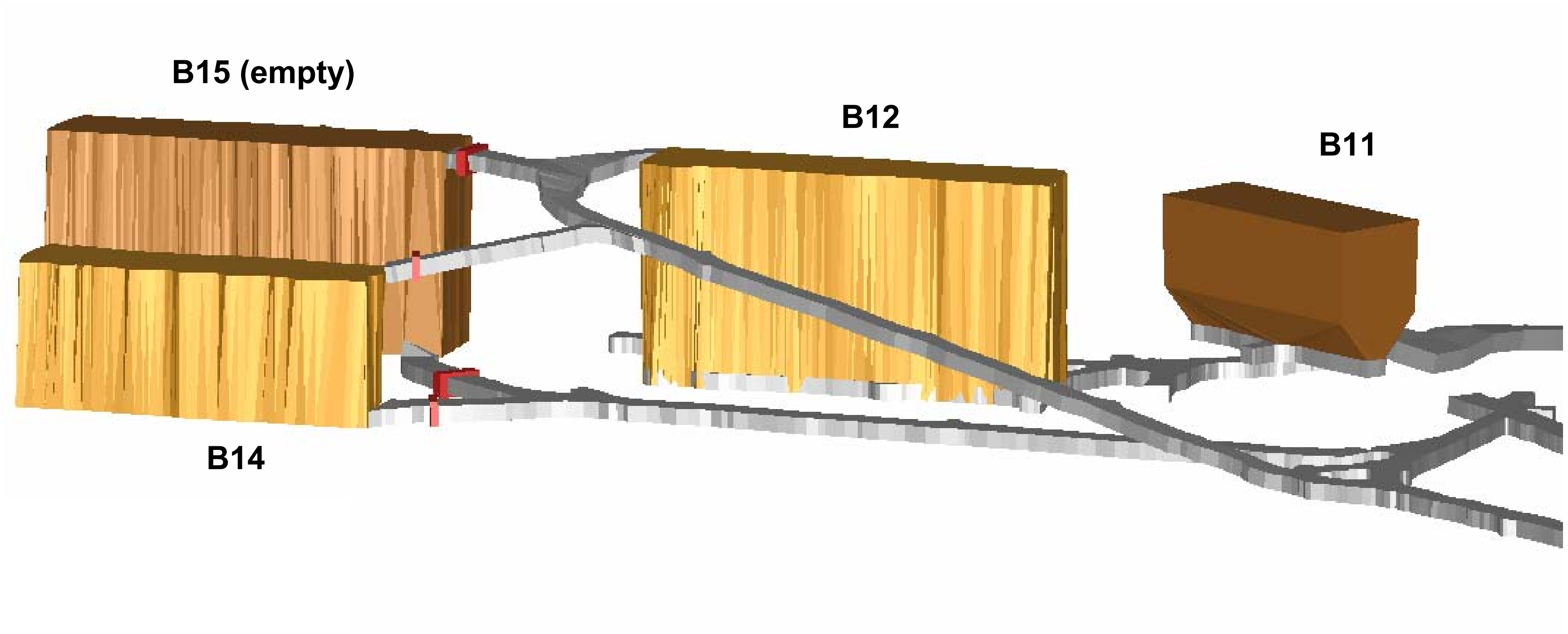
3.3.4 Stability of Stope and Chamber Walls and Crown Pillars

The geotechnical stability of the chambers and stopes used to store the arsenic trioxide was reviewed by SRK (2001b). The convoluted shapes of the stope walls could be a source of instability. Large slabs or wedges of rock on the upper "hanging walls" could collapse into the dust and, in fact, collapses may already have occurred in some areas. In contrast, the chamber walls, being more regular in shape and vertical, are likely to remain stable in the long term. Access workings leading to the chambers are also generally simple, consisting of a small number of regularly spaced draw points at the base and a dust distribution drift across the top.

The "crown pillar" is the bedrock directly above the roof of a chamber or stope. The thickness of the crown pillar (from the roof of the excavation to the contact with overburden above), relative to width of the excavation, is a critical factor in the stability of the pillar. No detailed investigation of the crown pillars above the arsenic chambers and stopes has been completed. The chambers all have relatively thick crown pillars, and failures appear to be unlikely. The crown pillars above the stopes are not as thick, and their long-term stability may be a concern. In particular, the excavation of the B1 pit adjacent to stopes B208 and B214 appears to have created areas where the crown pillars (and stope walls) are thin and fractured.

3.3.5 Bulkheads

Before being commissioned for arsenic trioxide dust storage, all access workings leading to each chamber or stope were sealed with bulkheads to prevent the escape of arsenic trioxide dust. A total of 61 of these bulkheads remain in service, of which 26 are located near the bottom of the excavations. The stability and potential for a build-up of water pressure behind some of these bulkheads is a source of concern, and is the subject of ongoing investigations (SRK 2001c, Klohn Crippen 2002). Many of the bulkheads cannot be accessed, and their condition is unknown.



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PURPOSE-BUILT CHAMBERS IN AR1

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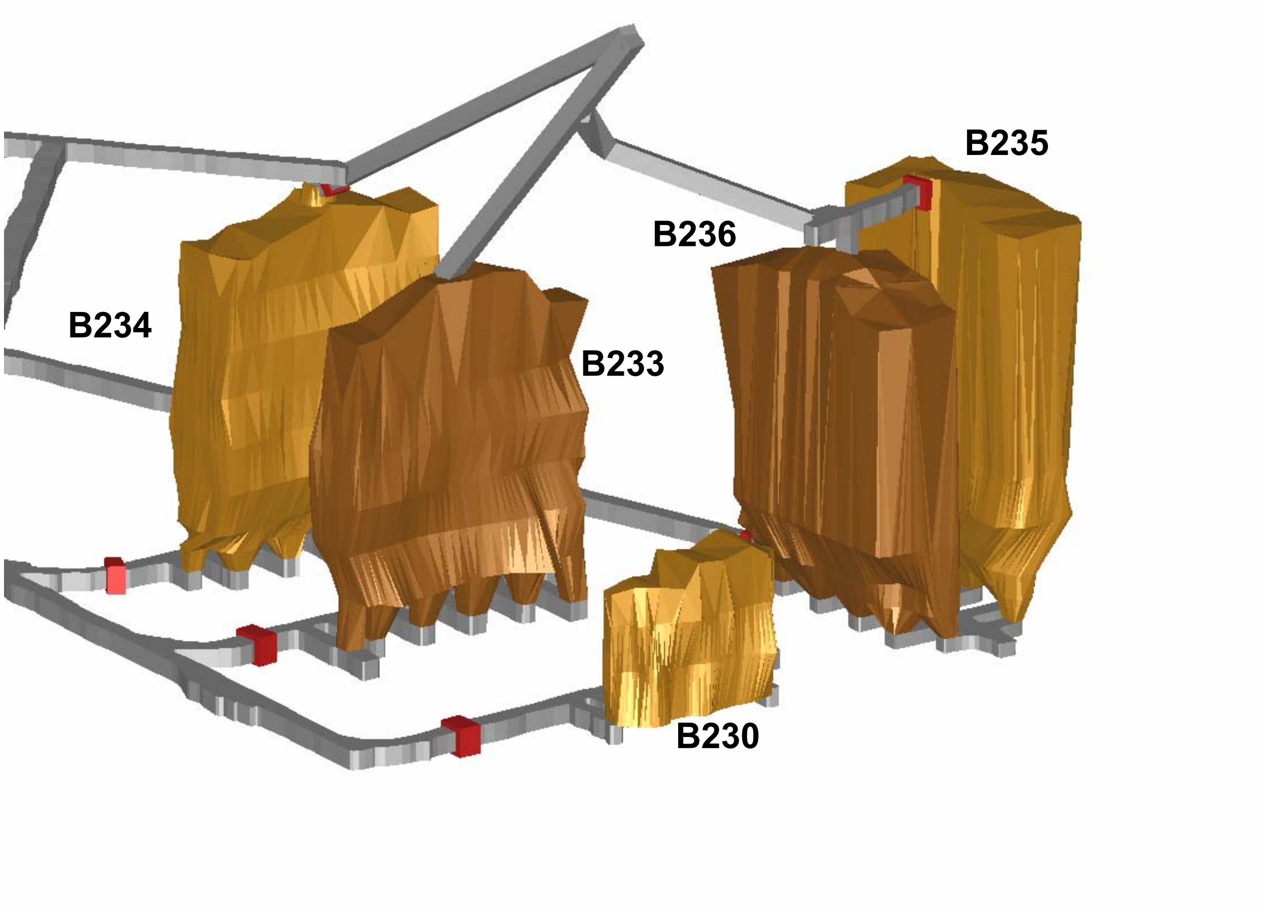

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PURPOSE-BUILT CHAMBERS IN AR3

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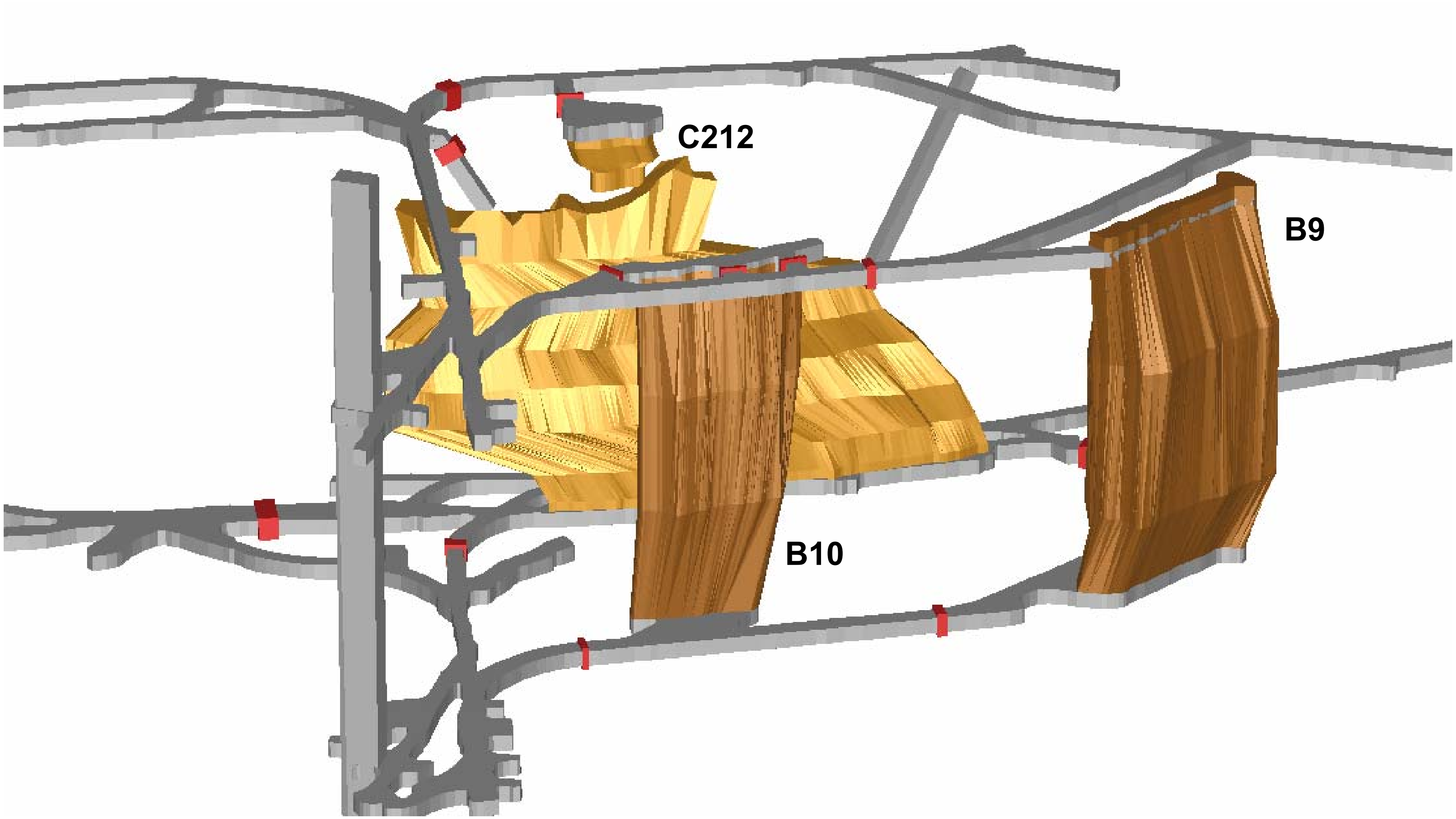

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MINED-OUT STOPES IN AR2

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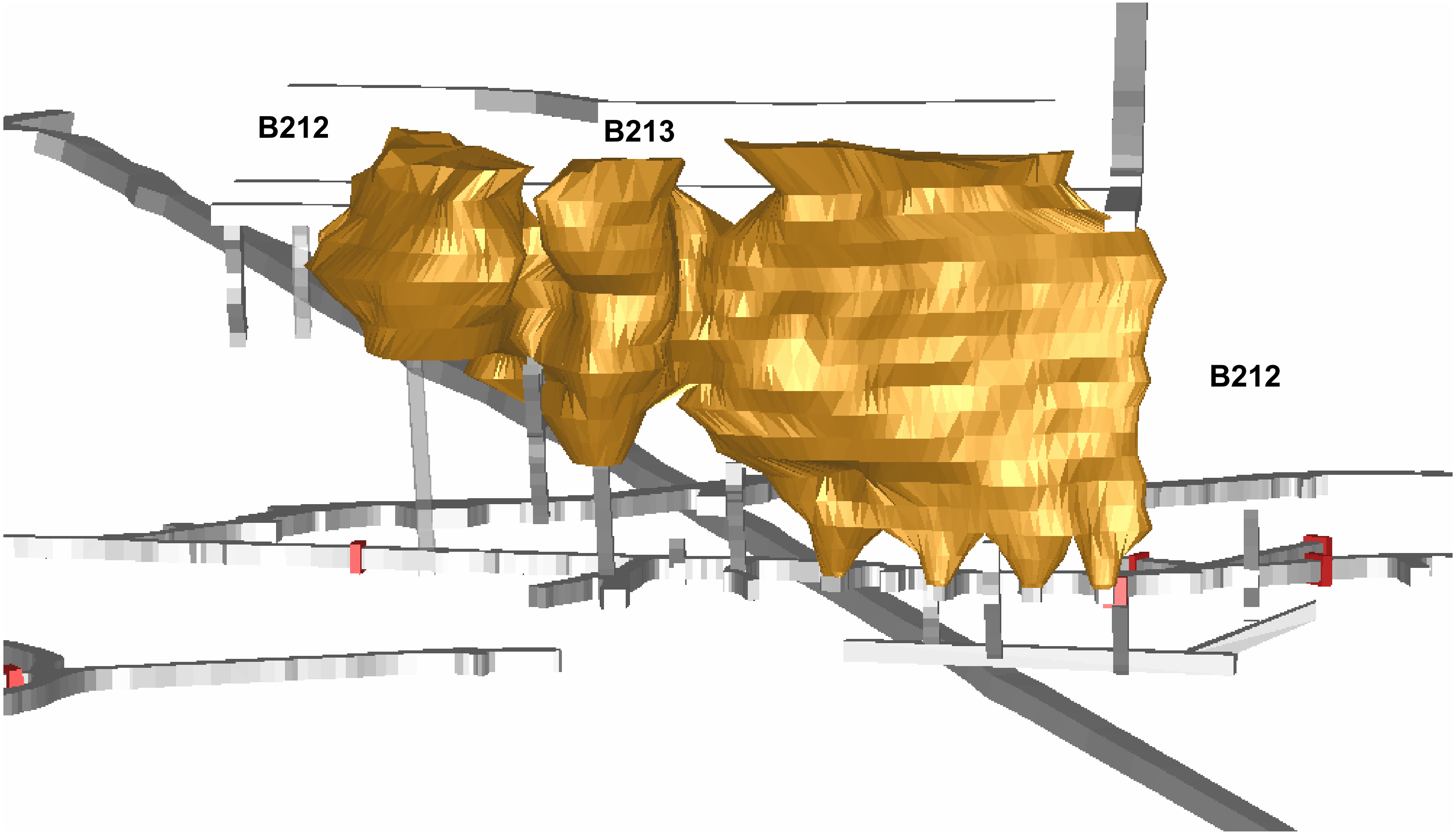

