MERG Report 2002-3

Monitoring of Low Permeability Cover Performance Arctic Gold and Silver Mine Site Carcross, Yukon

By EBA Engineering Consultants Ltd.

July 2002

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MONITORING OF LOW PERMEABILITY COVER PERFORMANCE ARCTIC GOLD AND SILVER MINE SITE CARCROSS, YUKON

Submitted To:

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Mining Environment Research Group
Government of Canada
Whitehorse, Yukon

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EXECUTIVE SUMMARY

The production of acid rock drainage (ARD) from mine tailings is a significant environmental concern at various abandoned mine sites in Yukon. Leachate with low pH and high dissolved metals concentrations deriving from mine tailings impoundment areas can negatively impact various groundwater and surface water resources.

The presence of both *oxygen* and *water* is required for ARD to develop. Therefore, the reduction of the oxygen source and the water source from the mine tailings through the use of a low permeability cover (which acts as an oxygen/infiltration barrier) will limit ARD production. This is the basis of the design and recent reclamation (1998-99) of the Arctic Gold and Silver (AGS) Tailings Site in Carcross, Yukon that EBA has been involved with in association with PWGSC.

The use of a low permeability cover to reduce ARD such as that used at the AGS site is one of the first such reclamation applications in Yukon, however, there are up to 40 abandoned mine sites in Yukon that have been evaluated by INAC which may require future remediation. EBA and partners initiated a study of the performance of the low permeability cover system in the fall of 2000 as part of a Mining Environment Research Group (MERG) funded study. The goal for the first phase of this project was to collect information relating to the performance of the cover at AGS to gain further information regarding this reclamation technique, so that it could potentially be applied to future reclamation projects in Yukon. The preliminary information from the first phase of the study was optimistic for the use of this type of system for future reclamation at other mine sites throughout Yukon. However, limited data, and data variability restricted the effectiveness of identifying and interpreting definitive trends at such an early stage. Further monitoring was recommended.

With funding from MERG, and laboratory analytical costs covered by INAC – Contaminants and Waste, the second phase of the study was undertaken by EBA and project partners to collect additional information regarding the performance of the low permeability cover system. The second phase of the monitoring program was designed to evaluate the following:

- Concentrations of oxygen within the tailings and cover.
- Moisture conditions within the low permeability cover and near surface tailings.
- Temperature profiles within the cover, tailings and underlying native material.
- Groundwater quality using existing monitoring wells at the site.
- Surface water quality within the adjacent unnamed lake and Tank Creek.

Observations from the second phase of the field-program support the preliminary evidence reported in Phase 1 of the study that the low permeability cover at AGS is functioning to limit moisture and oxygen flux into the tailings. It appears, however, based on the difference between the data recovered during each of the phases of the study, that the cover does not completely inhibit oxygen flux into the tailings, but rather the cover limits the flux. In general, the observations of oxygen and moisture profiles between phase 1 and 2 of the study might suggest that the cover is not acting as effectively as it was during the first phase of the study.

Groundwater and surface water sampling have provided valuable data for comparison of pre-reclamation to post-reclamation water quality. In general, groundwater results showed moderately higher concentrations of certain metals, and similar pH ranges between the pre- and post-consolidation events.

Surface water sampling results from both the unnamed lake and the outflow of the lake at Tank Creek showed that pH during each of the pre-reclamation and post-reclamation events were neutral to alkaline, while total metals concentrations remain below CCME guidelines and the water license criteria.

It is recommended that long-term observations of the cover be continued to recognize long-term trends in the effectiveness of this type of system to suppress ARD production, and to assess the effective lifespan of this reclamation technique in a semi-arid cold climate. It would be valuable to continue monitoring temperature, oxygen levels, moisture contents, and groundwater and surface water chemistry over time.

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1.0 INTRODUCTION

1.1 Historical Context

The Arctic Gold and Silver Tailings site (AGS site), also known as the Arctic Caribou Tailings site, is located approximately 4 km south of the Village of Carcross, Yukon (See Figure 1). It was the location of a 180 tonnes per day ore concentrating operation during the late 1960's. Ore from underground workings several kilometres from the site was processed in the mill with gold and silver concentrate being the final product.

In September 1969, the mining operation was not viable and all operations at the tailings site ceased. During operations, the waste stream from the milling operation included tailings and process water, both of which were discharged into a roughly trapezoidal 1.8 hectare tailings impoundment at the location shown on Figure 2. It is estimated that up to 47 000 tonnes of ore was processed during the mining operation and up to 27 000 m^3 of tailings were discharged into the tailings impoundment. In addition to the discharge of tailings into the impoundment, it was evident that some tailings were spilled from the mill and from the tailings impoundment leaving two channels on the site with the remnants of spilled tailings. Some of the spilled tailings were also found to have reached the unnamed lake located 80 m west of the impoundment. Over the years since abandonment of the site, and prior to reclamation activities in 1999, tailings were also blown from the impoundment creating a plume of wind blown tailings north east of the impoundment.

In the period since the mine became inactive, the site has become classified as an orphaned site and it was sporadically monitored for environmental performance by various federal agencies.

Starting in 1993, the AGS site was screened as part of the Arctic Environmental Strategy – Action on Waste program. This screening suggested that further evaluations were necessary to identify the environmental and physical risks associated with the site and to develop suitable restoration activities to mitigate such risks, should they exist.

Detailed evaluation of the AGS site followed between 1997 and 1999. The detailed studies were completed under the direction of the Environmental Services Directorate of Public Works and Government Services Canada (PWGSC) using funding provided by the Indian and Northern Affairs Canada (INAC) – Contaminants and Waste Program.

Environmental Services in turn retained the services of Steffen Robertson & Kirsten Consulting Engineers (SRK) and EBA Engineering Consultants Ltd. (EBA) to complete site specific environmental and geotechnical evaluations, and to review risk levels and potential remediation alternatives. The activities of SRK and EBA were reported to Environmental Services by SRK in the February 1999 report entitled: "Final Report - Assessment of Remedial Measures for Arctic Gold & Silver Tailings Site". During the drilling investigation completed within the tailings impoundment by EBA, it was observed that the tailings thickness ranged from 1.4 to 2.5 m. The tailings consisted of two layers distinguished by the extent of oxidation (as evidenced by the characteristic rust colour associated with the ferric hydroxide presence in the tailings). The thickness of the oxidized tailings appeared to vary from 0.8 m to 1.7 m. The geochemical properties of the tailings are discussed in a PWGSC March 1998 report entitled *Phase III ESA of the Arctic Gold & Silver Mill and Tailings Impoundment*. Table 1.1.1 provides a summary of geochemical information from that report. In brief, the tailings are strongly acidic and contain very high levels of solid and soluble arsenic.

TABLE 1.1.1

Tailings Geochemical Properties (from PWGSC, 1998)

Parameter	Range	Average
Acid Base Accounting		
Paste pH	1.8 to 3.5	2.6
AP (kg$CaCO_3$/t)	0.63 to 92	20
NP (kg$CaCO_3$/t)	-23 to -2.5	-12
NNP (kg$CaCO_3$/t)	-107 to -3.1	-33
Solids Metals		
Al(%)	0.09 to 0.41	0.22
As (ppm)	3193 to > 10,000	6712
Cu (ppm)	29 to 1266	164
Fe (%)	1.1 to 5.73	2.8
Pb (ppm)	590 to 4222	1730
Ag (ppm)	25 to > 200	82
Zn (ppm)	33 to 643	183
Soluble Metals		
Al (mg/L)	3.1 to 99	33
As (mg/L)	0.3 to 50	17
Cu (mg/L)	0.34 to 6.4	3.4
Fe (mg/L)	6.5 to 287	136
Pb (mg/L)	<0.05 to 3.7	1.4
Ag (mg/L)	0.03 to 0.2	0.12
Zn (mg/L)	0.36 to 13	5.6

The recommendations of the SRK report were that the environmental and physical risks at the site would be most economically addressed by completing a "consolidate and cover" operation. A consolidate and cover operation would require that all ore and tailings exterior to the impoundment be consolidated within the impoundment and that the impoundment be upgraded and covered.

Based on this recommendation, the overall remediation plan for the site was developed by Environmental Services and presented within specification documents issued in the spring and fall of 1999, and in the spring and summer of 2000. Remediation activities at the site were contracted by PWGSC to the Carcross Tagish Development Corporation (CTDC) in July 1999. Remediation activities at the site were conducted by CTDC between July 1999 and September 2000.

Reclamation work during the summer of 1999 under the supervision of EBA generally consisted of the following:

- leveling and grading of the existing tailings,
- placement of between 0.5 m and 0.6 m of sand and gravel (with some cobbles) fill from local borrow over the tailings to allow equipment to travel across the tailings, and,
- covering the tailings with a final 0.3 m thick layer of clayey silt.

A well-graded sand till berm exists around the perimeter of the tailings impoundment. This material was put in place when the tailings pond was active, and remains in place following reclamation work. Further details regarding the site reclamation are detailed in a contract report prepared for Public Works and Government Services Canada by EBA in March 2001; *Summary Report Arctic Gold and Silver Tailings Site Remediation*.

In the fall of 2000, PWGSC contracted Adorna Landscaping to revegetate the surface of the cover.