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MINED-OUT STOPES IN AR4

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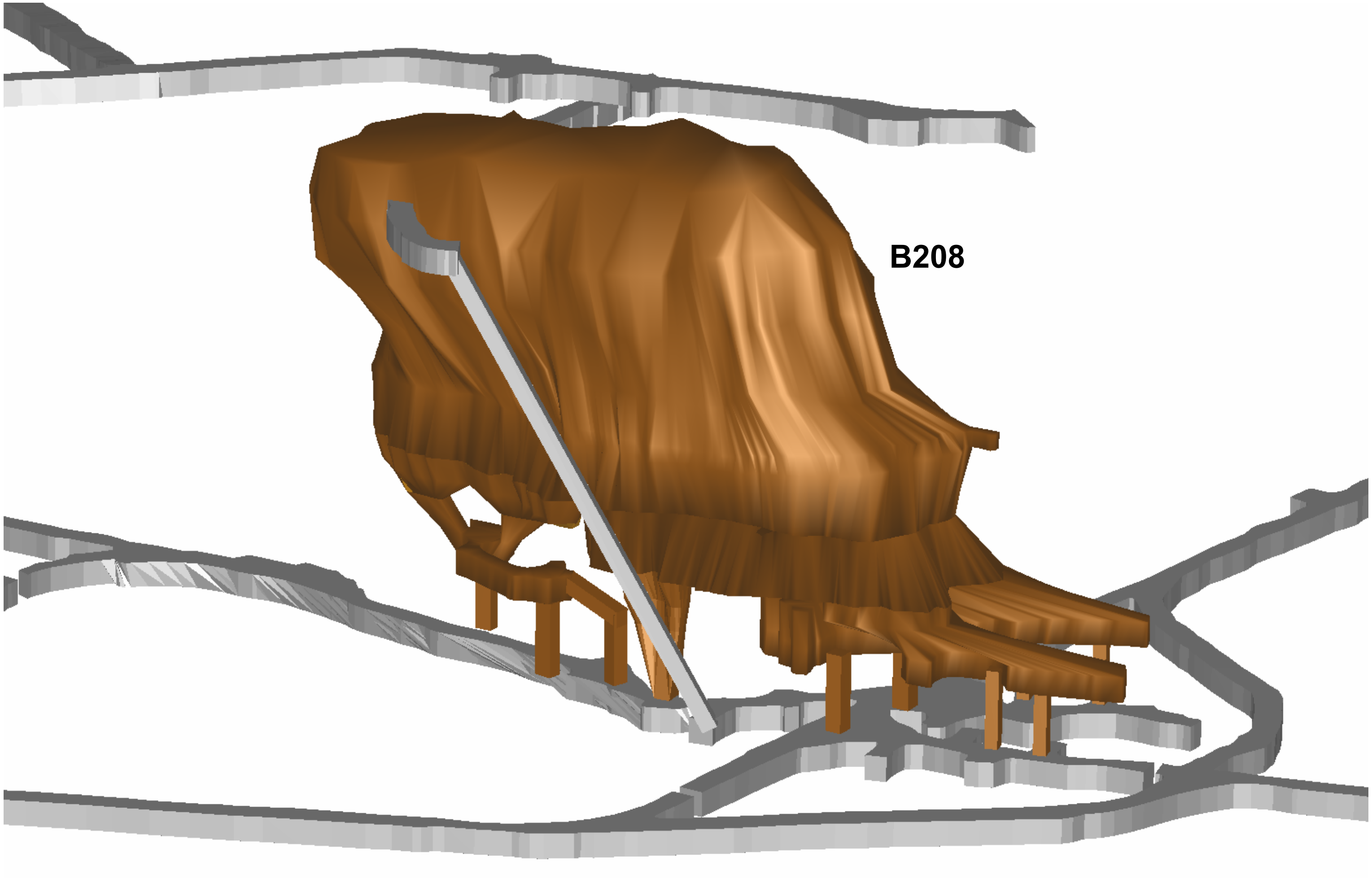

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MINED-OUT STOPE B208

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3.4 Water Quality and Current Water Management

3.4.1 Surface Water and Surface Sources of Arsenic

Routine monitoring of surface flows and arsenic concentrations is carried out by MGML as part of the Surveillance Network Program (SNP) required by the site Water License. The SNP includes regular monitoring of stations upstream of the mine (Baker Creek and Trapper Creek), discharges from the underground mine to the Northwest Tailings Pond, discharges from the water treatment plant, and a sampling station at the mouth of Baker Creek.

Surface sources of arsenic at the Giant Mine were characterized as part of the Abandonment and Restoration Plan prepared by Golder Associates Ltd. (2001). The Technical Advisor checked the numbers using the most recent monitoring data, and developed a set of “water balance” and “arsenic balance” calculations to quantify the contribution of arsenic from background sources, discharges from the treatment plant, and surface runoff from the mine site. The calculations are presented in detail in Supporting Document 17.

The quality of water in Baker Creek, both upstream and downstream of the mine development, is determined on a routine basis as part of the SNP. Just upstream of the mine area, the typical concentration of arsenic in the creek water is 0.05 mg/L. Flow in Baker Creek is measured by an automated stream gauging station, operated by Environment Canada at the outlet of Martin Lake. Typical discharge from the creek is 5,800,000 m^3 per year. From these data, the typical background arsenic load in Baker Creek as it enters the mine area is about 290 kg per year. The background contribution represents a significant portion of the total arsenic release to the downstream environment. The source of the background arsenic is thought to be naturally elevated arsenic levels in the bedrock and historical deposition of arsenic from roasting operations.

The discharge of treated water, between June and October each year, currently contributes approximately 1,000,000 m^3 of water to the creek, at an average arsenic concentration of about 0.4 mg/L. The discharge of treated water represents an additional arsenic load of about 430 kg/year to Baker Creek.

Average flowrates and arsenic concentrations at the mouth of Baker Creek indicate a typical arsenic load of about 1,100 kg/year at that point, showing that, in addition to the effluent discharge load, about 380 kg/year of arsenic is picked up by the creek as it passes through the mine area. The major sources of the additional arsenic are runoff from contaminated soils and tailings spills, creek sediments that are slowly releasing arsenic which was taken up from historical effluent discharges, and seepage from the Northwest Tailings Pond.

3.4.2 Underground Minewater and Arsenic Sources

Monitoring of minewater flows and chemistry within the mine has been carried out since 1999, initially by Fracflow Consultants Inc. and subsequently by DIAND and the Technical Advisor. The objectives of the program are to identify and characterize the principal sources of arsenic within the mine, and to develop water and arsenic balances for the minewater system. Results of recent investigations of groundwater around the mine are presented in Supporting Document 2. A detailed discussion of the minewater sampling programs and minewater chemistry is presented in Supporting Document 3.

The results of the minewater sampling programs indicate that the main sources of water entering the mine are direct infiltration of snowmelt and precipitation, infiltration from Baker Creek, and seepage from the tailings ponds. Deep saline groundwater enters laterally into the lower levels of the mine. However, the isotopic signatures measured in the minewater quality samples indicate that the majority of water entering the mine is infiltration from the surface.

As water percolates downwards into the mine, it interacts with the mine walls and surrounding bedrock. Water samples collected from boreholes and fractures at the extremities of the mine have relatively low arsenic concentrations, ranging from 0.018 to 0.063 mg/L. Interaction with the mine workings nearer the ore zone leads to further increases in arsenic concentrations, to the range of 0.5 mg/L.

Water that contacts the arsenic trioxide dust is characterized by very high arsenic and antimony concentrations, slightly acidic pH, and high magnesium, sulphate and ammonia concentrations. Arsenic concentrations in seeps close to dust-filled chambers are in the range of 4000 mg/L. The isotope data indicate that most of the seepage from the chambers originates from snowmelt and rainwater. However, a sample collected below Chamber C212, which lies under Baker Creek, was more characteristic of creek water.

Water from the tailings ponds and polishing pond also enters the mine via direct infiltration. The tailings seepage tends to have arsenic concentrations in the range of 4 to 6 mg/L, as well as elevated concentrations of sodium, chloride, ammonia and nitrate.

Some of the mine stopes are backfilled with waste rock and tailings. Seepage from stopes that are backfilled with tailings typically has arsenic concentrations ranging from 0.4 to 6.6 mg/L, while seepage from stopes that contain waste rock have arsenic concentrations ranging from 0.2 to 1.6 mg/L. Laboratory testing of backfill samples is described in Supporting Document 4. Results to date confirm the above ranges.

The deep groundwater is characterized by very high total dissolved salts content, and high calcium, sodium and chloride concentrations. The deep groundwater appears to contribute significantly to the sodium/chloride release from the mine, but is a relatively minor source of arsenic.

Typical concentrations of arsenic in water from each of the above sources are summarized in Table 3.7

TABLE 3.7
Arsenic Concentrations from Different Sources in the Underground Mine

Mine Component	**Arsenic Concentrations (mg/L)**
Soils, Bedrock, and Mine Walls	0.05
Northwest Tailings Pond	5
Backfilled Tailings	5
Backfilled Waste Rock	1.5
Arsenic Chambers	4000

Prepared by: KSS
Checked by: DBM

A water and load balance of the underground mine flows is presented in Supporting Document 3. The load balance indicates that approximately 38 kg/day of arsenic is discharged to the Northwest Tailings Pond. Approximately 35 kg/day of this load enters the mine between C-Shaft and 1000 North, which is the area of the mine that is beneath the arsenic chambers. An additional 3 kg is from north of 1000 North, and can be attributed primarily to seepage from the Northwest Tailings Pond.

The underground mine workings form a network of connected voids, including horizontal drifts, inclined raises, vertical shafts, ramps, chutes and ore stopes. In addition, many thousands of exploration drill holes intersect the workings, creating an extensive drainage system for the rock in the mine area. Because the drainage system extends to the bottom of the deepest shaft, 610 metres below the surface, the local groundwater table is artificially lowered in the area of the mine. This has the effect of continuously drawing groundwater towards the workings and preventing the escape of contaminated minewater.

3.4.3 Water Treatment

Water from the underground mine is collected and pumped to the surface, and then discharged to the Northwest Tailings Pond. The water is stored in the tailings basin until the summer season, when it is treated to remove contaminants, using hydrogen peroxide oxidation and ferric iron precipitation, and then discharged to Baker Creek.

The current water treatment system begins with the addition of hydrogen peroxide to oxidize arsenite to arsenate. Ferric sulphate is then added at a lime-adjusted pH of approximately 8.5 and a molar ratio of 10:1 iron to arsenic. The discharge flows to a polishing pond where the precipitates are allowed to settle. The polished water is then discharged to Baker Creek. The treatment process removes approximately 98% of the arsenic from solution.

The treatment plant is operated on a seasonal basis, typically from June to October, and treats approximately 1,000,000 m^3 of water during this period. Arsenic concentrations in the treatment plant effluent ranged from 0.29 to 0.48 mg/L in the 2001 operating season, and were typically in the range of 0.4 mg/L. The Water License effluent quality limit is 0.5 mg/L total arsenic, averaged over four consecutive 24-hour sample analyses.

3.5 Receiving Environment

3.5.1 Data Sources

The levels of arsenic in the receiving environment around Yellowknife have been a subject of scientific research since at least the early 1970's. Numerous studies have been completed to characterize arsenic levels in water, sediment, air, soils, vegetation and fish. Supporting Document 6 and its Attachment A present a compilation of data from over 25 of such studies. Supporting Document 6 also includes tabulations of summary statistics calculated from the compiled data. Representative results are reviewed in the following sections.

3.5.2 Arsenic in Receiving Water

Table 3.8 summarizes the arsenic concentrations measured in water around the Yellowknife area. These values can be compared to the CCME water quality guidelines for the protection of aquatic life (5 µg/L) and for drinking water (25 µg/L). Arsenic concentrations measured in the Yellowknife River are also included in the table as a basis for comparison. The Yellowknife River is the source of drinking water for the City of Yellowknife. It is upstream of the Giant Mine and therefore not impacted by current discharges from the site.

TABLE 3.8
Measured Arsenic Levels in Water

Location	**Number of Samples**	**Range (µg/L)**	**Typical Values by Decade (µg/L)**			
			1970's	**1980's**	**1990's**	**2001**
Baker Creek	43	0.3 – 12,600		300	70	70
Back Bay	49	0.3 – 740	140		2.1	
North Yellowknife Bay	26	0.3 – 83	80		<0.3	
South Yellowknife Bay	35	0.3 – 350				
Yellowknife River	8	<0.3 – 0.3				

Prepared by: DEH
Checked by: DBM

The very wide ranges reported in the table are indicative of the significant changes in water quality associated with periods where no effluent is being discharged from the minewater treatment system, and the series of upgrades to the water treatment process (especially the 1978 improvements, see section 2.3.5 above). The rightmost four columns of the table indicate some of the trends:

- Arsenic concentrations in the outflow from Baker Creek have fallen from levels as high as 12,600 µg/L measured in the 1970's to approximately 300 µg/L in the 1980's. In 2001, the arsenic concentrations in Baker Creek reached concentrations around 70 µg/L during periods when there was no discharge of treated effluent from the Giant Mine. However, the most recent data suggest that the arsenic concentrations in the Baker Creek outlet remain above the CCME arsenic guidelines for drinking water and the protection of freshwater aquatic life.

- There has been a marked reduction in the concentration of arsenic in surface waters since the 1970's. In Back Bay, arsenic concentrations dropped from 140 µg/L in 1972 to levels around 2.1 µg/L in 1994. In Yellowknife Bay, arsenic levels dropped from 80 µg/L in 1972 to less than 0.3 µg/L in 1994. Current arsenic concentrations are slightly below the CCME guideline for protection of freshwater aquatic life in Back Bay, and well below the guideline in Yellowknife Bay.

3.5.3 Arsenic in Sediments

The results of sediment sampling campaigns are summarized in Table 3.9. As a point of comparison, the background concentrations of arsenic in the sediments are in range of 15 to 25 µg/g, based on core sampling of deep sediments in Yellowknife Bay (Mudroch *et al*. 1989). The table shows that arsenic contamination of the upper layer of sediment has occurred throughout Back Bay and upper Yellowknife Bay.

In this case, the ranges in the measured concentrations are attributable primarily to differences in location. The very high concentrations measured in Baker Creek and Back Bay are probably attributable to tailings. Within the natural sediments, concentrations clearly decline with distance from the mouth of Baker Creek, indicating that discharges from the mine site are the primary source.

The improvements since the 1970's, which are clearly evident in the water quality data, are not as evident in the sediment data. In part, that may be due to changes in sampling locations and procedures. However, it is also likely that the sediments act as a "buffer" and tend to store historical contamination for much longer periods. The implications of this effect are discussed further in Chapter 4 below.

TABLE 3.9

Measured Arsenic Levels in Sediment

Location	**Number of Samples**	**Range (µg/g)**	**Geometric Mean Values (µg/g)**
Baker Creek	16	220 – 3757	1510
Back Bay	21	200 – 3140	847
North Yellowknife Bay	39	12 – 1000	105
South Yellowknife Bay	11	10 -90	26

Note: Surficial sediments (0- 5 cm) only were considered.

Prepared by: DEH
Checked by: DBM

3.5.4 Arsenic in Aquatic Biota

Measured arsenic concentrations in fish organs were available for a number of different species and locations. Measured concentrations in muscle of various fish species ranged from 0.03 to 0.55 µg/g wet weight. For liver and kidneys, the arsenic concentrations ranged from 0.02 to 1.15 µg/g and 0.05 to 1.48 µg/g, respectively.

Koch (1998) found that arsenobetaine is the major extractable arsenic species in freshwater fish from Yellowknife Bay near the Baker Creek outlet. Arsenobetaine, an organic arsenic compound, is known to be much less toxic than inorganic arsenic species.

The benthic fauna of Yellowknife Bay were investigated by Moore *et al*. (1979), cited by Jackson *et al*. (1996), who found that benthic diversity progressively increased with distance from the outlet of Baker Creek. Signs of recovery of the benthic populations were reported to occur at a distance of 1000 to 1200 m from the outlet of Baker Creek.

Snails were collected from the Baker Creek Outlet and from Baker Creek near the mill area at the Giant Mine (Koch *et al.* 2000). Composite samples of whole and shelled snails were prepared for analysis. There was little difference between the arsenic concentrations in the whole (83 µg/g dry weight) and shelled (82 µg/g) snails. Speciation analysis of the snails indicated that 40 to 60% of the arsenic was in an organic form, tetramethylarsonium. The inorganic species of arsenic were found to represent from 25% to 40% of the extracted arsenic.

A range of 150 to 3700 µg/g arsenic in aquatic plants was reported for Kam, Grace, Keg, Likely and Chitty Lakes (Wagemann *et al.* 1978, cited by RMCC 1999). Koch *et al.* (2000) reported that submergent plants (e.g. *Myriophyllum* sp.) collected during an August sampling campaign predominantly contained arsenic in the form of inorganic arsenate.

3.5.5 Arsenic in Air

The territorial Department of Resources, Wildlife and Economic Development monitors air quality in the Northwest Territories. Ambient air quality measures the contribution from all sources, including background. Several ambient air quality parameters are measured in Yellowknife including arsenic. Annual average arsenic concentrations were 0.005 µg/m^3 in 1997 and 0.004 µg/m^3 in 2000.

3.5.6 Arsenic in Soil

Wildlife and humans may be exposed to arsenic in soil as a result of the inadvertent ingestion of soil or as a result of uptake by vegetation which is subsequently consumed. Arsenic levels in soil in the Yellowknife area are high due to the surface exposure of naturally mineralized geologic material and due to past mining activities. Consequently, several investigations have been carried out over the years to characterize levels in the study area, (Hutchinson *et al* 1982, Con Mine 1987, ESG 2000, ESG 2001 Risklogic 2002, YASRC). For sites around Yellowknife, arsenic concentrations in soil ranged from 2.5 to 1190 mg/kg dry weight. For the Giant Mine Site, the arsenic concentrations in soil ranged from 22 to 15,800 mg/kg.