The low hydraulic conductivity cover of clayey silt underlain by the sand and gravel above the tailings forms a composite cover system. This type of cover inhibits the flux of oxygen into the tailings impoundment using the capillary barrier concept, which occurs when a fine-grained material is placed over a coarser one. The difference in unsaturated hydraulic characteristics of the two adjacent materials is designed to favour a high degree of saturation in the top, fine material layer and, in turn, reduce the oxygen flux to the lower layer since the saturated porous media acts as an oxygen barrier. The coarser bottom gravel drains to residual saturation (minimum water content at high suction), which prevents significant moisture drainage from the clayey silt.

1.2 Project Background

EBA has been involved with different aspects of the reclamation and environmental monitoring activities at the Arctic Gold and Silver Mine Site (the site) since 1998. The low permeability cover for the tailings impoundment area was constructed under EBA's supervision in the summer of 1999. As this was one of the first such reclamation applications of low permeability covers to reduce Acid Rock Drainage (ARD) in Yukon, EBA sought to establish an on-going role in the project. When the Mining Environment Research Group (MERG) made funding for research available, EBA viewed this as an excellent opportunity to continue its involvement with the site by monitoring the performance of the low permeability cover. There are up to 40 abandoned mine sites in Yukon that have been evaluated by INAC which may require future remediation. It is hoped that the results of this study can further the understanding of mine reclamation in Yukon.

Funded primarily by MERG with additional funding from INAC, and in-kind contributions of some time and resources by EBA, this study endeavored to research, monitor, and evaluate the performance of the low permeability cover at the tailings impoundment area beginning in the fall of 2000. EBA's partners in the first phase of the project were the Carcross Tagish First Nation and PWGSC. The following sequence of tasks were completed by EBA as part of the study:

1. Literature Review and Research.
2. Design of the Monitoring System.
3. Implementation of the Monitoring System.
4. Evaluation and Reporting of Findings with Recommendations for Further Work.

Initial field observations and monitoring equipment installations were conducted by EBA during September 2000. The monitoring program consisted of data acquisition related to several indicative parameters associated with the performance of the low permeability covers. The following parameters were monitored during three successive site visits in September and November 2000, and January 2001:

- Concentrations of oxygen gases within the tailings were measured to evaluate the concentrations of O_2 within the cover and tailings.
- Moisture conditions within the low permeability cover and near surface tailings were monitored to evaluate infiltration conditions.
- Ground temperature profiles were plotted based on thermistor readings taken within the cover, tailings, and underlying native material.
- The average thickness of the low permeability cover material was measured.

The findings of the study were documented in the EBA report *Research of Low Permeability Cover Performance Arctic Gold and Silver Mine Site Carcross, Yukon* (EBA File: 0201-00-14535) issued in July 2001. The study concluded that the low permeability cover appeared to be functioning effectively as a moisture and oxygen barrier. Several recommendations came from the study for future work. To further assess the performance of the low permeability cover, it was deemed necessary to continue on-going monitoring of oxygen concentrations, ground temperature, moisture, and groundwater chemistry.

This report documents the results of the second phase of the study to monitor the low permeability cover performance at the Arctic Gold and Silver Site.

2.0 THEORETICAL BACKGROUND TO ACID ROCK DRAINAGE

The production of ARD from mine tailings is a significant environmental concern at various abandoned mine sites in Yukon. ARD is the product formed by the atmospheric oxidation (i.e. by water, oxygen and carbon dioxide) of the relatively common iron-sulphide minerals pyrite (FeS_2), pyrrhotite ($Fe_{n-1}S_n$), and chalcopyrite ($CuFeS_2$) in mine tailings. Leachate with low pH (from the increase in sulfuric acid, an end product of ARD) and high dissolved metals concentrations deriving from mine tailings impoundment areas can negatively impact various groundwater and surface water resources.

In addition to these iron-sulphides, the presence of both oxygen and water is required for ARD to develop. Current research has shown that the oxidation of pyritic waste rock and the subsequent generation of ARD are controlled to a large extent by the availability and transport of oxygen and water. Therefore, the removal of the oxygen source and the water source from the mine tailings through the use of a low permeability cover (which acts as an oxygen/infiltration barrier) will reduce the rate of, or halt ARD production. This was the basis of the design and recent reclamation (1998-99) of the Arctic Gold and Silver (AGS) Tailings Site in Carcross, Yukon that EBA was involved with. The following sections provide background information on various factors that affect the performance of low permeability covers.

2.1 Effects of Oxygen within the Cover and Tailings

The presence of oxygen in tailings is affected by three main factors: consumption (by redox and/or biochemical reactions), gaseous diffusion, and advection. Consumption by microorganisms, particularly *T.Ferrooxidans*, will result in the lowering of oxygen concentration within the tailings. The metabolic processes of bacteria in concert with the pyrite oxidation will further increase the rate of oxygen consumption. The conversion of ferrous to ferric iron in the overall pyrite reaction sequence has been described as the "rate determining step", and this conversion can be greatly accelerated by Thiobacillis ferroxidans. Oxygen concentrations are reintroduced and increased by the processes of advection and diffusion through the barrier. Oxygen transport rates through diffusion are controlled by the diffusion coefficient, which is dependent on the porosity and moisture content of the cover. Another mode of oxygen flux to consider is convective and barometric pumping through the bottom and sides of the impoundment. However, this was not considered to be a major issue at AGS due to the nature of the impoundment construction since it was expected that the relatively low conductivity berms around the impoundment would limit oxygen flux laterally through the sides of the impoundment.

2.2 Effect of Physical Parameters on Cover Performance

It has been illustrated that the transport of oxygen through tailings covers was shown to be mainly by molecular diffusion resulting from concentration gradients established between the atmosphere and soil void spaces (MEND Report 2.21.1, 1992). The rate of oxygen diffusion is dependent on moisture content, grain size, and other physical properties such as flow path length (cover thickness) and porosity. The ability of a cover material to restrict water flow is dependent primarily on hydraulic conductivity.

2.2.1 Effects of Moisture

Moisture content affects oxygen transport in several ways. The primary effect is a matrix effect whereby as moisture content increases, the small pores within the matrix fill with water consequently increasing the distance oxygen must diffuse through the water. If a fine-grained cover is to be effective as an impermeable barrier to oxygen movement then it must be able to retain moisture. Retention of moisture results in a more effective oxygen barrier in fine-grained covers because the water occupies void spaces that otherwise would act as oxygen conduits.

The second effect of moisture within the cover system is that the surface tension between water particles sorbed on the small silt and clay particles increases the cohesion of the cover system thereby making the cover more resistive to desiccation.

2.2.2 Effects of Grain Size

The grain size of the cover material is important as it relates to the ability of the cover to transmit water and air. Smaller grain sizes generally have lower conductivities and have a higher affinity for moisture retention within their matrix.

2.2.3 Effects of Hydraulic Conductivity

Hydraulic conductivity (k) may be used as a measure of the ability of the fractured or porous media to transmit water. Soils with a relatively small amount of void space such as silt or clay tend to have low hydraulic conductivity, thus inhibiting the flow of water. Gravels and clean sands would have a high hydraulic conductivity on account of the relatively large void spaces they contain. The other important parameter related to groundwater flow is porosity. Porosity is the volume of voids divided by the total unit volume of the soil matrix.

2.2.4 Effects of Cover Thickness

Cover thickness directly affects the path length of oxygen from the atmosphere into the tailings, and thus, affects oxygen concentrations within the tailings. The cover must be sufficiently thick that the lower portion of the cover retains moisture and thereby increasing the effective oxygen barrier.

2.2.5 Effects of Microorganisms

Microorganisms are often integrally involved in the chemical alteration of minerals. Minerals, or intermediate products of their decomposition, may be directly or indirectly necessary to their metabolism. Microorganisms participate through a number of different modes, as follows:

a) The dissolution of sulphide minerals under acidic conditions (ARD).
b) The precipitation of minerals under anaerobic conditions.
c) Catalysis of naturally occurring redox reactions, such as pyrite oxidation.
d) The adsorption of metals by bacteria or algae.
e) The formation and destruction of organometallic complexes.

Microorganisms may be directly involved in cell metabolic processes where minerals are available as soluble trace elements, serve as specific oxidizing substrates, or are electron donors/acceptors in oxidation-reduction reactions.

In the case of *T.Ferroxidans*, these bacteria are known to accelerate the generation of ARD from pyritic and pyrrhotitic rocks under suitable conditions by using sulphur and sulphides for energy production as part of their metabolic processes. Bacteria tend to catalyze the most energetically favourable reaction or a reaction where the change in free energy from the oxidized to the reduced species is the greatest, which is true for ferrous oxidation. *T.Ferroxidans* have been shown to increase the iron conversion reaction rate by a factor of hundreds to as much as one million times. The by-product of the metabolic process is sulphuric acid (H_2SO_4).

2.2.6 Effects of Ground Temperature

The significance of temperature within the impoundment for the purposes of this investigation was three-fold. Firstly, given that ARD is an exothermic (heat generating) reaction, knowledge of ground temperatures within the tailings lends valuable information as to whether ARD may be occurring at that location. Secondly, ground temperature has a marked influence on the rate of biological activity such as *T.Ferrooxidans*. The biochemical reactions that cause ARD are slowed down at lower temperatures (MEND Report 1.62.2, 1998). The third important effect of temperature on the performance of the cover system is that freeze thaw cycles in clay-rich materials change the fabric and structure of fine-grained soils owing to freezing induced large suctions in the pores partially filled with ice (Konrad and Samson, 2000). Thus in cold regions, the successive cycles of freezing and thawing may significantly alter soil hydraulic properties. Many researchers have shown that soils, particularly clays compacted wet of optimum, showed increases of one or two orders of magnitude in hydraulic conductivity after freeze-thaw (Othman et al. 1993).