3.5.7 Arsenic in Terrestrial Vegetation

ESG (2001b) studied arsenic concentrations in vegetables from gardens around the Yellowknife area. Arsenic concentrations in garden produce ranged from 0.02 to 0.29 mg/kg wet weight. In berries, the arsenic concentration ranged from 0.02 to 1.9 mg/kg.

Arsenic level measurements on terrestrial mosses, mushrooms and lichens collected from the Con Mine and Giant Mine site have been reported by Koch *et al.* (2000). The mosses generally contain the highest levels of arsenic, although the highest individual measurement was recorded on a lichen sample. The arsenic levels in moss ranged from 490 to 1900 mg/kg dry weight, and for lichen from 6.4 to 2300 mg/kg. Arsenic speciation measurements carried out by Koch *et al.* (2000) demonstrated that the mosses generally contain only inorganic arsenic. In lichens, inorganic forms comprise 62% to 93% of the total extracted arsenic.

Additional sampling on the contaminant levels in mushrooms in the Northwest Territories has been reported by Obst *et al.* (2000). Samples were collected from an area of 50 km x 200 km centered around the City of Yellowknife. The total arsenic levels in fungi ranged from 0.2 to 494 mg/kg dry weight. Arsenic speciation analyses indicated that, in two samples of fungi, organic arsenic compounds represented more than 99.75% of total arsenic.

4. ASSESSMENT OF ECOLOGICAL AND HUMAN HEALTH RISKS

4.1 Overview

The arsenic trioxide dust at the Giant Mine is of concern primarily because of the potential for arsenic to impact ecological and human health. To provide insight as to the level of risk presented by possible future releases of arsenic from the dust, Supporting Document 6 and its attachments present a "risk assessment". The risk assessment includes a complete review of available data on arsenic levels in the Yellowknife area, prediction of arsenic intakes by ecological and human "receptors", and a comparison of the predicted intakes to toxicological benchmarks. The following sections summarize that work.

Figure 4.1 provides an overview of the calculation steps involved in this type of risk assessment. In general terms, the calculations allow a risk assessor to estimate the intake of arsenic by selected ecological and human "receptors", *i.e.* by animals and humans with particular dietary habits living in the study area. Although the calculations follow a relatively straightforward logic, the assessment of ecological and human health risks by this method is never an exact science. In fact, the method requires a number of inputs and assumptions, some of which are well established and some of which are less well understood. In each of the remaining sections, an attempt is made to briefly describe each step and to indicate what is well known and what is uncertain. The last section of this chapter brings together the risk assessment results and uncertainties, and provides a summary of the key conclusions.

4.2 Arsenic Sources

4.2.1 Current and Historical Releases from Giant Mine

Figure 4.2 shows the area considered in the risk assessment. Section 3.3 above presents the results of investigations into current arsenic releases from the Giant Mine site to the Baker Creek watershed. The conclusions reached are that approximately 1100 kg/year currently enters Back Bay via Baker Creek. Of that total, approximately 290 kg/year of arsenic enters the mine area from upstream sources, the minewater treatment plant effluent contributes approximately 430 kg/year, and other surface sources in the mine area contribute an additional 380 kg/year.

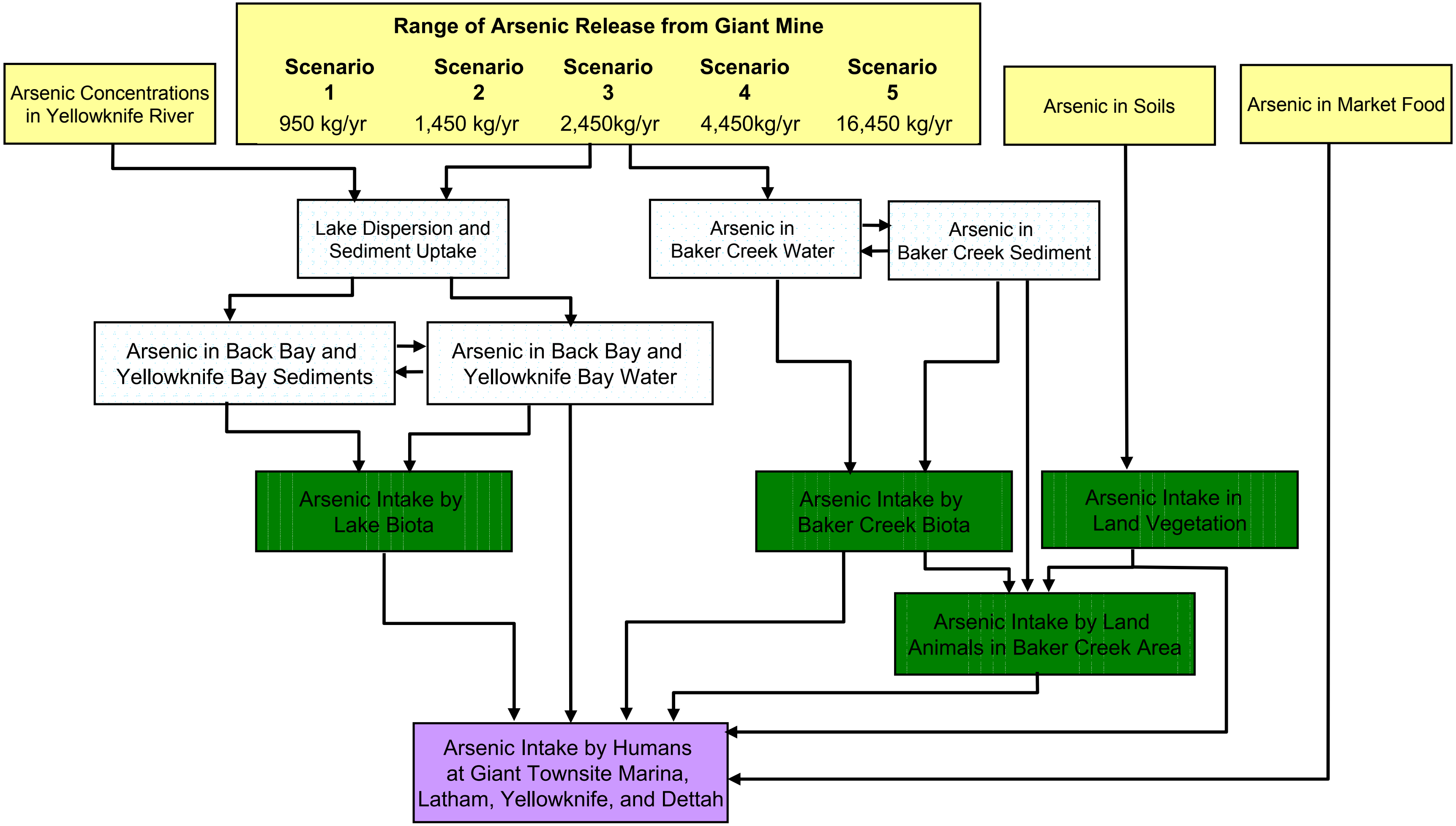
No similarly definitive estimates of historical arsenic releases from the Giant Mine are available. It is possible to construct estimates of historical arsenic release rates from isolated sampling events. The periods represented by each estimate can be inferred from the changes in air emissions controls and water treatment that are discussed in Chapter 2 above. That method was used to develop initial estimates of historical arsenic releases from the mine to Baker Creek and Back Bay. However, comparison to historical receiving water and sediment analyses indicated that the initial estimates were too low, probably because of additional contributions from arsenic releases to the air. The historical releases assumed in the risk assessment calculations were therefore based on a calibration of the pathways model (see Section 4.3 below) to arsenic concentrations in water and sediment samples.

4.2.2 Possible Future Releases from Giant Mine

To estimate the possible range of future arsenic releases from the site, the current release rates discussed in Section 3.3 above were used as a starting point. However, the modifications proposed in the recent Abandonment and Reclamation Plan are expected to significantly decrease the arsenic discharges from surface sources within the mine area (Golder Associates, 2001). After those measures are implemented, it is reasonable to expect that background and mine area arsenic releases will be reduced from the current 670 kg/yr (290 kg/yr background and 380 kg/yr from the mine area) to somewhere between 400 and 500 kg/yr. A total background and mine area arsenic release of 450 kg/yr was therefore assumed for the risk assessment calculations.

The more uncertain component is the arsenic release from the underground mine and the arsenic trioxide storage areas. As is discussed in Section 3.3, currently the minewater is collected and treated prior to release. The arsenic release from the treatment plant totals approximately 430 kg/yr. Possible arsenic release rates associated with various alternatives for long term management of the arsenic trioxide dust also fall into the 500 kg/yr range (see Supporting Document 18). However, in the case where the minewater treatment system and/or other future management measures fail completely, the rate of arsenic release could increase to levels as high as 16,000 kg/yr.

To cover the range between the lower limit of 500 kg/yr and the upper limit of 16,000 kg/yr, a series of five scenarios were considered in all of the risk assessment calculations. When the background and mine area arsenic releases were added, the following five scenario's resulted:



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STEPS IN RISK ASSESSMENT CALCULATIONS

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AREAS CONSIDERED IN RISK ASSESSMENT

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- Scenario 1 - 950 kg/yr,
- Scenario 2 - 1,450 kg/yr,
- Scenario 3 - 2,450 kg/yr,
- Scenario 4 - 4,450 kg/yr,
- Scenario 5 - 16,450 kg/yr.

4.2.3 Arsenic in Other Environmental Media

In order to assess the total intake of arsenic by ecological and human receptors in the Yellowknife area, it was necessary that the risk assessment consider sources other than direct releases from the Giant Mine. Section 3.4 above presents a summary of previous studies of arsenic concentrations in water, sediment, benthic organisms, aquatic plants, fish, air, soil, and terrestrial vegetation in the Yellowknife area. Complete data summaries are provided in Appendix A of Supporting Document 6.

In brief, there is a substantial data set available to characterize the concentrations of arsenic in environmental media in the Yellowknife area. The data were used in several different ways in the risk assessment calculations:

- Water and sediment quality data were used to calibrate a model of arsenic transport and fate in Baker Creek, Back Bay, and Yellowknife Bay (see Section 4.3 below);

- Data on arsenic concentrations in soils, garden vegetables, and berries were used to calculate summary statistics that were then used directly in probabilistic calculations of arsenic intakes; and,

- Data on arsenic concentrations in fish, benthic organisms, and aquatic plants were used to estimate site-specific transfer factors.

Two weaknesses in the available data became apparent. A lack of data on arsenic levels in terrestrial wildlife (arsenic levels were typically below detection limits) necessitated the use of cautious assumptions, supported by information from studies elsewhere, as to how much arsenic would accumulate in wildlife. Limited data on the chemical forms of arsenic in fish necessitated the use of assumptions about how much of the organic fraction could potentially affect human health, again supported by information from studies elsewhere.

4.2.4 Arsenic in Market Foods

Concentrations of arsenic in store bought foods, *i.e.* foods that are not locally grown or harvested, were estimated from Canada wide surveys of arsenic levels in market foods (Dabeka *et al.*, 1993).

4.3 Transport and Fate of Arsenic in the Aquatic Environment

4.3.1 Transport and Fate Processes

The behaviour of arsenic in natural waters is reasonably well understood. Studies of other lake systems and the Yellowknife area studies cited in Appendices A and B of Supporting Document 6 show that arsenic exists primarily as the soluble inorganic form in lake water, and is therefore transported along with the water. The same studies also show that arsenic is removed from natural waters by reactions with sediments. Settling solids scavenge arsenic from the water column and carry it to the lake bottom, where it can be buried by subsequent sediment deposition. However, the contaminated sediments can then release the arsenic back into the water column. In cases where the concentrations of arsenic in the water were historically higher than they are today, the sediments can become a significant long-term source of arsenic.

The interactions between waterborne and sediment-bound arsenic are very important in determining the exposure of aquatic organisms. Therefore it was necessary that the risk assessment calculations take those interactions into account.

4.3.2 Transport and Uptake Modeling

For the risk assessment calculations, the arsenic released from the Giant Mine was assumed to enter Baker Creek and from there into the three portions of Great Slave Lake shown in Figure 4.2.

The arsenic transport and sediment uptake processes within Back Bay, North Yellowknife Bay and South Yellowknife Bay were simulated with the help of a mathematical model known as LAKEVIEW. The model is described in detail in Supporting Document 6, Appendix B. The processes simulated by LAKEVIEW include:

- Historical inputs of arsenic and arsenic accumulation in sediments;
- Future inflows of water and dissolved arsenic from Baker Creek and the Yellowknife River;

- Distribution of the arsenic among Back Bay, North Yellowknife Bay and South Yellowknife Bay;
- Adsorption of arsenic on sediments, arsenic reactions in lake sediments, and subsequent release back into the water column;
- Burial of sediments by natural deposition of suspended solids; and,
- Transport of water and arsenic into and out of the three segments.

All available sediment and water quality monitoring data from the areas shown in Figure 4.2 were reviewed and used to calibrate the LAKEVIEW model. In brief, the calibration comprised quantifying sediment porewater, surface water and sediment-solids interactions, and adjusting estimates of historical arsenic loading to match available data. Supporting Document 6, Attachment B provides details.

The calibration results provided interesting insights into how the system responds to changes in arsenic inputs. In particular, the model calibration showed that the water in Back Bay and Yellowknife Bay responded within a few years to previous reductions in arsenic inputs, but that arsenic concentrations in sediments are responding much more slowly. One implication is that the currently elevated arsenic concentrations in sediments are in large part due to the very high arsenic discharges that occurred in the 1960’s and 1970’s, *i.e.* prior to the water treatment improvements at the mine. Another implication is that future improvements in arsenic concentrations in sediments would take decades, even if the arsenic releases to the lake could be completely eliminated.

4.3.3 Future Concentrations of Arsenic in Water and Sediments

The calibrated LAKEVIEW model was then used to simulate dispersion and sediment uptake of the arsenic that would be released from the mine workings under the five different arsenic release scenarios. Table 4.1 summarizes the water quality predictions, as compared to the CCME water quality guidelines for the protection of aquatic life and for drinking water.

As indicated in Table 4.1, predicted arsenic concentrations fall above the CCME (1999) guideline for the protection of freshwater aquatic life in Baker Creek, Back Bay (except Scenario 1) and North Yellowknife Bay (Scenarios 4 and 5 only). However, the federal guideline is designed to be protective of a wide range of species and water uses. The risk assessments reported in the next two sections provide a more site-specific assessment of the significance of the predicted arsenic concentrations.

TABLE 4.1
Comparison of Water Quality Predictions to CCME Guidelines

	CCME Guideline for Protection of Freshwater Aquatic Life (5 µg/L)				**CCME Guideline for Drinking Water (25 µg/L)**			
	Baker Creek	**Back Bay**	**North YK Bay**	**South YK Bay**	**Baker Creek**	**Back Bay**	**North YK Bay**	**South YK Bay**
Scenario 1	x	✓	✓	✓	x	✓	✓	✓
Scenario 2	x	x[a]	✓	✓	x	✓	✓	✓
Scenario 3	x	x	✓	✓	x	✓	✓	✓
Scenario 4	x	x	x	✓	x	✓	✓	✓
Scenario 5	x	x	x	✓	x	x	✓	✓

Prepared by: HP
Checked by: BH

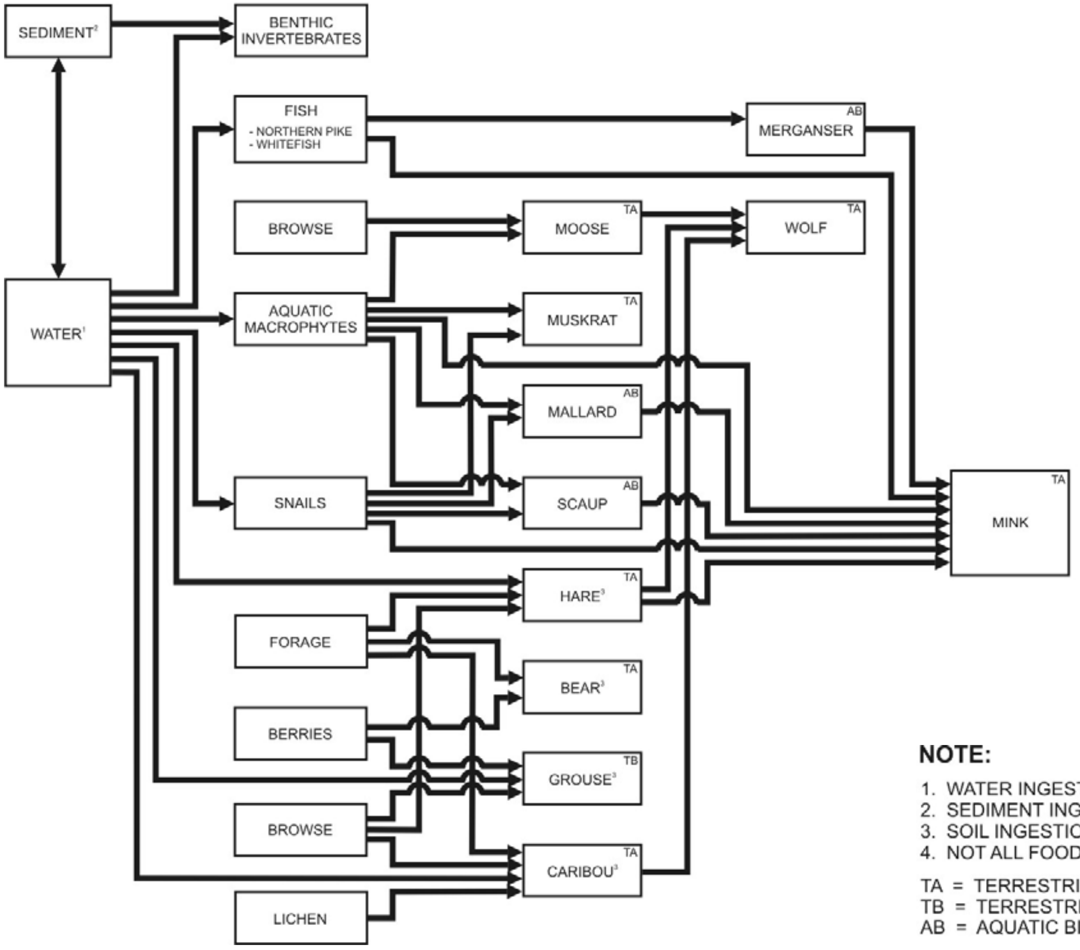
Notes: x[a] - Indicates exceedance of guideline for the predicted 95th percentile only.
x - Indicates exceedance of the appropriate guideline for both the predicted mean and 95th percentile values.
✓ - Indicates that predicted arsenic concentration in water is below the appropriate guideline.