Past studies have indicated that low permeability barriers such as the one at the Arctic Gold and Silver Site moderate the ground temperature, thus keeping the tailings cooler in the summer when the biochemical reactions causing ARD are most likely to occur. This is desirable, as reduced temperature should lead to reduced microbial activity and thus limit the potential for ARD generation.

3.0 FIELD PROGRAM DESIGN

3.1 Background to Field Program Design

Following the literature review during the last phase of the study in 2000, a field program and monitoring system was designed to gather empirical data with respect to the performance of the low permeability cover material as an infiltration and oxygen barrier to reduce acid generation in mine tailings at AGS. As discussed earlier, the oxidation of iron pyrite (this term is used to collectively refer to all disulphide minerals) requires oxygen and water. The generally accepted initial reaction for this process is shown below:

$$2\ FeS_2 + 7\ O_2 + 2\ H_20 \dashrightarrow 2\ Fe_2^+ + 4\ SO_4 + 4\ H$$

This reaction is exothermic and thus generates heat as well as acid. Therefore, even without a quantitative knowledge of the gas and heat transport properties of the tailings pond, measurements of the oxygen, moisture and temperature profiles can be interpreted to provide insight into the oxidation and, hence, potential of a tailings pond to produce acid rock drainage.

The main objective of the field program (including both the first and second phase) was to collect data regarding the performance of the low permeability cover at AGS to act as an oxygen and moisture barrier. Secondary objectives were to:

- Design and install monitoring equipment (soil gas probes, ground temperature cables) to supplement further monitoring of the Arctic Gold and Silver Site in the future.
- Provide the Carcross Tagish First Nation (CTFN) with the knowledge to carry on further monitoring at the site should it be considered worthwhile.

The monitoring program was designed by EBA based on the information obtained from the literature review and with the technical support of Dr. Carl Mendoza of the University of Alberta, and Scott Hannam of Aurora Laboratory Services Environmental Ltd. (ALS) (formerly ASL) in Vancouver. The monitoring program was designed to evaluate the following:

- Concentrations of oxygen gases within the tailings and cover.
- Moisture conditions within the low permeability cover and near surface tailings.
- Temperature profiles within and below the cover, tailings and underlying native material.
- Average thickness of low permeability cover material.
- Groundwater conditions using existing monitoring wells at the site.

3.2 Oxygen Concentration Monitoring Program Design

Based on the results of the literature review of the first phase of the study, and consultation with Dr. Carl Mendoza of the University of Alberta and Mr. Scott Hannam of Aurora Laboratory Services, the soil gas probe (SGP) design was finalized. The SGPs consist of a screened stainless steel tip with a high-density polyethylene (HDPE) tube that exits at the surface and is completed with a Luer Loc™ (multiple port) valve for soil gas sampling.

These vertical SGPs were installed by EBA within the reclaimed tailings pond at two locations; one at the center of each of the north and south halves of the impoundment that is separated by a drainage channel. SGPs were installed with a hollow tube hilti-hammer system to advance the screened tip and high-density polyethylene (HDPE) tube vertically into the ground with minimum annulus to limit short-circuiting of atmospheric oxygen down the annulus. At each location, probe tips and tubes were advanced to the following layers: one into the low conductivity cover, one in the coarse ramp material (capillary barrier), and two at progressively deeper depths within the tailings. Once the advancing rod was removed from the hole, the area around the HDPE tube was tamped to repack the annulus around the tube. A hydrated bentonite seal was placed from 0 to 0.3 m below grade to ensure a vapour seal around the annulus of each tube. As well, a polyethylene sheet was placed along ground surface to further inhibit short-circuiting of atmospheric oxygen into the SGPs (see Photograph 1). The polyethylene sheet was then covered with some of the clayey silt cover material.

Photograph 1: View of the completed soil gas vapour probe SGP1. (September 2000)

3.3 Physical Properties Monitoring Program Design

The field program was designed to collect information regarding the physical properties of the cover material as they relate to observed oxygen concentrations and water conditions within the tailings impoundment, these included moisture contents testing and ground temperature readings. Data regarding other important physical parameters, like hydraulic conductivity and capillary moisture relationship, was acquired during the previous phase of monitoring at the site. It was deemed necessary to obtain more data regarding moisture contents to verify past conclusions.

3.4 Water Chemistry Monitoring Program Design

The water chemistry monitoring program was designed to evaluate groundwater and surface water chemistry by two means: (1) collecting water samples and submitting them to Aurora Laboratory Services (ALS) in Vancouver for analytical analysis, and (2) conducting field analysis using field water chemistry equipment. The purpose was to observe groundwater chemistry to identify potential spatial differences and changes in groundwater quality prior to the consolidate and cover reclamation.

Among the physical parameters evaluated through the first and second phases of the study were pH, conductivity, dissolved oxygen, ORP (oxygen reducing potential). These parameters could be general indicators of changes in geochemistry or spatial anomalies and thus could be used as potential indicators of ARD.

During the first phase of the assessment, there was insufficient funding to evaluate water chemistry by analytical means. During the second phase of the study, INAC provided funding for chemical analyses to be carried out by ALS. Testing parameters were chosen using three criteria; they were indicators of ARD, they were parameters tested for in previous rounds of site work, and/or they are contaminants of concern for which regulatory guidelines exist. Metals leaching, is a major concern associated with ARD, and therefore total dissolved metals analysis was the main focus of the groundwater chemistry analysis program while total metals was the main focus of the water chemistry program. Hardness was also analyzed so that metals concentrations could be compared with regulatory guidelines, and so that these results could be used in future acid-base accounting calculations, which were beyond the scope of this research project.

3.5 Logistics of Field Program

The monitoring system design, installation, and initial field monitoring activities were carried out by EBA. The project was designed such that the on going monitoring would be conducted by the Carcross Tagish First Nation (CTFN) in association with INAC. There was a training session during the first monitoring event to instruct the CTFN technician, Frank James, in the use of on-site equipment to measure groundwater levels, soil vapour oxygen concentrations, and field sampling for groundwater quality. As well, EBA prepared a Field Manual for use by the CTFN, which outlined the field procedures for the monitoring as part of the field program. The field manual was included as Appendix A of the previous report on the first monitoring event. Following the first monitoring event (September 2000), subsequent monitoring events (November 2000 and January 2001) during the first phase were conducted by Frank James of the CTFN who provided field data to EBA for evaluation.

EBA conducted sampling and monitoring during the two most recent events of the second phase of the study. The EBA representative, Mr. Ryan Martin was accompanied by the grade seven class of Carcross School (shown in Photograph 2) and their teacher, Leslie Doran, during the October 2001 monitoring event. During the March 2002 monitoring event Mr. Martin was accompanied by Mr. Jared Buchko and Mr. Michael Nahir of PWGSC and Mr. Werner Liebau of INAC.

Photograph 2: Students of the Grade 7 Class of Carcross School assisting with the monitoring program. (October 2001)

4.0 SAMPLING AND MONITORING METHODOLOGY

4.1 Oxygen Concentration Sampling and Monitoring Methodology

Oxygen sampling from the SGPs was carried out during two sampling events in the second phase of the study; there have been 5 monitoring events in total. A Minigas® portable oxygen meter rented from EnviroRentals was used for this program to measure the oxygen percentage in gas. The Minigas® monitors oxygen within the range of 0 to 35% by volume with a 0.1% resolution. The sampling protocol is summarized in detail within the Field Manual in Appendix A of the first phase summary report (EBA 2001). The general sampling sequence is outlined below:

- Removed 1L of gas with SKC air sampling pump (200 mL/ minute) from each SGP to purge the well.
- Closed the Luer Loc™ to ensure that atmospheric oxygen cannot enter SGP tubing
- Conditioned the well for 5 minutes
- Pass soil gas through sampler with hand pump at low flow rate
- Continue pumping at 30 second intervals until oxygen concentrations reach minimum or stabilize

4.2 Physical Properties Sampling and Monitoring Methodology

During the first phase of the study, two shallow testpits were hand dug and soil samples were collected from regular intervals within the three distinct zones (cover material, granular ramp material and tailings). A third testpit was excavated as part of the current monitoring program. Representative samples were selected for moisture content testing as per the American Society for Testing and Materials (ASTM) standard test method A2216.

Temperature profiling and monitoring was accomplished by installing a solid PVC pipe into a testpit within the impoundment. Within the PVC pipe, a string of thermistor beads (ground temperature cable) was installed into a glycol solution that was used to fill the cavity between the cable and the PVC. The bottom of the ground temperature cable was installed to a depth of approximately 1.8 m below ground surface with one thermistor bead above surface to measure air temperature.

4.3 Water Chemistry Sampling Methodology

The fieldwork program for this most recent sampling program consisted of performing water level measurements, purging the wells, and sampling selected wells. Well purging is the process of removing stagnant waters from the well to ensure that representative groundwater samples from within the aquifer are obtained for analytical testing purposes. All selected monitoring wells were purged prior to collecting water samples.

Each of the wells was found to be intact and functioning properly. The groundwater samples were retrieved with a dedicated Teflon bailer to prevent cross contamination between sampling locations. All samples were shipped in a cooler with ice to ALS for analysis.

The necessary equipment required to measure field chemistry parameters including pH, redox (ORP), dissolved oxygen, temperature and conductivity was used in conjunction with the collection of water samples. All the field equipment was supplied by EBA.

The analytical methodology used by ALS has been included in with their laboratory reports in Appendix A.

5.0 FIELD PROGRAM RESULTS AND DISCUSSION

5.1 Oxygen Monitoring

Observed oxygen readings for SGP 1 measured with the Minigas® during the three field monitoring events of phase 1 and two field monitoring events of phase 2 are shown in Table 5.1.1. Due to the effects of elevation on air density, the ambient oxygen concentrations as registered on the Minigas® are generally slightly less than 20.9% and fluctuate slightly between and during monitoring events. The ambient oxygen concentration as registered on the Minigas® was always recorded at the onset of each sampling event, however, for the purposes of data representation, the value of 20.9% is used on the graphs below.

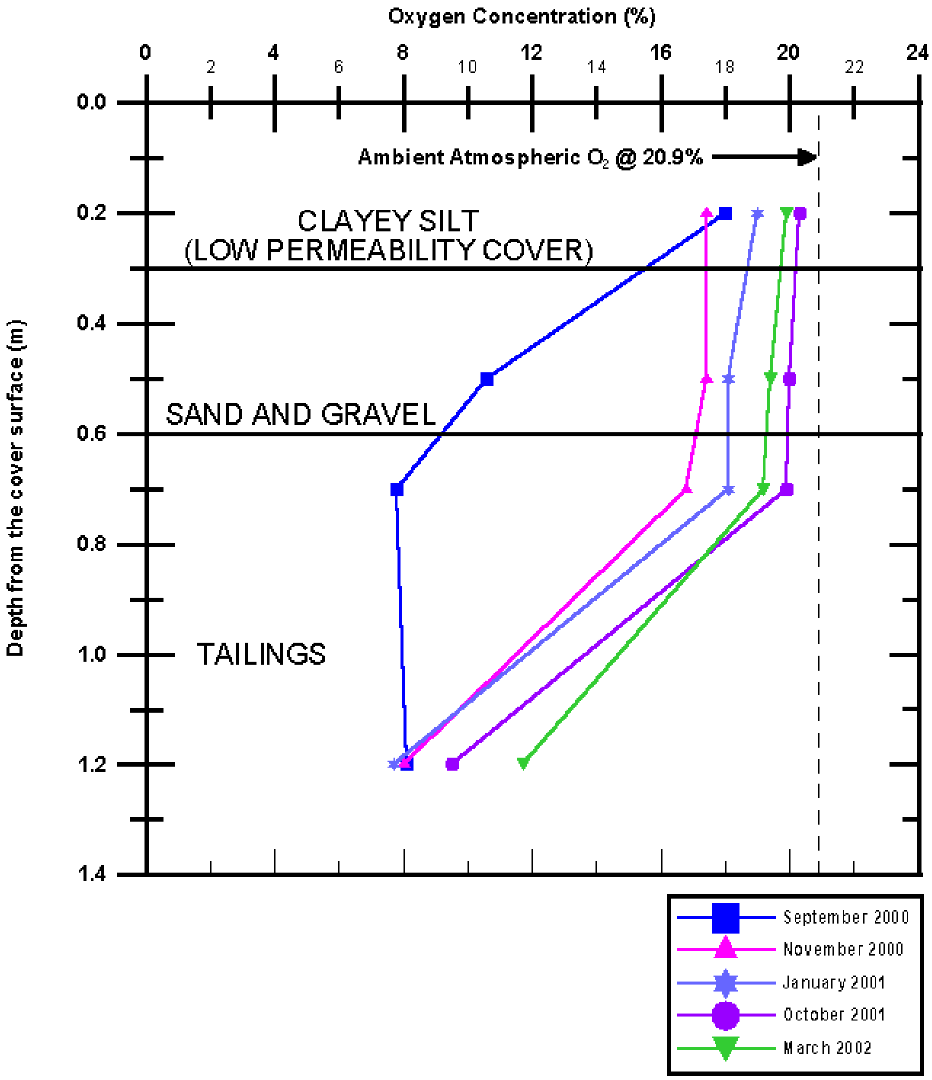
Table 5.1.1

Oxygen Monitoring Results from SGP 1

Depth (m)	Lowest O_2 Reading					Average O_2 Reading
	09/19/00	11/09/00	01/14/01	10/03/01	03/13/02	
0.2	18.0	17.4	19.0	20.3	19.9	18.1
0.5	10.6	17.4	18.1	20.0	19.4	15.4
0.7	7.8	16.8	18.1	19.9	19.2	14.2
1.2	8.1	8.0	7.7	9.5	11.7	9.0

A graphical representation of this data is illustrated in Figure 5.1.1.

Figure 5.1.1: Oxygen Profiles for SGP 1

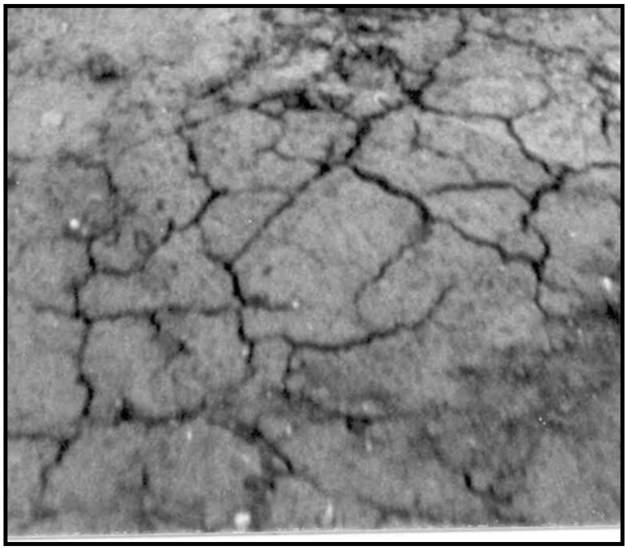


The trends that can be observed based on the oxygen profile graph are the following:

- During each monitoring event, there is less oxygen by % volume within the cover material than in ambient air. The clayey silt cover material has had on average over the five monitoring events approximately 18% by volume of oxygen at a depth of 0.2 m. This suggests that there is some limitation of oxygen flux between the atmosphere, and the tailings. Note that the oxygen concentrations within the cover, however, were highest during two most recent sampling events during this second phase of the study.

- During each monitoring event, there was a significant reduction in oxygen levels between the cover material and the tailings. The oxygen levels within the tailings ranged between 7.7% and 11.7 % by volume. Note that the concentrations observed within the tailings during the second phase of the study were higher than during the first phase.

Although there are discernible and consistent trends with respect to oxygen concentrations within the clayey silt low permeability cover, and tailings over the five monitoring events, there appears to be a temporal and seasonal variability in oxygen levels within the sand and gravel and upper tailings. This could be explained by factors such as groundwater table fluctuations, seasonal frost variations, temperature effects on *T.Ferooxidan* activity, and barometric pumping, which would affect the oxygen concentrations in the sand and gravel due to the higher porosity within this layer. There is also indication that there may be annual variation in the oxygen flux, as evidenced by comparing the November 2000 plot to the October 2001 plot. Based on only two annual observations, there is insufficient data to make a conclusive determination as to the cause of the inconsistencies between the plots for November 2000 and October 2001. However, factors such as variations in annual temperature and precipitation, and possible formation of micro-fissures and cracks in the cover could account for the inconsistencies. Note that there are some signs of near surface micro-fissures or cracks that are likely a result of drying, or the effects of freeze-thaw (see Photograph 3).



- Photograph 3: View of typical distribution of surface cracks in the cover prior to re-vegetation of the cover. (September 2000)

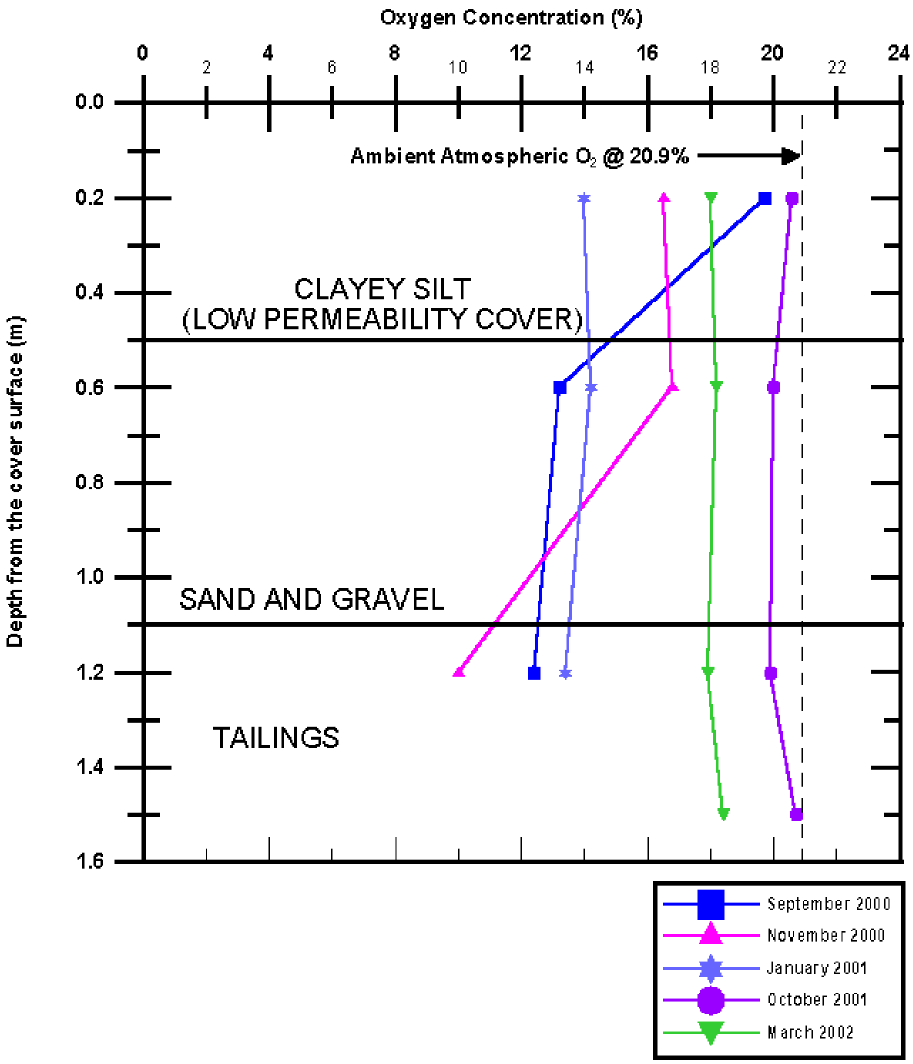
Observed oxygen readings for SGP 2 measured with the Minigas® during the three field monitoring events of phase 1 and two field monitoring events of phase 2 are shown in Table 5.1.2. and shown graphically in Figure 5.1.2.