4.4 Arsenic Intakes by Ecological Receptors

4.4.1 Assessment Methods

To make the connection between predicted arsenic concentrations and intakes by plants, fish and animals, it was necessary to carry out "pathways" calculations. The pathways calculations estimate the amount of arsenic taken in by species at various levels in the food chain, on the basis of assumptions as to the amount of time that each species spends in the arsenic-contaminated areas, and their water and food intakes during that period. Figure 4.3 illustrates the main pathways considered in the ecological risk assessment.

For estimating the intake of arsenic by aquatic species, it was assumed that they would be exposed to arsenic in Baker Creek, Back Bay and/or Yellowknife Bay. It is not known with certainty how long aquatic species will be present in a given location. For risk assessment purposes, it was assumed that the aquatic species were present 100% of the time in each water body.



NOTE:

1. WATER INGESTION BY ALL SPECIES
2. SEDIMENT INGESTION BY MINK, MUSKRAT, MOOSE & DUCKS
3. SOIL INGESTION BY HARE, GROUSE, BEAR, WOLF & CARIBOU
4. NOT ALL FOOD SOURCES SHOWN, MODELLED PATHWAYS ONLY

TA = TERRESTRIAL ANIMAL
TB = TERRESTRIAL BIRD
AB = AQUATIC BIRD

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PATHWAYS CONSIDERED IN ECOLOGICAL RISK ASSESSMENT

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For the terrestrial receptors, the estimates took into consideration exposure to arsenic in drinking water, soils and terrestrial vegetation. Arsenic bioavailability in soils and sediments was considered. There was no site-specific information on arsenic bioavailability in Yellowknife soils and sediments, thus, literature data was used to obtain this information. Supporting Document 6, Appendix C, provides details of the assumed feeding habits for each species, and the calculations to estimate arsenic intake by each pathway.

Probabilistic methods were used to show account for uncertainty in some of the model inputs. For all of the terrestrial species, mean, 5th, 50th and 95th percentile daily intakes of arsenic were estimated. Supporting Document 6, Appendix C, provides more detail on the pathways calculation and species selection.

4.4.2 Potential for Impacts on Aquatic Species

To assess the level of risk to aquatic species, the estimated concentrations of arsenic in the water (mean, 5th, 50th and 95th percentile values) at each location were compared to appropriate toxicological benchmarks. For aquatic species considered in the assessment, the toxicological benchmark was set at the lowest concentrations at which 25% of the test species might show a toxic effect in a long-term test. These benchmarks were based on laboratory tests reported in the literature.

Comparison of the estimated arsenic concentrations to toxicity benchmarks showed that none of the arsenic discharge scenarios are likely to have an adverse effect on the aquatic community in Back Bay or Yellowknife Bay. However, the predicted arsenic levels could affect benthic invertebrates (snails) and white suckers in Baker Creek at arsenic loadings greater than 950 kg/y.

4.4.3 Potential for Impacts on Terrestrial Species

The estimated daily intakes of arsenic by the terrestrial species were also compared to toxicological benchmarks. The benchmarks in this case were Lowest Observable Adverse Effects Levels (LOAEL) obtained from literature data. A LOAEL is the lowest concentration where an effect can be seen in laboratory testing.

There were a number of uncertain components in the terrestrial risk assessment. Cautious assumptions were adopted whenever the uncertainties could not be resolved. For example, for the terrestrial receptors, it was assumed that while in the study area, they spent time in the location of highest arsenic exposure (i.e. Baker Creek). It was also assumed that the species obtain 100% of the food and water from the study area and that the arsenic present in these media is directly transferred into the species. In addition, the species were assumed to consume either soil or sediment and that only a portion of the arsenic in these media was biologically available.

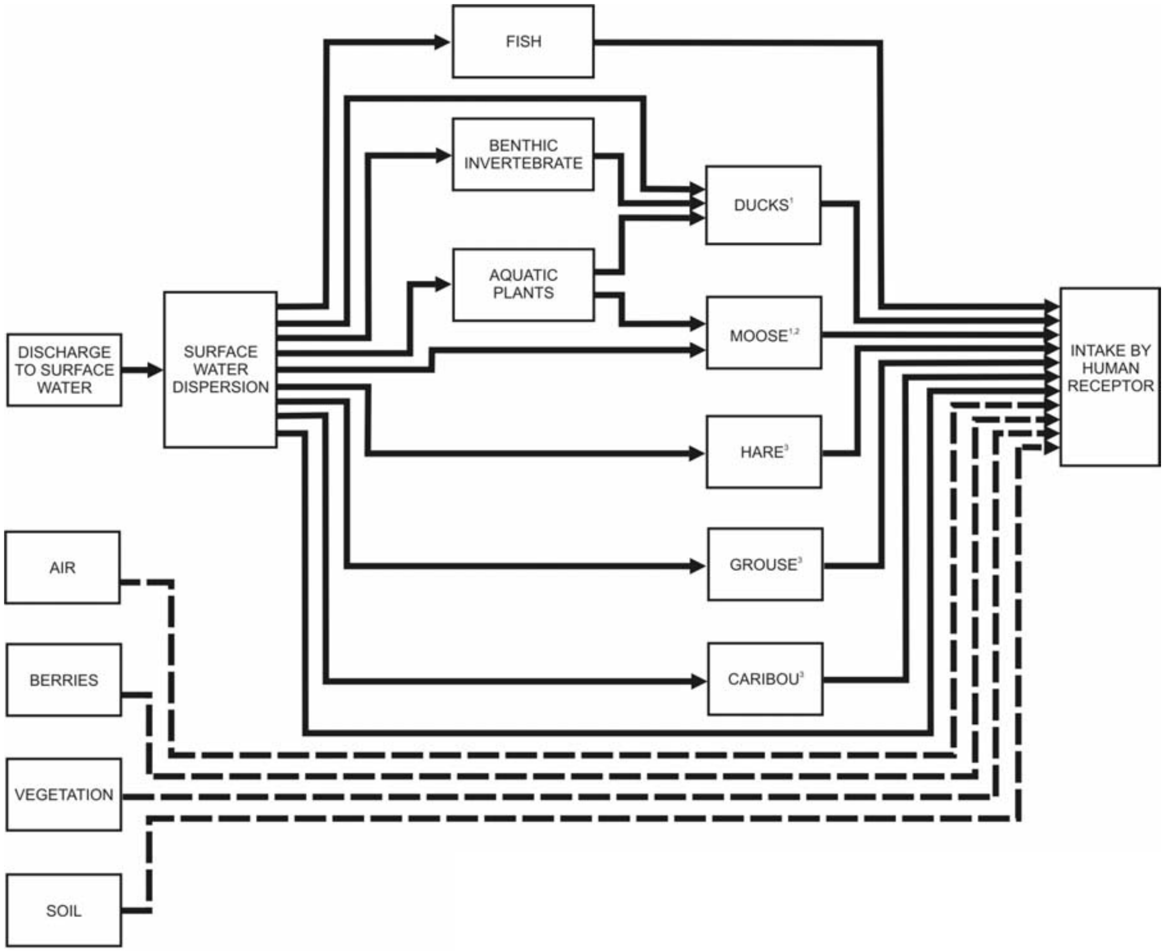
The results of the risk assessment showed that, with limited exceptions, the estimated arsenic intakes for terrestrial species are below toxicity benchmarks for all scenarios. One exception is that, for mink and muskrat in Baker Creek, toxicity benchmarks were predicted to be exceeded for all of the scenarios. The major source of arsenic for these two species was sediment ingestion. Arsenic levels in the sediments in Baker Creek are elevated due to historical discharges, and are not directly related to the management of arsenic trioxide dust. These levels pose a potential risk to aquatic and terrestrial species and will persist unless direct action is taken to remediate the creek. The second exception was that, under the very high arsenic releases of Scenario 5, there could be risk to moose and bear living in the Baker Creek area.

4.5 Arsenic Intakes by Human Receptors

4.5.1 Assessment Methods

To estimate the amount of arsenic that could be taken in by humans living in the study area, a set of pathways calculations was also necessary. In this case, the pathways considered are shown in Figure 4.4. To account for differences in dietary characteristics, the assessment considered six "receptors" with diets selected to cover a wide range of possibilities. The top half of Table 4.2 summarizes the different receptors and the sources of their dietary components.

The estimation of arsenic intakes involved some uncertainties. Cautious assumptions were used whenever the uncertainties could not be resolved. For example, it was assumed that all receptors spend their entire lifetime in the study area and are exposed to the maximum concentration of arsenic throughout this lifetime. Individuals are also assumed to obtain a large portion of their dietary intakes from local sources. With the exception of fish, it was assumed that all of the arsenic present in drinking water and other food sources is in the (more toxic) inorganic form. The organic arsenic in fish was assumed to be non-toxic for most of the calculations, and that assumption was subsequently assessed by sensitivity analyses. Supporting Document 6 provides details of the calculations.



Source: SENES Consultants Limited

NOTE:

1. SEDIMENT INGESTION BY DUCKS & MOOSE
2. MOOSE ALSO CONSUMES BROWSE
3. EXPOSURE THROUGH CONSUMPTION OF TERRESTRIAL VEGETATION & SOIL ALSO MODELLED

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4.5.2 Estimated Daily Arsenic Intakes

Table 4.2 presents the daily intake total (inorganic and organic) arsenic for each receptor. The results show that Receptors 3 and 4 are predicted to have the highest arsenic intakes, followed by Receptors 5 and 6. This is a reflection of the assumed dietary characteristics of these receptors, especially the fact that a large portion of their food and water is assumed to be obtained from Back Bay.

Estimated mean intakes that are above the range typical for the general Canadian population (Environment Canada, 1993) are underlined in Table 4.2. Bold values in the table indicate cases where either the mean or 95th percentile estimates exceed the Health Canada (1996) Provisional Daily Tolerable Intake of 0.002 mg/(kg d).

4.5.3 Potential for Human Health Effects

Perhaps the greatest source of uncertainty in the risk assessment process is in the relationship between arsenic intakes and potential health effects. Evidence from many studies shows that long-term intake of arsenic at sufficiently high doses results in a pattern of skin changes. The changes can include the appearance of small “corns” or “warts” on the torso and on the palms of hands and the soles of feet as well as darkening of the skin. A small proportion of corns may develop into skin cancer. The skin cancers generally develop after prolonged exposure, and are highly treatable if detected in time. The most serious form is melanoma. Ingestion of inorganic arsenic has also been reported to increase the risk of cancer in the liver, bladder, kidneys and prostate. Inorganic arsenic is also associated with other health related effects of a less serious nature. (ATDSR, 2000 and references therein)

The most difficult question surrounds whether health effects such as those described above can be expected to result from long-term exposure to low levels of arsenic. The U.S. EPA reviewed studies with information on the linkage between arsenic intake and skin cancer, and determined that the most useful basis for quantitative risk assessment was an epidemiology study conducted in an area of Taiwan where the well water content was high in arsenic (Tseng et al. 1968, 1977). That study had a number of limitations relating to the poor nutritional status of the population and exposure to other sources of arsenic. Furthermore, the quantitative relationships between arsenic intake and cancer risk in the Taiwanese study apply directly only to relatively high arsenic intakes. There is no agreed basis for extrapolating the data to the lower intakes

TABLE 4.2

Estimated Intake of Arsenic by Human Receptors

Diet	**Receptor 1**	**Receptor 2**		**Receptor 3**		**Receptor 4**		**Receptor 5**		**Receptor 6**	
	High Fish Diet	**High Fish Diet**		**Average Fish Diet**		**High Fish Diet**		**Average Fish Diet**		**High Fish Diet**	
Dietary Component											
Drinking Water	Municipal Supply	Municipal Supply		Back Bay		Back Bay		South Yellowknife Bay		South Yellowknife Bay	
Soil	Proposed Marina	City of Yellowknife		Latham Island		Latham Island		Dettah Community		Dettah Community	
Garden Produce	Not Applicable	City of Yellowknife		Latham Island		Latham Island		Dettah Community		Dettah Community	
Berries	Giant Mine Site	City of Yellowknife		Latham Island		Latham Island		Dettah Community		Dettah Community	
Large Game	Baker Creek	Baker Creek		Baker Creek		Baker Creek		Baker Creek		Baker Creek	
Small Game	Baker Creek	Baker Creek		Baker Creek		Baker Creek		Baker Creek		Baker Creek	
Ducks	Baker Creek	North Yellowknife Bay		Back Bay		Back Bay		South Yellowknife Bay		South Yellowknife Bay	
Fish	Back Bay	North Yellowknife Bay		Back Bay		Back Bay		South Yellowknife Bay		South Yellowknife Bay	
Estimated Mean Inorganic Arsenic Intakes (mg/(kg d))											
	Adult	**Adult**	**Child**	**Adult**	**Child**	**Adult**	**Child**	**Adult**	**Child**	**Adult**	**Child**
Scenario 1	0.0003	0.0003	0.0007	0.0006	0.0012	0.0006	0.0012	0.0005	0.0009	0.0005	0.0008
Scenario 2	0.0003	0.0003	0.0007	0.0007	0.0013	0.0007	0.0012	0.0005	0.0009	0.0005	0.0008
Scenario 3	0.0003	0.0003	0.0007	0.0007	0.0013	0.0007	0.0013	0.0005	0.0009	0.0005	0.0009
Scenario 4	0.0005	0.0003	0.0007	0.0008	**0.0014**	0.0008	**0.0014**	0.0005	0.0009	0.0005	0.0009
Scenario 5	0.0007	0.0003	0.0007	**0.0016**	**0.0023**	**0.0017**	**0.0025**	0.0007	0.0011	0.0007	0.0012

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Notes:

Mean Inorganic Arsenic Intakes included contribution from market foods.

Underline indicates that estimated mean intake exceeds the typical range of intakes for the general Canadian population, *i.e.* 0.0001-0.0007 mg/(kg d) for adults and 0.0002 to 0.0021 mg/(kg d) for children aged 5 to 11 years old.

Bold indicates that either estimated mean intake or estimated 95th percentile intake (not shown in table – see Supporting Document 6, Table 7.4.1) exceeds the Health Canada Provisional Daily Tolerable Intake of 0.002 mg/(kg d).

typical of other cases. The U.S.EPA recommends the cautious assumption that a linear relationship exists and that any exposure to arsenic, even at very low intakes, will result in a proportionate increase in cancer risks. But that approach is recognized to be cautious, and therefore to over-estimate cancer risks.

An additional source of uncertainty is related to the effects of organic arsenic compounds in humans. Animal studies demonstrate that methylated and dimethylated organic arsenic compounds are generally less toxic than inorganic arsenic and that some complex organic compounds are virtually non-toxic. (Several references are provided in Supporting Document 6). For most of the risk assessment calculations, organic arsenic from fish was assumed to be non-toxic. However, two recent studies (Mass *et al.*, 2001, Cohen *et al.*, 2002) have suggested that some forms of the dimethylated organic arsenic could be toxic. To address that possibility, a sensitivity analysis was carried out with the organic arsenic from fish assumed to be from 5% to 25% toxic. The resulting estimated intakes of toxic arsenic remained within the range of typical Canadian intakes for Scenarios 1 and 2, but not for Scenarios 3, 4 and 5.

Figure 4.5 compares estimated arsenic intakes for the Yellowknife area adult receptors to intakes related to the development of skin, bladder and liver cancers. The estimated intakes for the maximum exposed individual for all scenarios are below the intakes associated with the development of these cancers. The figure also provides a comparison to arsenic intakes in other Canadian communities with high arsenic exposures. Scenarios 1 to 3 result in estimated intakes that are below levels in these other communities (CANTOX Environmental Inc., 1999; Environment and Occupational Health Plus and SENES, 2002; O'Connor Associates, 2000). These other communities do not report increased incidences of skin cancer.

Figure 4.5 also shows that the intakes of arsenic for Scenarios 1 to 3 are below the "provisional daily tolerable intake" (PDTI) for arsenic recommended by Health Canada (1989). That value is based on technical reports from a joint meeting of FAO/WHO Expert Committee on Food Additives. The Health Canada PDTI is at the upper end of typical daily intakes for Canadians, and is intended to be protective of the development of less serious effects of arsenic exposure.

Figure 4.6 shows a comparison of arsenic-related risks in the Yellowknife to other cancer risks (Canadian Cancer Statistics, 2001; Cuzick *et al.*, 1992; Health Canada, 1989). Using the Taiwanese data and the U.S EPA assumption discussed above, it is possible to estimate the increased risk of cancer associated with the levels of arsenic intake shown in Table 4.2. The resulting estimates of cancer risk range from 7 in 10,000 for Scenario 1, to 2 in 1000 for Scenario 5. Figure 4.6 shows those estimates to be below the risks associated with skin cancer in the general Canadian population, and comparable to the risks associated with the current and proposed drinking water Maximum Acceptable Concentrations (MACs) of 25 µg/L and 10 µg/L respectively.

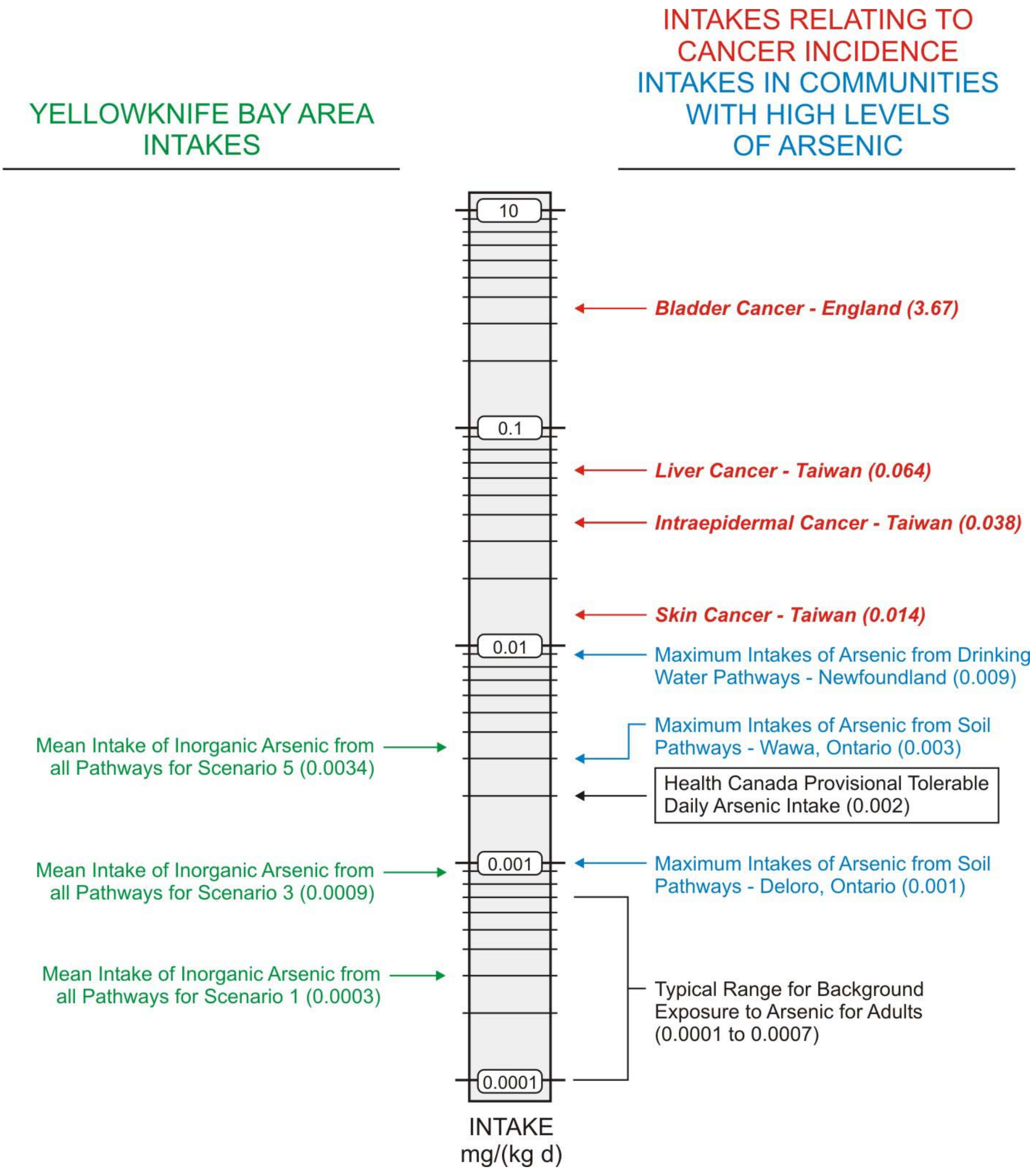
4.6 Summary of Risk Assessment and Uncertainties

For the purposes of developing an arsenic trioxide management plan, the conclusions of the ecological and human health risk assessments can be most clearly stated as follows:

- Results of the ecological risk assessment suggest that arsenic releases as high as about 16,000 kg/year (Scenario 5) result in no significant increase in the risks to aquatic plants and fish in Back Bay and Yellowknife Bay. In Baker Creek, even the current arsenic releases of 950 kg/year (Scenario 1) pose a potential risk to fish. All arsenic release scenarios result in potential risk to some terrestrial species that could inhabit Baker Creek (e.g. muskrat and mink). The primary source of risk in that case is the arsenic in Baker Creek sediments, which is linked to historical contamination.
- Results of the human health risk assessment suggest that an arsenic release rate of about 4,000 kg/year (Scenario 4) could result in arsenic intakes that exceed the Health Canada “provisional daily tolerable intake”.

The uncertainties discussed in each of the above sections need to be taken into consideration when these results are put to use. Table 4.3 summarizes the major assumptions adopted for the ecological and human health risk assessments. Each assumption was reviewed to determine whether it was likely to lead to under-estimation or over-estimation of risks. The resulting table allows the overall effect of these assumptions to be examined. It is clear that the majority of assumptions lead to “over-estimation” of risks. This is not surprising because the risk assessment was designed to remove as many uncertainties as possible and, where uncertainties remain, to adopt cautious assumptions. There are three assumptions however, that are either of “unknown effect” or could “possibly lead to under-estimation of risks”.

Given the uncertainties listed in Table 4.3, the Technical Advisor proposes the level of 2,000 kg/year as a target for maximum arsenic releases from the Giant Mine. That level of arsenic release would result in human health risks below the thresholds identified above, and it would keep average arsenic concentrations in Back Bay at or below the CCME criterion for freshwater aquatic life.



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COMPARISON OF ARSENIC INTAKES

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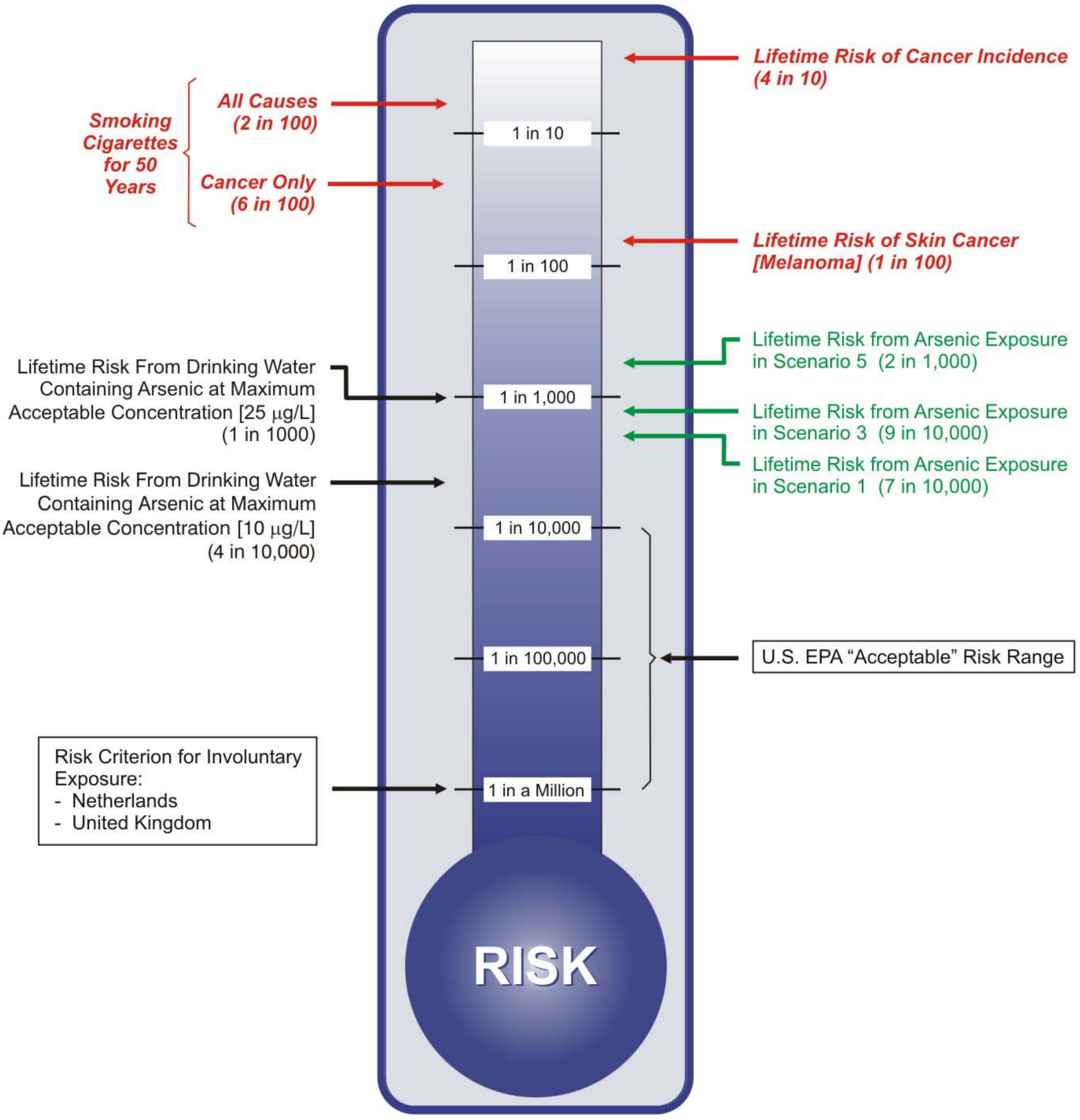

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COMPARISON OF CANCER RISKS

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TABLE 4.3
Summary of Uncertainties in Assessment of Ecological and Human Health Risks

Assumption	**Effect of Assumption**			
	Possibly Leads to Under-estimation of Risks	**Leads to Neither Over- nor Under-estimation**	**Likely Leads to Over-Estimation of Risks**	**Unknown Effect**
Arsenic Sources				
Estimates of arsenic release from Giant Mine			x	
Estimates of arsenic in water, soils, sediments		x		
Estimates of arsenic in market foods		x		
Arsenic Transport and Fate				
Mass Transfer Coefficients - Exchange between water column and sediment calibrated against measured levels		x		
Historic Loads to Area - Not known with certainty but estimated in part through model calibration		x		
Arsenic Intake by Ecological Receptors				
Residence time of Aquatic Species - Assumed to be in each water body 100% of time				
- Fish			x	
- Benthos and Aquatic Plants		x		
Aquatic Toxicity Benchmarks - Based on Laboratory Toxicity Testing			x	
Dietary and Feeding Characteristics of Terrestrial Species - Based on Literature Information		x		
Exposure of Terrestrial Species				
- Assumed while in the study area to obtain all food and water from Baker Creek			x	
- Ducks assumed to spend 100% of whole time in study area on each waterbody			x	
Bioavailability -Assumed 50% of arsenic in soil and sediments is bioavailable, based on the upper end of levels reported in the literature			x	
Terrestrial Toxicity Benchmarks - Based on Laboratory Toxicity Testing[1]				x
Arsenic Intake by Human Receptors				
Residency Time - Assumed to be present for a full 70-year lifetime at each location and to be exposed at maximum conditions			x	
Soil Ingestion for Humans - Assumed soil ingestion constant for whole year			x	
Backyard Garden Produce - Assumed to occur every day for whole year. Amount of produce grown based on literature studies		x		
Drinking Water Intakes - Assumed to occur from Back Bay or Yellowknife Bay every day for 70 years			x	
Dietary Intake Rates of Food			x	
Local Meat Sources - Assumed that all arsenic is in toxic inorganic form			x	
Local Fish Sources				
- Assumed 3% of total arsenic is in inorganic form		x		
- Assumed some portion is in organic arsenic toxic form[3]	x			
Arsenic Toxicity Benchmarks				
- Health Canada Provisional Tolerable Daily Intake[2]				x
- Oral cancer slope factor based on Taiwanese Data			x	

Prepared by: HP
Checked by: BH

Notes:

1. It is unknown whether the toxicity benchmarks derived from laboratory studies on mice are directly applicable to the wildlife in question.
2. The comparison of intakes to the Health Canada PTDI is accepted as suitably cautious by Health Canada. However, there are other arsenic toxicity benchmarks (for example the U.S.EPA Reference Dose) that are lower than the Health Canada value.
3. Scientific information available at this time suggests that most of the arsenic present in fish flesh is in the non-toxic organic arsenic form. However, additional research is needed to determine the proportion of the organic arsenic in fish in Yellowknife Bay that is toxic, and to validate the assumption that most of the organic arsenic is non-toxic.

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5. ARSENIC TRIOXIDE DUST MANAGEMENT ALTERNATIVES

5.1 Assessment Methods

5.1.1 Initial Review of Methods

Various studies of dust management alternatives have been undertaken by earlier workers. The above sections 2.5.3, 2.5.4, and 2.5.5 present an overview of many of those studies. In March 2000, the Technical Advisor convened a Senior Technical Workshop, attended by some of the top engineering specialists in Canada. One of the primary objectives of that meeting was to review the methods considered in the previous studies, identify other potentially applicable methods, and develop complete alternatives that could be carried through further analysis. Table 5.1 presents a list of the methods that came out of that workshop.

Two things were clear from Table 5.1. First, most of the methods are not independent, and would need to be combined with other methods to create complete management alternatives. A distinction was therefore made between 'methods' presented in the earlier reports and the 'alternatives' that would need to be considered in a further analysis:

> "… The term 'method' was defined as referring to an individual step in the management of the arsenic trioxide dust, and the term 'alternative' was defined as referring to a complete combination of methods that covers all steps in the project life cycle. By these definitions, pressure oxidation of the arsenic trioxide is as an example of a 'method'. However, it would need to be combined with a method to extract the dust from the underground and methods to dispose or manage residual wastes in order to form an 'alternative'. This distinction is necessary because, while some 'methods' may be very attractive as stand alone entities, the process of option selection must take into consideration all inputs and outputs. In other words, option selection needs to consider complete 'alternatives' rather than 'methods' …" (SRK, 2000)

The second thing that was clear from Table 5.1 is that many methods are worthy of consideration. Given that each combination of methods creates a new 'alternative', the number of possible alternatives is enormous. However, it was also clear that a

TABLE 5.1

Methods Considered for Management of Giant Mine Arsenic Trioxide Dust

In Situ Management	Removal of Dust	Re-Processing to Recover Gold and/or Arsenic Value	Waste Stabilization and Disposal
• Pump and treat methods - Status quo pump and treatment - Flow segregation - Partial flood - Inflow reduction Isolation methods - Hydraulic cage - Grout curtain - Diversion of Baker Creek - Surface cover - Ground freezing In situ modifications - Engineered dilution - Dust freezing - Biological treatment Relocation underground - Move deeper underground - Move above water table - New engineered/purpose built vaults	Bulk Mining Methods - Open pit mining - Re-stoping of dust - Freezing and re-stoping of frozen dust - Remote mechanical mining - Clamshell excavation (from top of chamber) Methods of Retrieving Dust in a Pipe - Wet vacuum - Dry vacuum - Fluidization from base - Flooding and pumps - Wet reverse circulation - Dry reverse circulation - Jet Boring - Dredging Other Mining Methods - Solution mining - Volatilization	Direct shipment of crude dust Production and shipment of refined dust - Fuming (selective sublimation) - Leaching & recrystallization (Hot water, caustic, etc.) Arsenic metal production Manufacture of added value products - Copper Chromated Arsenate - Lumber treated with CCA Stabilization of As_2O_3 and preparation of refractory gold values for recovery - Pressure oxidation - Biological treatments Cyanidation and gold recovery Water treatment - Water treatment for arsenic removal - Cyanide destruction	Isolation and Containment - Conventional landfill - Lined basins - Concrete/steel vaults (permanent) - Concrete/steel structures or containers (temporary) - Underground disposal Physical stabilization - Bitumen encapsulation - Cement encapsulation - Zeolite or Clay Additive - Vitrification - Vibrasonic Chemical stabilization - Precipitation With Iron - Precipitation With Calcium - Slag Disposal - Polysilicates

Prepared by: DEH
Checked by: JTC

reasonably comprehensive analysis of risks and costs would be required before any of the alternatives could be rejected or recommended. Carrying out a comprehensive analysis of the risks and costs associated with a very large number of alternatives was clearly impractical.