Table 5.1.2

Oxygen Monitoring Results from SGP 2

Depth (m)	Lowest O_2 Reading					Average O_2 Reading
	09/19/00	11/09/00	01/14/01	10/03/01	03/13/02	
0.2	19.7	16.5	14.0	20.6	18.0	16.7
0.6	13.2	16.8	14.2	20.0	18.2	14.7
1.2	12.4	10.0	13.4	19.9	17.9	11.9
1.5	Plugged	Plugged	Plugged	20.7	18.4	18.4

Figure 5.1.2: Oxygen Profiles for SGP 2



Based on the oxygen profile graph, the following trends can be observed:

- There appear to be some temporal variations in the oxygen levels observed within the low permeability cover material at 0.2 m below grade over the monitoring period. Oxygen concentrations ranged from 14.0 % to 20.6 % by volume, consistently below the ambient oxygen concentrations (with the exception of SGP2 at 1.5 m in depth which had same as ambient concentrations during the October 2001 sampling event) suggesting that the cover material is limiting the flux of ambient air into the tailings impoundment.

- There was a noticeable reduction in O_2 concentrations between the clayey silt and the sand and gravel ramp material during the September 2000 monitoring event, yet there appears to be no significant reduction in O_2 during the subsequent sampling events. This may suggest that either the low permeability cover is no longer performing as well as an oxygen barrier, or perhaps ARD reactions within the tailings are no longer driving the gradient by consuming oxygen at the same rate as during the first phase sampling events.

- Note that the general trend of a reduction of oxygen concentrations with depth as observed during the first phase monitoring events was not observed during the second phase sampling events. The elevated oxygen concentrations suggest that ARD is not occurring, or is only occurring at a nominal rate in the vicinity of SPG 2, because there are no significant drops in oxygen concentrations within the tailings. This is in contrast to SPG 1 where there is an obvious drop in the oxygen concentration concentrations within the tailings.

At SGP 1 it has been observed that there is a notable oxygen reduction with depth into the tailings. This suggests that there is some oxidation and ARD occurring within the tailings, or that decomposition of the organic silts and peats that underlie the tailings is consuming oxygen. Given that higher concentrations of oxygen exist within the sand and gravel unit above the tailings, there is a concentration gradient between these two units, which would result in the driving force for diffusion. For a typical pyritic mine waste dump, the mass of oxygen required to oxidize all the pyritic material is about a thousand times greater than the oxygen initially available in the pore space of the pile (MEND Report 1.22.1a, 1993). Thus for complete oxidation of pyritic wastes, oxygen needs to flow from the surface of the wastes to oxidation sites within the wastes. The low permeability cover system is designed to restrict this oxygen flux leading to a low oxidation rate and hence a low rate of generation of contaminants within the wastes. At SGP2, however, it has been observed that a reduction in oxygen concentrations within the tailings is no longer being observed during the second and most recent phase of the study.

Within the final report for the first phase of the study, it was stated that it would be valuable to observe a gradual decrease in oxygen concentrations within the AGS tailings over time, as this would indicate that oxygen flux through the cover system is limiting the amount of oxygen available for pyrite oxidation within the tailings. It appears based on the sampling results for phase 2 of the study, the oxygen concentrations within the tailings are higher than observed during the first phase (this is true for both SGP 1 and 2). There are several potential explanations for this observation:

1. Pyrite oxidation rates have decreased, and therefore the more oxygen is available, which would suggest that the cover system does not completely inhibit oxygen flux into the system, or,
2. The performance of the cover system to limit oxygen flux into the tailings has decreased between the two phases of the study, or
3. The performance of the SGPs to collect representative gas samples at some locations has changed between the first and second phases of the study.

5.2 Physical Properties Monitoring

5.2.1 Moisture Content

Moisture content is the ratio of the mass of water to the mass of solids in soil. Samples from each of the hand excavated testpits were transported to the EBA laboratory in Whitehorse where the moisture contents were determined by weighing a wet soil sample, drying the sample in an oven at a temperature of 105 °C, and then reweighing the sample. Moisture contents for samples obtained from the testpits are calculated in Table 5.2.1., and represented graphically in Figures 5.2.1., 5.2.2., and 5.2.3.

Table 5.2.1.

Moisture Contents

Depth (m)	Moisture Content (%)		
	Testpit 1	Testpit 2	Tespit 3
	September-00	September-00	October-01
0.1	22.9	23.6	21.1
0.2	26.3	27.8	-
0.3	17.5	8.8	20.2
0.4	11.5	7.0	4.0
0.5	-	7.0	4.8
0.6	8.3	6.1	4.6
0.75	9.8	5.9	15.8
0.8	-	-	20.7
0.9	-	7.9	-
1.05	-	7.8	-

Figure 5.2.1: Moisture Profile for Test Pit 1

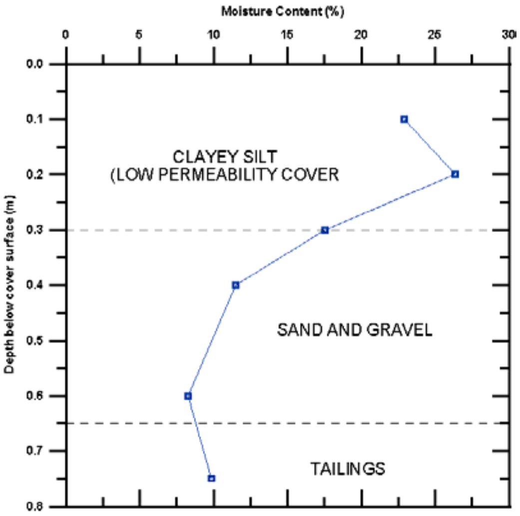


Figure 5.2.2: Moisture Profile for Test Pit 2

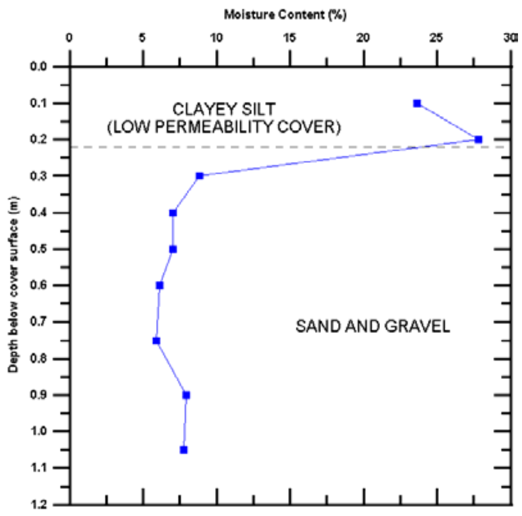
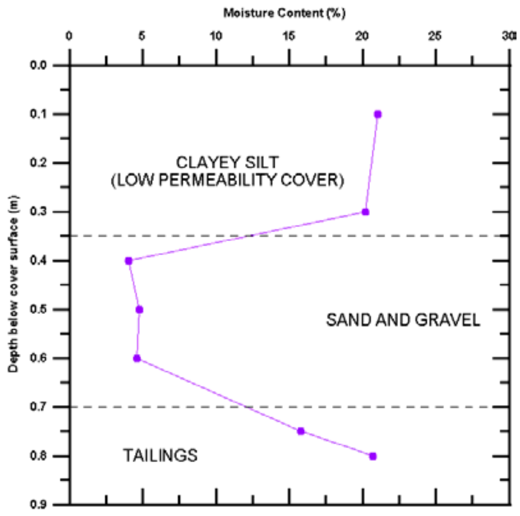


Figure 5.2.3: Moisture Profile for Test Pit 3



As observed from the table and graphs presented above, the results of moisture content testing for Testpit 1 and 2 (TP1 and TP2) which were excavated during the first phase of the study were very similar. At these locations, the moisture contents started at approximately 23% at 0.001 m and increased to approximately 27 % (full saturation) at 0.20 m within the cover material. Within the sand and gravel ramp material below the cover, the moisture contents continued to decrease slowly. The hand-dug testpit at TP1 had refusal within the sand and gravel ramp material on a cobble, and hence was not advanced into the tailings. TP2, however, was advanced into the tailings, where the moisture content increased slightly. The moisture content results at TP1 and TP2 suggested that the cover material was working effectively to limit moisture migration into the tailings impoundment at the time of sampling. TP3 was excavated in the same area as TP1 in October 2001 (See Figure 2). Although the general trends observed for TP1 hold for TP3, there are some notable differences, these are: (1) the moisture content in the cover decreases slightly with depth in TP3 in contrast with TP1, (2) the moisture content near the interface between the sand and gravel layer and the cover is higher for TP3 than for TP1, (3) the moisture content in the tailings is higher in TP3 than in TP1, and (4) the moisture content with depth in the tailings increases much more dramatically for TP3 than for TP1. These differences are likely explained by the difference in climate between the summers of 2000 and 2001. In 2000, there was much more precipitation, which was sustained over the entire summer season, and in many places the ground was saturated. In 2001, there was above average precipitation in the period from April to June, which was then followed by hot dry conditions. As mentioned previously, Adorna Landscaping under a PWGSC contract revegetated the cover in October 2000. During the October 2001 sampling event some grass growth was obvious at various locations across the cover (see Photograph 2).