It was therefore decided that a small number of ‘representative alternatives’ would be selected to represent groups of similar alternatives. The representative alternatives would then be analyzed and the results presented to DIAND and other stakeholders. That process is referred to herein as the Phase 1 assessment. It is described in more detail in SRK (2001a) and summarized in Section 5.1.2 below.

Results of the Phase 1 assessment and the subsequent dialogue with stakeholders led to modifications to the original alternatives, and to selection of new alternatives for further review. The further review is referred to herein as the Phase 2 assessment, and is the primary subject of Sections 5.1.3 and 5.2 to 5.4 below, as well as Supporting Documents 7 through 19.

5.1.2 Phase 1 Assessment (October 2000 – June 2001)

In the Phase 1 assessment completed in May 2001, alternatives were selected to represent four major groups:

1) *In situ* management of the arsenic trioxide dust;
2) Removal of the dust and processing to recover gold and high purity arsenic;
3) Removal of the dust and processing to recover gold and stabilize arsenic; and,
4) Removal of the dust and processing to create a stabilized waste.

The use of representative alternatives in Phase 1 was not meant to rule out all other combinations and permutations of the methods shown in Table 5.1. Rather the intent was that, if the assessment showed one of the representative alternatives to be attractive, other similar alternatives could be given further attention in subsequent work. Conversely, if one of the representative alternatives was shown to be unattractive, it would indicate that others within the same group would only warrant further investigation if they could provide significantly better results.

Each of the Phase 1 representative alternatives was carried through engineering design, risk assessments and cost estimates. The analyses considered all aspects of each alternative, including the management of process residues and the treatment of arsenic-contaminated water.

The Phase 1 assessment indicated that the representative alternative for *in situ* management, which included freezing the ground around the chambers, would be less risky and less costly than any of the other three representative alternatives. The other alternatives all required that the dust be removed to surface, which resulted in a similar range of increases in both the risks of arsenic release and risks to worker health and safety. Of the three alternatives involving removal of the dust, the one where the dust would be mixed with cement to produce a stabilized waste was the least costly.

The Phase 1 assessment also clarified a number of questions and identified where further science and engineering studies would be needed before a final recommendation could be made. Those findings are discussed in more detail in SRK (2001a). Suggestions for further studies and for additional alternatives were also received during the public communication process that followed the completion of the May 2001 report, and were incorporated in the Phase 2 program.

5.1.3 Phase 2 Assessment (July 2001 – July 2002)

The Phase 2 assessment began with the critical scientific studies identified at the end of Phase 1. Chapters 3 and 4 above summarize the major findings. Supporting Documents 1 through 6 present details as well as relevant information gathered from earlier studies.

A short list of dust management alternatives was then selected for detailed analysis. On the basis of the Phase 1 finding that *in situ* alternatives were less risky and less costly than those requiring extraction of the dust, additional *in situ* measures were included:

- Perpetual water collection and treatment from the mine areas around the arsenic trioxide dust, including several variants of reflooding, pumping, and water treatment;

- Isolation of the dust by freezing the area around or within each chamber and stope, by three variants of the method considered in Phase 1; and

- Removal of the dust from its current locations and disposal in specially excavated caverns at the base of the mine, as proposed by participants at the June 2001 workshop.

The Phase 2 *ex situ* alternatives generally represented modifications or improvements on those considered in Phase 1. A significant change to all of the *ex situ* measures was a revision of the mining method to eliminate the need for an open pit, which had been the source of much of the risk in the Phase 1 designs. The *ex situ* alternatives considered were:

- Removal of the dust to surface and disposal in an off-site hazardous waste disposal facility, as proposed in public information sessions;

- Removal and processing to recover gold and produce a high purity arsenic product, (the processing portion of this alternative was essentially unchanged from Phase 1);

- Removal and processing to recover gold and stabilize the arsenic (also essentially unchanged from Phase 1); and,

- Removal and stabilization with cement or bitumen, as in Phase 1 but with laboratory testing to prove feasibility and support cost estimates.

Scoping level engineering and feasibility assessments were completed for each of the Phase 2 alternatives. Supporting Documents 7 through 16 present summaries of the available information. The Supporting Documents are organized by method, rather than by alternative. So, for example, Supporting Document 7 deals with the extraction of the dust from the underground stopes and chambers, which is the first step in several of the alternatives.

The engineering assessments in all cases included review of available information, both from the previous studies referred to above, and from experience elsewhere. The review of water treatment methods applicable to arsenic-contaminated water (Supporting Document 8), the conceptual design of the processes for arsenic trioxide purification (Supporting Document 12), gold recovery and arsenic stabilization (Supporting Document 13), and dust encapsulation (Supporting Document 15) required only minor modifications to the Phase 1 work in those areas. In other cases, additional studies were carried out to address specific questions raised during and after the Phase 1 assessments. The additional studies included:

- Detailed inspection of the underground access to stopes B212/213/214 and B208, and development of a dust extraction method that would not require an open pit (Supporting Document 7);
- A field test of a deep thermosyphon to confirm that passive freezing methods would work at the depths required in this application, as well as literature reviews and thermal modeling to determine the limits of feasibility of the ground freezing variants (Supporting Document 9);
- Conceptual design of a deep disposal site at the base of the mine, and methods for transporting the dust there (Supporting Document 10);
- Laboratory testing of the methods needed to handle slurries of arsenic dust prior to re-processing or shipment off-site (Supporting Document 11);
- Laboratory testing of cement and bitumen stabilization of the arsenic trioxide dust (Supporting Document 14); and,
- Field reconnaissance to identify possible sites for residue disposal (Supporting Document 16).

5.2 Description of Phase 2 Alternatives

5.2.1 Overview

Table 5.2 lists the activities that would be required under each of the Phase 2 alternatives. For simplicity, the activities are grouped into four categories "preparation activities", "implementation activities", "post-implementation activities" and "long-term requirements". Supporting Document 19, which develops a cost estimate for each alternative, provides more detail on scheduling and gives references to assumptions and engineering details to be found in the other Supporting Documents.

The following sections 5.2.2 through 5.2.8 provide more detailed descriptions of the key activities specific to each of the Phase 2 alternatives. Water treatment, residue disposals and long-term management activities that form part to all of the alternatives are discussed in Section 5.2.9. Like Table 5.2, the presentation below focuses on key concepts and simple descriptions.

5.2.2 Alternatives A1, A2, A3 – Long-Term Water Collection and Treatment

All of the Alternative A variants would rely on long-term collection and treatment of contaminated water from around the arsenic chambers and stopes. The difference among the variants A1, A2 and A3 is in the level of supplementary controls.

- Under <u>Alternative A1</u>, the mine would be allowed to flood without further controls, and wells would be installed in C-Shaft and within each dust storage area to capture all of the arsenic-contaminated water. The contaminated water would then be treated.

- Under <u>Alternative A2</u>, water would be collected from the 425 Level in the mine, *i.e.* below the bottom of the arsenic chambers and stopes. A pumping system would be installed in the 425 Level, and the groundwater around the mine would be drawn down to reduce the risk of any escape of contaminated water. The contaminated water would be treated.

- Under <u>Alternative A3</u>, additional efforts would be taken to minimize the amount of water that enters the ground surface above the arsenic trioxide chambers and stopes. The additional work would include covering the ground surface, backfilling the B1 and B2 pits, and channelizing Baker Creek where it passes over stope C212. Contaminated water would then be collected at the 425 level and treated, as in Alternative A2.

There is no doubt that these alternatives are feasible. The collection and treatment of arsenic-contaminated water is a well-established practice, both at the Giant Mine and elsewhere. Uncertainties in implementation of Alternatives A1, A2 or A3 would be limited to the amounts of water and concentrations of arsenic requiring treatment. Both types of uncertainty could be compensated for by relatively straightforward changes in the design of the collection or treatment system.

5.2.3 Alternatives B1, B2, B3 - Dust Isolation by Ground Freezing

All of the Alternative B variants would include freezing the ground around the arsenic chambers and stopes, then allowing the area to reflood slowly so that ice would form around and/or within in the chambers and stopes. A perpetual monitoring system would be established to ensure that the area around the arsenic chambers and stopes remains frozen. The difference among the variants lies in the methods that would be used to freeze the ground and keep it frozen.

- Under <u>Alternative B1</u>, the ground surface would be prepared so that there would be sufficient insulation to keep the ground frozen indefinitely. This variant was initially included to represent the case where the natural permafrost would be re-established, as was the plan in some of the very early assessments of underground disposal (see Section 2.4). Supporting Document 9 includes a comprehensive review of natural permafrost in the mine area, and concludes that it would be difficult to sustain naturally frozen conditions at the bottom of the chambers. Therefore, Alternative B1 was not carried through the subsequent assessments.

- Under Alternative B2, the ground around each chamber and stope would be frozen using a series of cooling devices installed in drillholes. The drillholes and the cooling devices would be installed from surface and would extend to below the bottom of each chamber or stope. Three types of cooling system were considered; an active cooling system similar to that used in hockey rinks; a passive cooling system consisting of thermosyphons similar to those used in the parking lot of the NWT Legislative Building; and a hybrid system that combines the other two. In all cases, the system would be installed and operated for several years until the ground around the chambers and stopes was cooled to approximately -2 °C. Groundwater would then be allowed to flood the area. The water would penetrate into the cooled rock and freeze, effectively sealing off all openings. The result would be a shell of frozen ice and rock around each chamber and stope that would prevent any future escape of arsenic. Hence the short name for this alternative is “frozen shell”.

- Under <u>Alternative B3</u>, a similar process would be followed but with the intent that ice would be formed both around and within the chambers and stopes, creating a “frozen block” rather than a frozen shell. In this case, it would first

TABLE 5.2a

Details of Alternatives A and B

	Alternative A1	**Alternative A2**	**Alternative A3**	**Alternative B1**	**Alternative B2**	**Alternative B3**
Brief description	Water Collection and Treatment with Minimum Control	Water Collection and Treatment with Continued Dewatering	Water Collection and Treatment with Seepage Control	Re-Establish Natural Permafrost	Frozen Shell	Frozen Block
Preparation activities	Clean areas around chambers and stopes. Install improved bulkheads.	Clean areas around chambers and stopes. Install improved bulkheads. Construct/upgrade long term ramp access to 425 Level.	Clean areas around chambers and stopes. Install improved bulkheads. Construct/upgrade long term ramp access to 425 Level. Backfill and cover B1 and B2 Pits. Construct impermeable channel for Baker Creek over C212.	Clean areas around chambers and stopes. Install improved bulkheads or plugs and backfill drifts. Backfill and cover B1, B2 Pits. Construct impermeable channel for Baker Creek over C212, and improve channel elsewhere. Lower and/or place rock collar around bedrock knoll over AR1. Cover surface over AR2, AR3, AR4 with low permeability soil and organic layer.	Clean areas around chambers and stopes. Install improved bulkheads or plugs and backfill drifts. Backfill drifts below stopes and chambers. Backfill and cover B1 and B2 Pits. Construct impermeable channel for Baker Creek over C212.	Clean areas around chambers and stopes. Install improved bulkheads or plugs and backfill drifts. Backfill drifts below stopes and chambers. Backfill and cover B1 and B2 Pits. Construct impermeable channel for Baker Creek over C212.
Implementation activities	Install wells to collect water around chambers and stopes. Allow mine to flood. Maintain 10 m drawdown by pumping from wells. Construct improved water treatment system. Treat contaminated water from well system.	Install pumping and piping system on 425 Level. Allow mine to flood to 425 Level only. Construct improved water treatment system. Pump minewater from 425 Level and treat.	Install pumping and piping system on 425 Level. Allow mine to flood to 425 Level only. Construct improved water treatment system. Pump minewater from 425 Level and treat.	Install active freezing system around chambers and stopes and freeze bedrock. Allow mine to reflood at controlled rate to create ice around chambers and stopes. Construct improved water treatment system.	Install freezing system around chambers and stopes and freeze bedrock. Allow mine to reflood at controlled rate to create ice around chambers and stopes. Construct improved water treatment system.	Install freezing system below and around chambers and stopes and freeze bedrock and dust. Allow mine to reflood at controlled rate to create ice around and within chambers and stopes. Construct improved water treatment system.
Post-implementation activities	Intensively monitor groundwater and surface water. Make necessary improvements to well system to ensure complete collection of contaminated water. Treat contaminated water from well system. Place water treatment sludge in secure disposal area.	Intensively monitor groundwater and surface water. Make necessary improvements to pumping system to ensure complete collection of contaminated water. Treat contaminated water from 425 Level pumping system. Place water treatment sludge in secure disposal area.	Intensively monitor groundwater and surface water Make necessary improvements to pumping system to ensure complete collection of contaminated water. Treat contaminated water from 425 Level pumping system. Place water treatment sludge in secure disposal area.	Monitor ground temperatures and groundwater to ensure chambers and stopes remain frozen. Make necessary improvements to surface conditions to ensure permafrost does not thaw. Treat contaminated water from reflooding of unfrozen perimeter around chambers and stopes. Place water treatment sludge in secure disposal area.	Monitor ground temperatures and groundwater to ensure chambers and stopes remain frozen. Add or replace freezing devices as needed to improve containment. Treat contaminated water from reflooding of unfrozen perimeter around chambers and stopes. Place water treatment sludge in secure disposal area.	Monitor ground temperatures and groundwater to ensure chambers and stopes remain frozen. Add or replace freezing devices as needed to improve containment. Treat contaminated water from reflooding of unfrozen perimeter around chambers and stopes. Place water treatment sludge in secure disposal area.
Long term requirements	Continue collection and treatment of water from well system. Monitor groundwater around mine. Monitor and maintain sludge disposal area.	Continue collection and treatment of water from 425 Level. Monitor groundwater around mine. Monitor and maintain sludge disposal area.	Continue collection and treatment of water from 425 Level. Monitor groundwater around mine. Monitor and maintain sludge disposal area.	Continue collection and treatment of water from remainder of mine. Monitor ground temperatures and groundwater around mine. Monitor and maintain sludge disposal area.	Continue collection and treatment of water from remainder of mine. Monitor ground temperatures and groundwater around mine. Re-activate freezing system as needed. Monitor and maintain sludge disposal area.	Continue collection and treatment of water from remainder of mine. Monitor ground temperatures and groundwater around mine. Re-activate freezing system as needed. Monitor and maintain sludge disposal area.

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TABLE 5.2b

Details of Alternatives C, D, E, F and G

	Alternative C	**Alternative D**	**Alternative E**	**Alternative F**	**Alternative G1**	**Alternative G2**
Brief description	Removal and Deep Disposal	Removal and Off-Site Disposal	Removal, Gold Recovery and Arsenic Trioxide Purification	Removal, Gold Recovery and Arsenic Stabilization	Removal and Cement Encapsulation	Removal and Bitumen Stabilization
Preparation activities	Prepare access to deep mine areas. Begin preparation and testing of new deep mine disposal vaults. Prepare dust transfer system. Initiate development of access for dust extraction.	Prepare surface plant for dust preparation and packaging. Initiate development of access for dust extraction.	Prepare surface plant for fuming and condensing arsenic trioxide into a purified product. Construct secure landfill to receive stabilized process residue. Initiate development of access for dust extraction.	Prepare surface plant for pressure oxidation of dust with iron. Construct secure landfill to receive stabilized waste. Initiate development of access for dust extraction.	Prepare surface plant for mixing dust with cement and aggregate. Construct secure landfill for receiving stabilized dust. Initiate development of access for dust extraction.	Prepare surface plant for mixing dust with bitumen. Construct secure landfill for receiving stabilized dust. Initiate development of access for dust extraction.
Implementation activities	Extract dust by combination of borehole mining, remote mucking and restoping. Transfer wet dust and rock through raises to deep disposal vaults. Recover settled water from the vaults and return to extraction process. Construct improved water treatment system. Collect and treat water lost to mine during extraction.	Extract dust by combination of borehole mining, remote mucking and restoping. Thicken, filter and package dust in surface plant. Ship dust off-site to hazardous waste disposal facility in Alberta. Construct improved water treatment system. Collect and treat water lost to mine during extraction.	Extract dust by combination of borehole mining, remote mucking and restoping. Thicken, filter and dry dust. Fume arsenic, clean off-gas, condense purified arsenic trioxide. Package and ship arsenic trioxide for sale. Stabilize fuming residue and recover gold for sale. Filter stabilized residue and discharge to secure landfill. Cover landfill cells with soil for interim. Construct final cover on landfill as cells become completely filled. Construct improved water treatment system. Collect and treat water lost to mine during extraction .	Extract dust by combination of borehole mining, remote mucking and restoping. Thicken dust slurry and feed to pressurized autoclave with iron, oxygen. Neutralize autoclave product with lime. Recover gold for sale. Filter stabilized residue and discharge to secure landfill. Cover landfill cells with soil for interim. Construct final cover on landfill as cells become completely filled. Construct improved water treatment system. Collect and treat water lost to mine during extraction.	Extract dust by combination of borehole mining, remote mucking and restoping. Thicken, filter and mix dust with cement and aggregate. Pipe cement-dust to cells in secure landfill. Cover cells with soil for interim. Construct final cover on landfill as cells become completely filled. Construct improved water treatment system. Collect and treat water lost to mine during extraction.	Extract dust by combination of borehole mining, remote mucking and restoping. Thicken, filter and mix dust with heated bitumen. Truck stabilized waste to cells in secure landfill. Cover cells with soil for interim. Construct final cover on landfill as cells become completely filled. Construct improved water treatment system. Collect and treat water lost to mine during extraction.
Post-implementation activities	Close out dust transfer facilities. Seal deep disposal vaults. Allow controlled reflooding of emptied stopes and chamber areas. Maintain drawdown and collect and treat contaminated water from around arsenic chambers and stopes. Place water treatment sludge in secure disposal area.	Close out surface facilities. Allow controlled reflooding of emptied stopes and chamber areas. Maintain drawdown and collect and treat contaminated water from around arsenic chambers and stopes. Place water treatment sludge in secure disposal area.	Close out surface facilities. Allow controlled reflooding of emptied stopes and chamber areas. Maintain drawdown and collect and treat contaminated water from around arsenic chambers and stopes. Dispose water treatment sludges in secure landfill.	Close out surface facilities. Allow controlled reflooding of emptied stopes and chamber areas. Maintain drawdown and collect and treat contaminated water from around arsenic chambers and stopes. Dispose water treatment sludges in secure landfill.	Close out surface facilities. Allow controlled reflooding of emptied stopes and chamber areas. Maintain drawdown and collect and treat contaminated water from around arsenic chambers and stopes. Dispose water treatment sludges in secure landfill.	Close out surface facilities. Allow controlled reflooding of emptied stopes and chamber areas. Maintain drawdown and collect and treat contaminated water from around arsenic chambers and stopes. Dispose water treatment sludges in secure landfill.
Long term requirements	Continue collection and treatment of water from remainder of mine. Monitor groundwater around mine. Monitor and maintain sludge disposal area.	Continue collection and treatment of water from remainder of mine. Monitor groundwater around mine. Monitor and maintain sludge disposal area.	Treat small volumes of leachate from secure landfill. Continue collection and treatment of water from remainder of mine. Monitor groundwater around mine. Monitor and maintain sludge disposal area.	Treat small volumes of leachate from secure landfill. Continue collection and treatment of water from remainder of mine. Monitor groundwater around mine. Monitor and maintain sludge disposal area.	Treat small volumes of leachate from secure landfill. Continue collection and treatment of water from remainder of mine. Monitor groundwater around mine. Monitor and maintain sludge disposal area.	Treat small volumes of leachate from secure landfill. Continue collection and treatment of water from remainder of mine. Monitor groundwater around mine. Monitor and maintain sludge disposal area.

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be necessary to install a cooling system below each chamber and stope. Once sufficiently cold conditions are established, the base of each chamber or stope would be saturated with water, which would create a frozen plug. Cooling devices similar to those in Alternative B2 would be installed along the walls of each chamber and stope, and more water would be added to form ice throughout the area.

In both Alternative B2 and B3, the cooling system would be turned off once sufficiently cold conditions are established, and only re-started if and when the monitoring system detected increasing temperatures. Results presented in Supporting Document 9 indicate that it may be possible to wait many decades between each freezing cycle, particularly if a "frozen block" is present in and around each chamber and stope.

Ground freezing is a well established construction method. It has been used extensively for the construction of tunnels and mine shafts, and in Northern Saskatchewan it has been used to prevent water entry into underground mines (Newman and Maishman, 2000). Investigations to assess the applications described here are presented in Supporting Document 9. In brief, the conclusions are that both Alternative B2 and B3 are feasible. There is some uncertainty about the time required for cooling, but that could be compensated for by increases or decreases in the number of cooling devices.

5.2.4 Alternative C - Removal and Deep Disposal

Under <u>Alternative C</u>, the arsenic trioxide dust would be extracted from the current locations and transported to the base of the mine, where it would be re-interred in specially prepared vaults. Extraction of the dust would be by a combination of three mining methods: wet borehole mining for the bulk of the dust; conventional mucking for the dust in regular-walled chambers; and re-stoping for the dust in the bottom of the irregular stopes B208 and B212-214. Details of the extraction methods are quite complex, especially at the base of the mined-out stopes, and presented in detail in Supporting Document 7.

The deep disposal vaults would be constructed at the base of the Giant Mine, approximately 700 m below the ground surface. Dust would be transported to the vaults by a system of raises. Details of the deep disposal system are presented in Supporting Document 10.

Deep disposal is recognized and accepted practice for hazardous waste management. In examples elsewhere, there have been requirements to demonstrate that the deep disposal area is sufficiently isolated from the ecosystem, and/or to ensure that the rock around the deep disposal vaults is as impermeable as possible. Results of the geochemical studies presented in Supporting Document 3, and similar studies from the deeper Con Mine, indicate that vaults at 700 m would be below the depth at which surface waters circulate through the ground (INTERA *et al.*, 1997). The implication is that the dust would be effectively isolated from the ecosphere. Testing of the rock permeability could be undertaken before and during construction, and alternative sites or improvement methods could be selected if poor conditions are encountered.

5.2.5 Alternative D - Removal and Surface Disposal

Under Alternative D, the arsenic trioxide dust would be removed from the chambers and stopes and then shipped off site to the nearest hazardous waste disposal site, assumed to be in Alberta. Extraction of the dust would be by the methods listed above and described in Supporting Document 7. The dust would be extracted in a slurry and so would need to be decanted, filtered, and packaged prior to shipping off site. The preparation of the dust for shipping would be very similar to that for processing, as described in Supporting Document 15.

Off-site disposal of the arsenic trioxide dust is certainly technically feasible. It may prove difficult to find a site that will accept such a large quantity of hazardous material, and it may prove difficult to get agreement to ship the dust through the intervening communities. However, both of those difficulties can in theory be overcome, so Alternative D was carried through the subsequent assessments.

5.2.6 Alternative E – Removal, Gold Recovery and Arsenic Trioxide Purification

Under Alternative E, the dust would be extracted and put through a fuming process to recover high purity arsenic trioxide and gold. The high purity arsenic trioxide would be sold to American wood preservative manufacturers. Residues from the process would be stored in an on-site hazardous waste landfill. The methods for removing the dust from the chambers and stopes would be those described in Supporting Document 7. The fuming process is described in Supporting Document 12.

Alternative E has much similarity to the WAROX project that was conceived by the mine operators in the 1980's. Certainly the idea of making a useful product from the arsenic trioxide dust is attractive. However, in response to regulatory changes recently proposed by the U.S. Environmental Protection Agency, American producers of wood preservatives have decided to curtail arsenic use. That decision will effectively make it very difficult to find a market for high purity arsenic trioxide. For that reason, Alternative E was not carried through subsequent analyses.

5.2.7 Alternative F – Removal, Gold Recovery and Arsenic Stabilization

Under Alternative F, the dust would be extracted and then put through a pressure oxidation process to recover gold and convert the arsenic trioxide to a more stable "scorodite" form. The "scorodite" residues would be stored in an on-site hazardous waste landfill. The methods for removing the dust from the chambers and stopes would again be those described in Supporting Document 7. The pressure oxidation process is described in Supporting Document 13.

The work presented in Supporting Document 13 concludes that pressure oxidation of the dust is feasible. The use of pressure oxidation to recover gold and stabilize arsenic has been demonstrated at other sites, including the Con Mine. The scorodite residues from those processes appear to be stable under most disposal conditions (CANMET, 2000). However, in all of the full scale examples known to the Technical Advisor, arsenic trioxide comprises only a small fraction of the input to the autoclave. Therefore, there is some uncertainty as to the size of the autoclave needed to achieve complete the conversion of arsenic trioxide to scorodite, and the requirements for other reagents, particularly iron. Those uncertainties translate into uncertainties in costs and in the extent to which the process residues will be stable. Alternative F assumes that the scorodite residue will need to be disposed in a secure landfill.

5.2.8 Alternatives G1, G2 - Removal and Encapsulation

Both of the Alternative G variants would require the dust to be extracted, again as described in Supporting Document 7, and then processed to make a more stable form. Supporting Documents 14 and 15 present the results of stabilization tests and the designs for full scale stabilization processes. In both cases, the "stabilized" waste would still require disposal in a hazardous waste landfill constructed on the site. The difference between the variants is in the method of stabilization.

Under Alternative G1, the dust would be mixed with cement, sand, aggregate and water to form a weak concrete. Laboratory studies presented in Supporting Document 15 suggest that the resulting material would be stable, but that leachability of arsenic from the cement material would remain high. The mixture would therefore need to be deposited in a lined landfill, and eventually covered with a low permeability cover.

Cement encapsulation is an-established waste disposal methods. It has been applied at full scale for a variety of waste materials (see Supporting Document 15, Appendix A for examples). The processing methods and requirements are well understood. It is clear from experience with other material that refinement of mix ratios and curing conditions can improve the physical stability of cemented wastes. However, the current Alternative G1 assumes that that the cement encapsulated dust will need to be covered within several days of deposition. In effect, the cement encapsulation is only relied upon to keep the dust from blowing away during the time needed to cover each cell.

Under Alternative G2, the dust would be incorporated into a mass of bitumen to produce a material that is water-repellant, and would minimize the dissolution of arsenic. The bitumen-stabilized dust would still need to be disposed in a secure landfill, due to the high total concentrations of arsenic. Laboratory studies presented in Supporting Document 15 show that stabilization with bitumen appears to be a very effective means of limiting the leaching of arsenic from the arsenic trioxide dust. Research into the use of bitumen, both alone and in combination with cement, for encapsulation of arsenic wastes is being actively pursued in this and other projects. However, to date the Technical Advisor has been unable to find an example of bitumen stabilization being applied at full scale. Alternative G2 was therefore not carried through the subsequent assessments.

5.2.9 Related Activities and Requirements

It is apparent from Table 5.2 that implementation of any of the alternatives will be more complex than indicated by the descriptions presented in the preceding section. In particular, all of the alternatives have associated water treatment and residue disposal requirements, and all require some form of long-term management.

Water treatment requirements can be most easily explained by reference to three time periods – during preparation and implementation, in the medium term after implementation, and over the long term:

- During preparation and implementation of an alternative, water treatment requirements would be limited to dealing with the water extracted by the mine dewatering system. In some alternatives, water contaminated by dust extraction or processing would also need to be treated. However, most such water would be recycled or consumed in processing of the dust.

- For Alternatives A1 through A3, the flow of water directly through the arsenic trioxide storage areas would determine water treatment needs in both the medium term after implementation and over the long term.

- For Alternatives B2 and B3, the flow of water through unfrozen areas around the chambers and stopes would drive water treatment needs in the medium term after implementation. For the assessments presented herein, it was assumed that only 1% of the dust will end up outside of the frozen zones. Still, that amount of dust would be sufficient to cause extensive contamination of the groundwater when the mine refloods. Alternatives B2 and B3 would therefore include a "chamber water" collection and treatment system, specifically designed to flush out and treat the residual arsenic.

- A similar requirement will exist for the medium term after implementation of Alternatives C through G. Those alternatives all include extraction of the dust. However, as explained further in Supporting Document 7, it will not be possible to extract all of the dust. The contact of water with any residual dust would lead to very high arsenic concentrations. Alternatives C through G would therefore also include a chamber water collection and treatment system, in these cases designed to flush and treat an assumed 2% residual dust.

- Over the long term under Alternatives B through G, the residual or unfrozen dust around the chambers and stopes would be flushed out and water quality in the area would approach that of the rest of the mine. The studies described in Supporting Document 4 suggest that water from the rest of the mine will also be contaminated with arsenic. Although arsenic concentrations are expected to be low, the mine area groundwater may still be too contaminated for direct release to Baker Creek or Back Bay. To account for that possibility, all of the alternatives include long-term collection and treatment of groundwater from the mine area.

A further complication in the water treatment needs arises because, as discussed in Supporting Document 8, water carrying high arsenic concentrations is most efficiently treated by a system that is different from the conventional arsenic treatment method. The most likely source of highly contaminated water would be the "chamber water" collection system discussed above and included in Alternatives B through G. Those alternatives would therefore include construction and operation of both a calcium precipitation system for medium-term treatment of the chamber water and a conventional ferric precipitation system for treatment of water from the rest of the mine.

Various forms of residues would be generated by the different alternatives. The two broad categories are process residues and water treatment sludges.

Alternatives D through G would produce some form of process residue. Under Alternative D, the residue would be the prepared dust that is shipped off site to a hazardous waste landfill elsewhere. Alternative F would produce approximately 1,300,000 m^3 of scorodite and process neutralization residues that would need to be placed in a secure disposal facility constructed somewhere on the site. Alternative G1 would produce approximately 400,000 m^3 of cement encapsulated waste that would also need to be placed in a secure disposal facility.

The water treatment activities discussed above would produce arsenic-contaminated sludges that would need to be placed in secure disposal facilities somewhere on the site. Although the volumes of water treatment sludges would be much smaller than the volumes of process residues, they are significant because they would result in a waste disposal requirement even for those alternatives where no dust processing occurs.

Supporting Document 16 presents designs for secure disposal facilities to store process residues and water treatment sludges (for Alternatives F and G), or the water treatment sludges only (for Alternatives A through D). The facilities would be lined and covered, and would incorporate a leachate collection system. Any leachates from these disposal facilities are likely to be contaminated with arsenic, so it was also assumed that the leachates would be collected and treated.

The combination of long-term water treatment and the presence of secure disposal facilities mean that all of the alternatives would require some form of long-term management. There are quite significant differences in long-term management costs among the alternatives. For examples, Alternatives A2 and A3 require that underground access be maintained indefinitely and therefore carry much higher long-term costs. For other alternatives, long-term management activities would include maintenance of disposal facilities, water treatment, and monitoring. Even when the associated costs are low, long-term management requirements have a negative connotation. In simple terms, the long term management requirements mean that none of the alternatives would allow a “walk away” outcome.

5.3 Assessment of Risks

Once the scoping level engineering was completed, the risks associated with each alternative were assessed. The risk analysis is presented in full in Supporting Document 18. For each of the Phase 2 alternatives, three categories of risk were considered:

- Risks of arsenic release in the short term – The risk that a release of arsenic sufficient to affect ecological or human health could occur during the preparation or implementation phase of each alternative;
- Risks of arsenic release in the long term – The risk that a quantity of arsenic sufficient to affect ecological or human health could be released to the receiving environment from the site after complete implementation of each alternative, within a period of 500 years after implementation; and,
- Worker health and safety risks – The conventional safety risks and the arsenic-related health risks that would be faced by workers active in the preparation, implementation, and post-implementation activities.

To assess the risks of short-term arsenic release associated with each alternative, it was assumed that a single arsenic release of 1000 kg or more would be significant in terms of environmental or human health effects. Supporting Document 18, Attachment

1, provides an assessment to support that assumption. The preparation and implementation activities required for each alternative were then listed, and the probability of a significant short-term arsenic release from each activity was estimated

The rates of long-term arsenic release under each alternative were predicted through a series of calculations that are presented in detail in Supporting Document 17. Table 5.3 provides a summary of the results. All of the alternatives are expected to keep total arsenic releases from the mine to around 500 kg/yr when they function as intended. However, a lack of maintenance or site supervision would eventually result in significantly higher arsenic release rates under most of the alternatives.

TABLE 5.3
Estimates of Long-Term Arsenic Release under Each Alternative

Alternative	**Release from Surface Sources (kg/yr)**	**From Mine and Surface to Treatment Plant (kg/yr)**	**Release from Treatment Plant (kg/yr)**	**Total with Treatment Plant Operating (kg/yr)**	**Total with Treatment Plant Inoperative (kg/yr)**
Current Conditions (for comparison)	664	14,536	389	1,053	15,200
A1. Water Treatment with Minimum Control	359	9,900	134	493	10,259
A2. Water Treatment with Drawdown	359	13,295	183	542	13,654
A3. Water Treatment with Seepage Control	359	2,548	182	541	2,902
B2. Frozen Shell	359	626	134	493	985
B3. Frozen Block	359	626	134	493	985
C. Deep Disposal	359	776	134	494	1,135
D. Removal and Surface Disposal	359	626	134	494	985
F. Removal, Gold Recovery and Arsenic Stabilization	359	903	136	497	1,264
G1. Removal and Cement Encapsulation	359	6,871	135	538	7,274

Prepared by: DEH
Checked by: DBM

To assess the risks associated with potential lapses in long-term maintenance or site supervision, three cases were considered for each alternative:

- A one-year failure of the water collection and treatment system, for example due to significant mechanical failures;
- A ten-year failure of the water treatment system and other site maintenance activities, for example due to a cessation of federal funding.
- A 100-year failure of all of the site maintenance and operation functions, including water collection, treatment and site security, for example due to a complete collapse of civil order.