Evapotranspiration resulting from the revegetation may also be contributing to the observed reduction in moisture content within the liner. One possible explanation for the elevated moisture content in the tailings is localized changes in moisture content and/or downward seepage of residual moisture from the previous wet summer. It should be noted that with only two seasonal sets of data, any explanations of the observed variations at this juncture have not been proven by adequate empirical data, and should be regarded as theories.

5.3 Ground Temperature

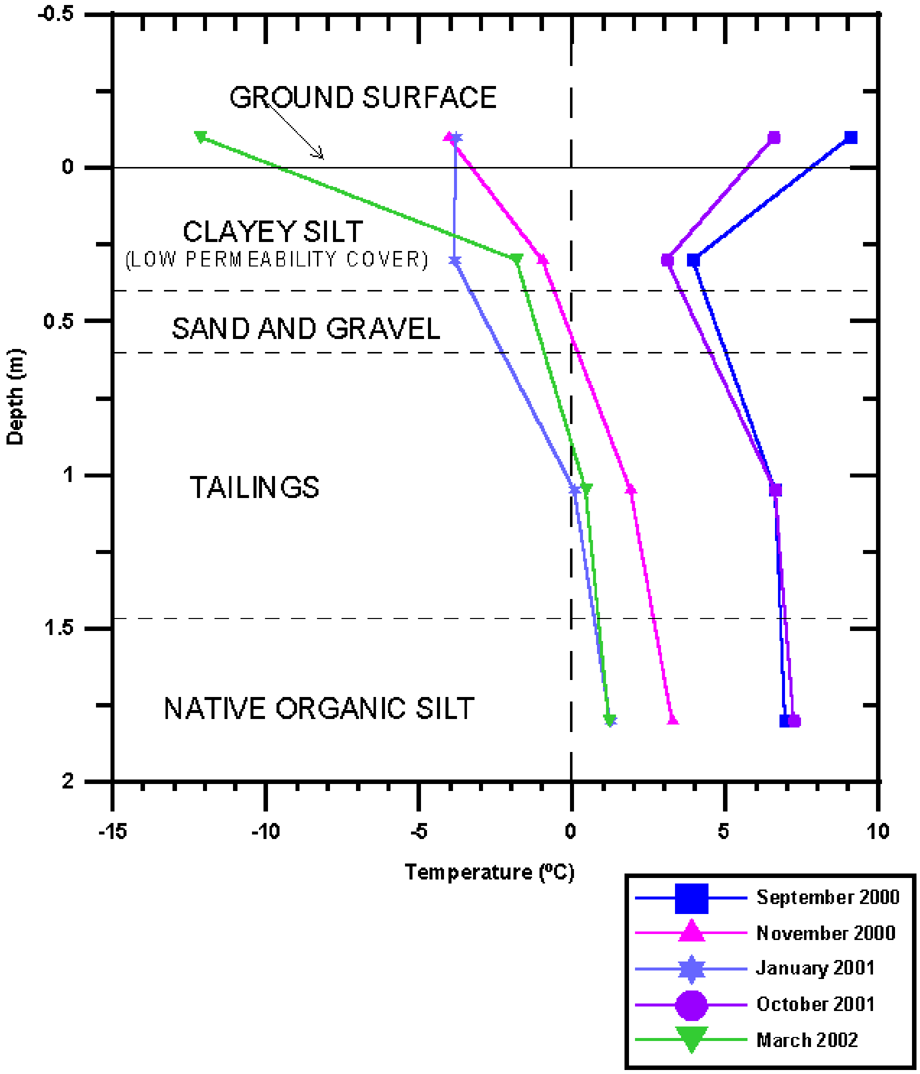
Ground temperatures were obtained by measuring the resistance at each of the beads on the ground temperature cable that was installed during the first phase of the study. The thermistor string was placed such that Bead #1 was located above grade and provides an ambient air temperature. Bead #2 is positioned within the cover material, while Bead #3 is within the tailings, and Bead#4 in the native organic silt that underlies the tailings. Ground temperature readings for the five monitoring events to date are shown below in Table 5.3.1, and represented graphically in Figure 5.3.1:

Table 5.3.1.

Ground Temperature Cable Readings

Switch	Depth (m)	Temp. (ºC) 09/19/00	Temp. (ºC) 11/09/00	Temp. (ºC) 01/14/01	Temp. (ºC) 10/03/01	Temp. (ºC) 03/13/02
1	-0.1	9.1	-4.0	-3.8	6.6	-12.1
2	0.3	3.9	-1.0	-3.8	3.1	-1.8
3	1.1	6.6	1.9	0.1	6.6	0.5
4	1.8	7.0	3.3	1.2	7.2	1.2

Figure 5.3.1: Temperature Profile



The following key observations are illustrated in Figure 5.3.1:

- The range of ground temperatures observed during each of the monitoring events did not fluctuate as much as did the ambient atmospheric temperatures, which suggests that the cover material has a moderating effect on the ground temperature within the tailings, resulting in cooler ground temperatures (in summer and fall) and hence less biological activity. This moderating effect is markedly apparent when looking at the temperature profile for March 2002. This is consistent with the results reported in other reports regarding low permeability covers.

- The tailings temperatures are very similar but always slightly colder than the underlying organic silt. Should ARD be occurring at this location, it would be expected that the temperature at 1.05 m within the tailings would be elevated with respect to that at 1.8 m within the underlying silt, due to the exothermic nature of pyritic redox reactions. It is noted that in September 2000 and October 2001, the two warmest ground monitoring events, the difference between the tailings temperature and organic silt temperature is negligible. This may be an indication that ARD is not occurring at this location, however, it should be noted that ARD is known to occur on a micro level and hence could be occurring at one location while it is not occurring at another location within the same deposit. Therefore, observing that ARD is not occurring at one location does not indicate that it is not occurring at other locations within a waste deposit.

- As expected, the results of the temperature profiles illustrate the fact that the cover material undergoes seasonal freezing and thawing cycles. As mentioned previously, freeze thaw cycles in clay rich materials changes the fabric and structure of fine-grained soils, which may significantly alter their soil hydraulic properties.

- The temperature within the tailings at 1.05 m below did not drop below 0°C and reached a maximum of 7°C in September (it is expected that this would approach the maximum ground temperature at this depth). A linear interpolation of this graph suggests that seasonal frost extended to the surface of the tailings during the November monitoring event, and to approximately 1.0 m at the time of the January monitoring event.

- The winter of 2000/2001 was exceptionally warm when compared to Yukon norms. This has resulted in warmer than normal ground temperatures for that period. However, the winter of 2001/2002 saw fluctuations of periods below and above seasonal norms, thus the cold temperature profile for March 2002.

5.4 Water Chemistry

EBA has accumulated groundwater and surface water chemistry data from several sampling events that have been conducted over the course of monitoring work at the site. Surface and groundwater samples were submitted to ALS for testing; these results are attached in Appendix A, and are summarized in Tables 5.4.1 and 5.4.3.

5.4.1 Groundwater

As this site is in federal care, there are no guidelines that apply to groundwater at this time. For comparison purposes, the Yukon Contaminated Sites Regulations (CSR) - groundwater standards for the protection of aquatic life have been presented with the results of groundwater sampling; however, the CSR standards are not enforceable at this site. The laboratory analytical results for groundwater, shown in Table 5.4.1 (pg. 27), reveal the following trends when comparing baseline conditions in September 1998 to post-cover conditions and CSR standards:

- There has been an increase in iron concentrations in all monitoring wells except for MW-5, which is located in the south half of the tailings impoundment area.
- There has been a notable increase in arsenic concentrations in sample results for MW2 and MW4, located in the north half of the impoundment, while there has been a notable decrease at MW5, located on the south side of the impoundment.
- The concentrations of arsenic, copper, and iron in several of the wells are above Yukon CSR numerical standards for aquatic life. The Yukon CSR standards have been included with the Table 5.4.3 for reference.
- Aluminum concentrations have increased in MW1D, MW2, MW3, and MW4. However, a decrease in aluminum concentrations has occurred in MW5.
- A marginal increase in copper concentrations is observed in MW1D, MW3, and MW4, while a larger increase is apparent in MW2 and MW5.
- MW2 and MW4 have seen an increase in zinc concentrations.