Results of the ecological and human health risk assessments presented in Chapter 4 and Supporting Document 6 suggest that there would be minimal risk at arsenic release rates as high as 4000 kg/year. To err on the side of caution in the alternatives assessment, a long-term release of 2000 kg/year was assumed to be significant.

The qualitative worker health and safety risk assessment considered the conventional risks (*i.e.* industrial accident risks) and arsenic exposure risks to workers involved in each of the alternatives. Risks were characterized by interviewing engineers familiar with major steps in each alternative and subjectively rating risks as “high”, “moderate”, or “low”, with the categories assumed to refer to conditions typical of the mining industry.

Table 5.4 presents a summary of the above risks associated with each of the Phase 2 alternatives. The primary sources of each type of risk are as follows:

- The very low and low risks of arsenic release in the short term under Alternatives A, B and C arise primarily from the potential for a spill from the water treatment sludge line or pond. The moderate short-term risks associated with Alternatives F and G1 arise from the potential for spills or releases during the dust extraction process. The highest short-term risks are under Alternative D, and arise from the risk of accidents during the off-site transportation of dust to a disposal area.
- The long-term risks associated with Alternative A are moderate or high because of the reliance on perpetual pumping to collect highly contaminated

water. Alternative A1 has a particularly high long-term risk, because the minimal drawdown means that contaminated water could escape the site if there is even a one-year failure of the water collection and treatment system. Alternatives A2 and A3 pose lower risks because, in the event of a collection system failure, the groundwater table would take several years to recover before any contaminated water would leave the site.

- Alternative B2 and B3 pose lower long term risks because the ground around the arsenic trioxide dust would remain frozen for decades, even without intervention. (That effect is described in Supporting Document 9).
- Alternative C poses very low long term risks because dust in the deep disposal vaults would effectively be isolated from all contact with the ecosphere.
- The low and very low long-term risks from Alternatives D, F and G1 are associated with the requirement for collection and treatment of leachate from residue disposal areas. Alternative G1 produces a less stable residue than Alternative F, and therefore poses a slightly higher long-term risk.
- Alternatives C, D, F and G1 require handling of the arsenic trioxide dust in confined underground conditions, which is the main contributor to the moderate worker health and safety risks.

TABLE 5.4

Summary of Risk Assessment for Phase 2 Alternatives

Alternative	**Probability of Significant Arsenic Release**		**Worker Health & Safety Risk**
	Short Term	Long Term	
A1. Water Treatment with Minimum Control	Low	High	Low
A2. Water Treatment with Drawdown	Low	Moderate	Low
A3. Water Treatment with Seepage Control	Low	Moderate	Low
B2. Frozen Shell	Very Low	Low	Low
B3. Frozen Block	Very Low	Low	Low
C. Deep Disposal	Low	Very Low	Moderate
D. Removal & Surface Disposal	High	Very Low	Moderate
F. Removal, Gold Recovery and Arsenic Stabilization	Moderate	Very Low	Moderate
G1. Removal & Cement Encapsulation	Moderate	Low	Moderate

Prepared by: DEH
Checked by: DBM

5.4 Cost Estimates

Cost estimates for each alternative were developed from the basic engineering analyses. Cost estimate summaries for each of the currently feasible alternatives are summarized in Table 5.5. The table summarizes estimated capital costs, operating costs and revenue for major components of each alternative. All costs are shown as net present values, calculated using a discount rate of 3%. Details of the cost estimates are provided in Supporting Document 19.

Table 5.6 presents a range of cost estimates to reflect uncertainties in the design assumptions and unit cost estimates. The ranges require explanation:

- For Alternatives A1, A2 and A3, the most significant uncertainty is how much of the groundwater that floods the mine will pass through the arsenic trioxide storage areas. Even small changes in the flowrates through those areas would significantly increase or decrease the concentrations of arsenic in the water, and thereby increase or decrease treatment costs. The requirements for surface improvements also contributes to uncertainty in the estimated cost of Alternative A3.

- For Alternatives B2 and B3, the most significant uncertainty is the rate of ground freezing. If freezing is more rapid or more difficult than predicted, it would be necessary to install fewer or more freezing devices.

- The cost of extracting the dust is a significant uncertainty for all of Alternatives C through G. The amount of dust that would remain in and around the chambers and stopes is also uncertain, and leads to uncertainties in medium-term water treatment costs for these alternatives.

- For Alternative C, additional uncertainties arise in the costs of mining the deep chambers and the need for dust re-handling between the current chambers and stopes and the deep disposal areas.

- For Alternative D, the costs of off-site shipment and disposal at a hazardous waste facility are highly uncertain, and contribute most of the very wide range shown in the table.

- For Alternative F, reagent costs and power requirements are additional sources of uncertainty, as is the capital cost for the autoclave.

- For Alternative G1, reagent requirements are somewhat better understood because of the recent laboratory testing, but uncertainty as to which ratios of dust and cement addition would prove acceptable leads to uncertainty in the operating cost estimates.

5.5 Comparison of Phase 2 Alternatives

Results of the assessments of the Phase 2 alternatives are compared in Table 5.7. The "overall risks" shown in the table reflect a combination of the various categories of risk characterized in Section 5.3 above. The approach was to assume that the overall risk would be determined by the highest risk, in any category, associated with each alternative. For example, Alternative A1 was assigned a "High" overall risk because of the high risks associated with long-term release of arsenic, although it otherwise presents low risks in the short term and low risks to worker health and safety. This approach effectively places equal emphasis on the three categories of risk. It should be noted that stakeholders will have different opinions as to how to weight the various risk categories. For example, some stakeholders may put less emphasis on long-term risks; others may argue that workers are compensated for the health and safety risks they are exposed to, and therefore that category of risk should be discounted.

The range of net costs shown in each table comes directly from Table 5.6 above. Given the technical and permitting uncertainties associated with each alternative, the Technical Advisor believes that the cost ranges provide a more realistic basis for comparison than the base case estimates.

TABLE 5.5
Summary Cost Estimates for Phase 2 Alternatives

	Item	Alternative A1 Water Treatment with Minimum Control	Alternative A2 Water Treatment with Drawdown	Alternative A3 Water Treatment with Seepage Control	Alternative B2 Frozen Shell	Alternative B3 Frozen Block	Alternative C Removal & Deep Disposal	Alternative D Removal & Surface Disposal	Alternative F Removal, Gold Recovery & Arsenic Stabilization	Alterative G1 Removal & Cement Stabilization
COSTS										
CAPITAL	Bulkhead stabilization	$2,780,000	$2,780,000	$2,780,000	$2,780,000	$2,780,000	-	-	-	-
	Pit backfilling	-	-	$5,090,000	$3,850,000	$3,850,000	-	-	-	-
	Baker Ck. improvement	-	-	$790,000	$790,000	$790,000	-	-	-	-
	Mine water pumping	$1,300,000	$70,000	$70,000	$1,100,000	$1,310,000	$1,140,000	$1,420,000	$1,180,000	$1,420,000
	Water treatment	$4,170,000	$4,950,000	$4,950,000	$6,780,000	$6,780,000	$6,230,000	$7,100,000	$6,350,000	$7,100,000
	Freezing system	-	-	-	$31,620,000	$35,450,000	-	-	-	-
	Underground development	-	-	-	-	-	$71,380,000	$18,770,000	$18,770,000	$18,770,000
	Dust processing	-	-	-	-	-	-	$24,080,000	$90,110,000	$27,940,000
	Sludge & waste disposal	$970,000	$1,140,000	$490,000	$2,270,000	$2,270,000	$2,410,000	$3,080,000	$27,230,000	$12,380,000
	UG Care & maintenance	-	$130,000	$130,000	$130,000	$130,000	$130,000	$130,000	$130,000	$130,000
	Monitoring	-	-		$1,330,000	$1,330,000	-	-	-	-
	Project closure	-	-		$140,000	$140,000	$80,000	$1,120,000	$2,890,000	$1,290,000
	NPV subtotal	$9,220,000	$9,100,000	$14,330,000	$50,780,000	$54,830,000	$81,370,000	$55,690,000	$146,660,000	$69,020,000
OPERATING	Mine water pumping	$1,340,000	$1,460,000	$1,460,000	$930,000	$810,000	$510,000	$740,000	$550,000	$740,000
	Water treatment	$16,940,000	$22,020,000	$19,480,000	$18,950,000	$18,310,000	$26,030,000	$24,710,000	$25,840,000	$24,710,000
	Freezing system maintenance	-	-	-	$7,160,000	$7,370,000	-	-	-	-
	Extraction/deep disposal	-	-	-	-	-	$56,190,000	$62,380,000	$53,140,000	$62,380,000
	Dust prep/processing	-	-	-	-	-	-	$661,460,000	$204,540,000	$59,300,000
	Waste disposal	$780,000	$790,000	$760,000	$7,170,000	$7,170,000	$9,680,000	$13,410,000	$14,460,000	$15,460,000
	U/G Care & maintenance	$10,650,000	$53,940,000	$53,940,000	$10,650,000	$13,620,000	$34,630,000	$20,100,000	$32,550,000	$20,100,000
	Monitoring	$1,140,000	$1,140,000	$1,140,000	$3,400,000	$3,400,000	$1,140,000	$1,140,000	$1,140,000	$1,140,000
	NPV subtotal	$30,850,000	$79,360,000	$76,780,000	$48,260,000	$50,680,000	$128,180,000	$783,960,000	$332,230,000	$183,840,000
SUBTOTAL		$40,070,000	$88,460,000	$91,110,000	$99,040,000	$105,510,000	$209,550,000	$839,650,000	$478,890,000	$252,860,000
REVENUE										
	Gold Sales	-	-	-	-	-	-	-	$42,060,000	-
	Arsenic Sales	-	-	-	-	-	-	-	-	-
	NPV subtotal	-	-	-	-	-	-	-	$42,060,000	-
NET COST	NPV	$40,070,000	$88,460,000	$91,110,000	$99,040,000	$105,510,000	$209,550,000	$839,650,000	$436,820,000	$252,860,000

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TABLE 5.6
Summary of Cost Ranges for Phase 2 Alternatives

Alternative	**Capital Cost ($M)**	**Operating Cost ($M)**	**Revenue ($M)**	**Net Cost ($Million)**	
				Expected	**Range**
A1. Water Treatment with Minimum Control	9	31	-	40	30-70
A2. Water Treatment with Drawdown	9	79	-	88	80-110
A3. Water Treatment with Seepage Control	14	77	-	91	80-120
B2. Frozen Shell	51	48	-	99	90-110
B3. Frozen Block	55	51	-	106	90-120
C. Deep Disposal	81	128	-	209	190-230
D. Removal & Surface Disposal	56	784	-	840	600-1000
F. Removal, Gold Recovery & Arsenic Stabilization	147	332	42	437	400-500
G1. Removal & Cement Encapsulation	69	184	-	253	230-280

Prepared by: DEH
Checked by: DBM

TABLE 5.7
Summary of Risks and Costs for Phase 2 Alternatives

Alternative	**Overall Risk**	**Dominant Risk Category**	**Net Cost Range ($Million)**
A1. Water Treatment with Minimum Control	High	Long term	30-70
A2. Water Treatment with Drawdown	Moderate	Long term	80-110
A3. Water Treatment with Seepage Control	Moderate	Long term	80-120
B2. Frozen Shell	Low	Long term	90-110
B3. Frozen Block	Low	Long term	90-120
C. Deep Disposal	Moderate	Worker H&S	190-230
D. Removal & Surface Disposal	High	Short term	600-1000
F. Removal, Gold Recovery & Arsenic Stabilization	Moderate	Worker H&S	400-500
G1. Removal & Cement Encapsulation	Moderate	Worker H&S	230-280

Prepared by: DEH
Checked by: DBM

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6. RECOMMENDATIONS

As stated in Section 1.4 above, the primary role of this report is to provide a basis for a program of intensive public consultation that will assist DIAND in selecting a preferred alternative for managing the arsenic trioxide dust. The background information, review of current conditions, risk assessments, and alternatives assessments presented herein provide a strong basis for narrowing the range of possible alternatives. However, both DIAND and the Technical Advisor believe that an additional type of information, namely the opinions and concerns of local stakeholders, must be understood before a final selection can be made.

In the public consultation carried out to date, the Technical Advisor has noted that segments of the local communities have variously expressed reservations about both options that leave the dust in place and those that bring the dust to surface. Therefore, the Technical Advisor recommends that at least two alternatives be taken through to further public consultation. One of the alternatives carried forward should be the best *in situ* (leave it underground) alternative, and one should be the best *ex situ* (take it out) alternative.

The Technical Advisor believes that the best *in situ* alternative is Alternative B3, isolating the arsenic trioxide dust in its current location by creating a frozen block, monitoring in perpetuity, and maintaining isolation by periodic re-freezing. The ground freezing alternatives are generally the lowest risk alternatives, and the frozen block variant has the advantage of being even more robust than other variants.

The Technical Advisor believes that the best *ex situ* alternative is Alternative G, dust extraction and encapsulation. The data available to date suggest that using bitumen would better confine the arsenic, thereby resulting in lower long-term risks. However, to our knowledge, bitumen encapsulation has not been applied at this scale. Cement encapsulation, on the other hand, is a well proven technology. The Technical Advisor therefore recommends that DIAND carry forward encapsulation with cement as the preferred *ex situ* variant, but that the development of full scale bitumen encapsulation be further considered if an *ex situ* approach is ultimately selected.

Reasons for not recommending the other alternatives described in Section 5 are as follows:

- All of the Alternative A variants would create a requirement for active management to prevent significant releases of arsenic from the site. The risk that such a requirement will fail to be met at some point in the future is the primary weakness of this group of alternatives. Alternative A1, water treatment with minimum control, is the lowest cost alternative, but presents a high risk of arsenic release over the long term. The Technical Advisor believes the high long-term risk associated with Alternative A1 is difficult to justify when other reasonable alternatives are available.

- Alternatives A2 and A3, respectively water treatment with drawdown and water treatment with seepage control, present lower long term risks than Alternative A1. However, the higher costs associated with Alternatives A2 and A3 mean that they should be compared with the similarly priced ground freezing alternatives, which provide much lower long-term risks. For that reason, the Technical Advisor believes that, while Alternatives A2 and A3 are certainly reasonable, they are not as attractive as Alternative B3. It should be noted that Alternatives A2 and A3 do have much lower capital costs than Alternative B3. Under some circumstances, such as limitations to up-front funding, that difference may lead to a preference for Alternative A2 or A3.

- Alternative C, deep disposal, presents very low long-term risks, but those must be balanced against a low risk of arsenic release in the short term and moderate worker health and safety risks. In addition to the risk concerns, Alternative C is significantly more complex and costly than other alternatives that leave the dust underground. Therefore, the Technical Advisor cannot recommend Alternative C as an *in situ* alternative. It could be argued that Alternative C qualifies as an *ex situ* option, since it removes the dust from its current location. In that case, it would compare favourably with Alternative G, which has similar risks and (probably) slightly higher costs. Since the distinction between *in situ* and *ex situ* is primarily of concern to some local stakeholders, it would be appropriate for DIAND to raise this issue in public consultation.

- Alternative D, removal and surface disposal, has many weaknesses. The first is the high risk associated with off-site transportation of the dust. The second is the high cost. Even at the low end of the current range of estimates, Alternative D is much more costly than other alternatives. Furthermore, the possibility of shipping the dust to another community raises several philosophical questions. For all these reasons, the Technical Advisor cannot recommend Alternative D.

- Alternative F, removal with gold recovery and arsenic stabilization, has the advantage that it chemically converts the arsenic trioxide into a more stable arsenic compound. However, there is some uncertainty as to whether the conversion would be complete, meaning that small amounts of soluble arsenic would remain, and would present a long-term risk. Furthermore, this alternative leads to a requirement for long-term care of a stabilized waste disposal site. That requirement means that Alternative F should be compared with Alternative G, which achieves a similar result at much lower cost. The Technical Advisor therefore cannot recommend Alternative F.

To avoid distraction from the main elements of this report, references to further information needs have not been included. However, there will be a need for further investigation to support the environmental review, licensing, design and implementation of any of the alternatives presented herein. The Supporting Documents make several specific recommendations in that regard.

Finally, the Technical Advisor recommends that Alternatives B3 and G be more fully described in plain language documents, with sufficient figures to illustrate all of the critical elements. The relevant sections of this report and the Supporting Documents should be excerpted and condensed to produce materials for use in the public consultation.

This document, **Giant Mine Arsenic Trioxide Management Alternatives, Final Report,** has been prepared under the supervision of:

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