In summary, there have been noticeable increases in many metals concentrations relative to the background metals concentrations within the monitoring wells located on the north side of the tailings impoundment (based on observations within three monitoring wells). Conversely, there were similar or reduced concentrations of most metals within the monitoring well on the south side of the tailings impoundment relative to the baseline sampling event.

Table 5.4.1

Laboratory Analytical Analysis of Groundwater Chemistry

Parameter	MW - 1D		MW - 2		MW - 3		MW - 4		MW - 5		MW - 6
	Aug/Sep-98	Oct-01	Aug/Sep-98	Oct-01	Aug/Sep-98	Oct-01	Aug/Sep-98	Oct-01	Aug/Sep-98	Oct-01	Oct-01
Physical Tests											
Conductivity	260	not measured	3310	not measured	245	not measured	not measured	not measured	3940	not measured	not measured
Total Dissolved Solids	331	not measured	4330	not measured	309	not measured	not measured	not measured	5970	not measured	not measured
Hardness (CaCO$_3$)	124	149	1180	1270	86.3	100	1760	1650	778	544	82.5
pH	7.49	not measured	5.79	not measured	7.34	not measured	not measured	not measured	3.66	not measured	not measured
Dissolved Anions											
Sulphate	22	not measured	2550	not measured	18	not measured	not measured	not measured	4590	not measured	not measured
Dissolved Metals											
Aluminum	0.029	0.73	0.37	8.2	0.029	0.35	0.88	33.2	130	75.6	0.2
Antimony	<0.2	<0.01	<0.2	<0.5	<0.2	<0.01	<1	<0.5	<0.4	<0.1	<0.1
Arsenic	0.025	0.060	0.8	1.920	0.042	0.013	20.3	80.5	88	30.4	0.06
Barium	0.05	0.05	0.03	0.05	0.12	0.04	0.07	<0.1	<0.02	0.02	0.09
Beryllium	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.03	<0.03	0.02	0.011	<0.005
Boron	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.5	<0.5	<0.2	<0.1	<0.1
Cadmium	<0.0002	0.0004	0.008	0.01	0.0004	0.0011	0.004	<0.01	1.7	1.27	<0.002
Calcium	37.3	44.7	352	340	24.9	29.5	455	421	187	117	24.5
Chromium	<0.001	<0.01	<0.001	<0.02	<0.001	<0.01	<0.001	<0.05	0.012	<0.01	<0.01
Cobalt	<0.02	<0.01	0.68	1.65	<0.02	<0.01	1.8	1.88	0.93	0.52	<0.01
Copper	0.001	0.005	0.03	0.41	0.002	0.005	<0.001	<0.05	1.47	4.43	<0.01
Iron	0.04	1.20	664	2000.00	<0.03	0.76	3150	3520	1290	921	3.69
Lead	<0.001	0.001	<0.001	<0.05	<0.001	<0.001	<0.05	<0.05	0.135	0.05	<0.01
Lithium	<0.02	<0.05	0.07	<0.1	<0.02	<0.05	<0.1	<0.3	0.16	0.13	<0.05
Magnesium	7.5	9.0	72.4	102.0	5.9	6.5	152.0	146.0	75.3	61.0	5.2
Manganese	0.110	0.55	68.2	55.9	0.187	0.09	163	116	23.4	11.9	1.44
Mercury	<0.00005	<0.0002	<0.00005	<0.0002	<0.00005	<0.0002	<0.00005	<0.0002	<0.00005	<0.0002	<0.0002
Molybdenum	<0.03	0.002	<0.03	<0.05	<0.03	<0.001	<0.2	<0.05	<0.06	<0.01	<0.01
Nickel	<0.05	<0.05	0.28	0.5	<0.05	<0.05	0.7	1.0	0.6	0.45	<0.05
Selenium	<0.0005	<0.001	0.0008	<0.05	<0.01	<0.001	<0.01	<0.05	<0.01	<0.01	<0.01
Silver	<0.0001	<0.0001	0.0004	<0.005	<0.0001	<0.0001	0.002	<0.005	0.0007	<0.001	<0.001
Sodium	4	4	39	19	14	4	12	15	19	11	4
Thallium	<0.2	<0.0002	<0.2	<0.01	<0.2	<0.0002	<1	<0.01	<0.4	<0.002	<0.002
Uranium	not measured	0.0016	not measured	<0.01	not measured	0.0010	not measured	<0.01	not measured	<0.002	<0.002
Vanadium	<0.03	<0.03	<0.03	<0.06	<0.03	<0.03	<0.2	<0.2	0.08	0.1	<0.03
Zinc	<0.005	<0.05	16.6	55.8	<0.005	<0.05	35.5	60.1	29.7	22.4	<0.05

- All reported in mg/L, except for physical tests

The results of groundwater chemistry testing for physical parameters using field equipment are shown below in Table 5.4.2. It should be noted that these results are typically less accurate than those obtained by laboratory analytical testing. During extremely cold conditions, the field equipment was not operable.

Table 5.4.2

Field Screening Analysis of Groundwater Chemistry

		pH	Conductivity (uS/cm)	Temp ºC	Dissolved Oxygen (mg/L)	ORP
MW1D	Sep-98	7.4	460	not measured	not measured	not measured
	Sep-00	not measured	288	4.7	2.97	+ 146
	Nov-00	not measured	282	2.6	3.78	+ 171
	Jan-01	not measured	267	1.4	4.49	+ 170
	Oct-01	6.6	334	4.4	8.60	+ 66
MW2	Sep-98	5.5	3,580	not measured	not measured	not measured
	Sep-00	not measured	3,600	4.9	4.54	+ 77
	Oct-01	5.0	5,190	5.3	8.44	+ 129
MW3	Sep-98	8.0	390	not measured	not measured	not measured
	Sep-00	not measured	215	5.3	1.97	+ 80
	Oct-01	7.4	211	5.8	5.55	+ 81
MW4	Sep-98	5.8	6,800	not measured	not measured	not measured
	Oct-01	5.6	6,600	5.7	6.5	+ 32
MW5	Sep-98	4.0	4,020	not measured	not measured	not measured
	Oct-01	4.17	2,920	3.6	2.51	+ 237
MW6	Sep-98	not measured	not measured	not measured	not measured	not measured
	Oct-01	7.8	206	4.6	1.49	- 13

The following points can be made regarding the data presented above.

- Field pH is similar (+/- 0.2) or lower in October 2001 than it was in September 1998 at all locations.
- Field conductivity increased over time at MW2, decreased at MW 3 and MW5, remained the same at MW4, and was variable over time at MW1D.
- Dissolved Oxygen has increased in MW1D, MW2, and MW3 between 2000 and 2001.

5.4.2 Surface Water

The laboratory analytical analysis results for surface water are shown in Table 5.4.3:

Table 5.4.3

Laboratory Analytical Analysis of Surface Water Chemistry

Parameter	Unnamed Lake		Tank Creek			Canadian Council of Ministers of the Environment CCME[B]	Water License Requirements[D]
	Aug-98[A]	Oct-01	Aug-98[A]	Jul-01	Oct-01		
Physical Tests							
Hardness ($CaCO_3$)		36.6	not measured	not measured	33.3	no guideline	no requirement
Total Metals							
Aluminum	not measured	0.11	0.065	not measured	0.07	0.1	no requirement
Antimony	not measured	<0.01	<0.2	not measured	<0.01	no guideline	no requirement
Arsenic	0.0028	0.005	0.0025	<0.2	0.002	0.005	0.5
Barium	not measured	<0.02	<0.01	not measured	<0.02	no guideline	no requirement
Beryllium	not measured	<0.005	<0.005	not measured	<0.005	no guideline	no requirement
Boron	not measured	<0.1	<0.1	not measured	<0.1	no guideline	no requirement
Cadmium	not measured	0.0004	<0.0002	not measured	<0.0002	0.000017	no requirement
Calcium	not measured	10.6	8.74	not measured	9.7	no guideline	no requirement
Chromium	not measured	<0.01	<0.001	not measured	<0.01	0.001[C]	no requirement
Cobalt	not measured	<0.01	<0.02	not measured	<0.01	no guideline	no requirement
Copper	not measured	0.003	<0.001	<0.005	0.002	0.002	0.3
Iron	not measured	0.36	0.36	not measured	0.36	0.3	no requirement
Lead	not measured	<0.001	<0.001	<0.05	<0.001	0.002	0.2
Lithium	not measured	<0.05	<0.02	not measured	<0.05	no guideline	no requirement
Magnesium	not measured	2.5	2.1	not measured	2.2	no guideline	no requirement
Manganese	not measured	0.040	0.010	not measured	0.02	no guideline	no requirement
Mercury	<0.00005	<0.0002	<0.00005	not measured	<0.0002	0.0001	no requirement
Molybdenum	not measured	<0.001	<0.03	not measured	<0.001	0.073	no requirement
Nickel	not measured	<0.05	<0.05	<0.02	<0.05	0.025	0.5
Selenium	not measured	<0.001	<0.0005	not measured	<0.001	0.001	no requirement
Silver	not measured	<0.0001	<0.0001	not measured	<0.0001	0.0001	no requirement
Sodium	not measured	<2	<2	not measured	<2	no guideline	no requirement
Thallium	not measured	<0.0002	<0.2	not measured	<0.0002	0.0008	no requirement
Uranium	not measured	<0.0002	not measured	not measured	<0.0002	no guideline	no requirement
Vanadium	not measured	<0.03	<0.03	not measured	<0.03	no guideline	no requirement
Zinc	not measured	<0.05	<0.005	<0.005	<0.05	0.03	0.5

Notes:

- All reported in mg/L except for physical tests

A) Sampling Conducted By Laberge Environmental Services

B) From Section 4 of Canadian Environmental Quality Guidelines, "Canadian Water Quality Guidelines for Protection of Aquatic Life", CCME, 1999.

C) Interim guideline for Trivalent Chromium is 0.0089, and guideline for Hexavalent Chromium is 0.001

D) Requirements of Water License MS99-131

The surface water analytical results as presented in Table 5.4.3, reveal the following trends:

- All metals concentrations have remained similar to those observed during the pre-cover sampling event in August 1998.
- There are no exceedances of CCME regulatory guidelines at the times and locations sampled.
- Surface water quality at Tank Creek meets with the water license requirements during each of the sampling events.

The results of surface water chemistry testing for physical parameters using field equipment are shown below in Table 5.4.4.

Table 5.4.4

Field Screening Analysis of Surface Water Chemistry

	Unnamed Lake			Tank Creek		
Parameter	Aug-98^A	Sep-00	Oct-01	Aug-98^A	Jul-01	Oct-01
pH	7.1	not measured	6.62	7.52	8.9	7.71
Conductivity (uS/cm)	71.1	120	106	64.6	-	77
Temp ºC	9.1	5.7	2.6	8.6	-	3.4
Dissolved Oxygen (mg/L)	10.5	10.87	12.33	10.7	-	13.41
ORP	-	+ 68	+ 5	not measured	not measured	+ 33

A) Sampling Conducted By Laberge Environmental Services

As seen in from the data presented above, pH has remained at neutral to slightly alkaline conditions in both the unnamed lake and in Tank Creek.

5.5 Monitoring Well Data

Groundwater elevations and monitoring well details have been compiled in table 5.5.1 based on the original drilling program conducted in 1998 by EBA, and subsequent monitoring event observations. The elevations of the bottom of the tailings relative to the groundwater table have been included in Table 5.5.1 to show locations where the groundwater table may fluctuate up into the tailings thereby providing the water source for an ARD reaction. It should be noted that elevations of the tops of piezometers have changed after the installation of the low permeability cover in 2000; the changes are shown in table 5.5.1.

Table 5.5.1

Monitoring Well Physical Data

		Well Elevation (m) (top of PVC)	Depth to H_2O (m)	Elevation of Groundwater^A (m)	Elevation of Bottom of Tailings (m)
MW1S	Sep-98	90.45	dry	dry	88.20
	Oct-01	90.45	2.250	88.20	88.20
	Mar-02	90.45	2.346	88.10	88.20
MW1D	Sep-98	90.20	2.400	87.80	88.20
	Sep-00	90.80	2.200	88.60	88.20
	Nov-00	90.80	2.310	88.49	88.20
	Jan-01	90.80	2.800	88.00	88.20
	Oct-01	90.80	2.660	88.14	88.20
	Mar-02	90.80	3.202	87.60	88.20
MW2	Sep-98	90.60	5.360	85.24	87.00
	Sep-00	89.80	4.000	85.80	87.00
	Oct-01	89.80	4.130	85.67	87.00
	Mar-02	89.80	4.720	85.08	87.00
MW3	Sep-98	92.25	3.150	89.10	no tailings
	Sep-00	92.25	2.302	89.95	no tailings
	Oct-01	92.25	3.060	89.19	no tailings
	Mar-02	92.25	3.395	88.86	no tailings
MW4	Sep-98	90.95	5.510	85.44	87.05
	Oct-01	90.65	3.798	86.85	87.05
	Mar-02	90.65	4.575	86.08	87.05
MW5	Sep-98	90.20	3.970	86.23	87.50
	Oct-01	90.90	4.370	86.53	87.50
	Mar-02	90.90	dry	dry	87.50
MW6	Sep-98	92.50	1.800	90.70	no tailings
	Oct-01	92.60	1.570	91.03	no tailings

Well	I998 elevation	2000 elevation	Change in Elevation
MW1D	90.20	90.80	0.60
MW2	90.60	89.80	-0.80
MW4	90.95	90.65	-0.30
MW5	90.20	90.90	0.70

Notes:

- all calulations use the well bottom elevations taken from borehole logs as a starting point
- some well elevations have changed from 1998 since the addition of the low permeability cover except for MW1S, MW3 and MW6, see table
- shading represents times when tailings are in contact with water

A) well data accuracy +/- 10 cm

As seen in Table 5.5.1, the highest water levels were observed during the September 2000 monitoring event, which coincides with unseasonably high precipitation during the summer of 2000. As indicated within the summary table, it appears that the groundwater table elevation did rise up into the tailings in the vicinity of MW 1D. It is expected that this may occur during periods of high groundwater levels at other locations within the tailings as well. Note that monitoring well 1D is located on the north side of the tailings impoundment where metals concentrations in groundwater samples have increased. Water, as indicated earlier, is one of the necessary ingredients for ARD. The presence of water within the tailings at this location on the north side of the impoundment might explain other observations that are indicative of ARD with regards to these wells.

6.0 CONCLUSIONS

The observations from this field program serve as an excellent supplement to the previous phase of the study to monitor the performance of a low permeability cover system at AGS.

Observations from this field-program support the preliminary evidence reported in Phase 1 of the study that the low permeability cover at AGS is functioning to limit moisture and oxygen flux into the tailings. It appears, however, based on the difference between the data recovered during each of the phases of the study, that the cover does not completely inhibit oxygen flux into the tailings, but rather the cover limits these fluxes. In general the observations of oxygen and moisture profiles between the first and second phases of the study might suggest that the cover is not acting as effectively as it was during the first phase of the study. Possible explanations are:

- the observed reduction in moisture which may be attributed to the recent revegetation of the cover, and/or
- the observed surface cracking due to freeze-thaw and/or drying and desiccation effects that may have increased the permeability of the system to both oxygen and water.

Groundwater and surface water sampling have provided valuable data for comparison of pre-reclamation to post-reclamation water quality. In general, groundwater results showed moderately higher concentrations of certain metals, and similar pH ranges between the pre- and post-reclamation events. It is interesting to note that the metals concentrations in MW-5 (south side of impoundment) had decreased concentrations, while each of the other three wells on the north side of the impoundment had increased metals concentrations. Increased oxygen concentrations within the tailings were also observed at SGP-2 on the south side of the impoundment, suggesting that oxygen is not being consumed at the same rate as previously observed. Analogous to this observation is the temperature profile also recorded on the south south side of the impoundment, which did not show indications of ARD effects.

Surface water sampling results from both the unnamed lake and the outflow of the Lake at Tank Creek showed that pH during each of the pre-reclamation and post-reclamation events were neutral to alkaline, while total metals concentrations remain below CCME guidelines and the water license criteria.

It is recommended that long term observations of temperature, oxygen and moisture concentrations within the cover and tailings, and groundwater quality from below the tailings, be continued to further the knowledge of the effectiveness of this type of system to suppress ARD production. As well, it would be valuable to gather further information regarding the performance of this type of system in a cold climate. Limited data and data variability are restricting conclusive identification and interpretation of definitive trends at this early stage. Thus, it would be valuable to continue monitoring temperature, oxygen levels, moisture contents, and groundwater chemistry over time.

7.0 RECOMMENDATIONS

The following work could be conducted at the AGS site to further this study, and the assessment of ARD conditions:

- Ongoing oxygen monitoring (two or three events per year) for at least 1 more year to get sufficient data set to make more definitive conclusions.
- Ongoing temperature monitoring (two or three events per year in conjunction with oxygen monitoring).
- Ongoing moisture content monitoring (one or two events per year in conjunction with oxygen monitoring)
- Groundwater Chemistry to compare with Baseline values (every two years for long term)

It would be useful to install supplementary soil gas probes (at least 2) to investigate spatial effects, and confirm observations made during the previous phases of this study.

8.0 ACKNOWLEDGEMENTS

This project was a collaborative effort involving the expertise of persons both in the private and public sector. EBA would like to acknowledge the contribution of the various people that aided in both the field program and the preparation of this report:

- The Carcross Tagish First Nation were a team partner and assisted in the collection of field data during the first phase of this study.

- The Mining Environment Research Group again provided funding for this project.
- EBA Engineering Consultants Ltd. contributed through a donation of time involved in the report preparation and sampling equipment use.
- INAC provided the funding for the laboratory analytical work for this phase of the study, and provided funding for CTFN involvement in the first phase of this study.
- Jared Buchko, currently a project manager with environmental services for PWGSC, conducted a peer review of this report.
- Richard Trimble, P.Eng., EBA's Project Director for the Yukon Region conducted the senior technical review for this report.
- The Grade 7 class of Carcross School assisted in the gathering of field data during the second phase of this project.

9.0 LIMITATIONS AND CLOSURE

EBA Engineering Consultants Ltd. has appreciated the opportunity to be involved in this research project for the Mining Environmental Research. If you have any questions or concerns regarding any of the information presented, please contact the undersigned.

Respectfully submitted,

EBA Engineering Consultants Limited.

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References

EBA Engineering Consultants Ltd. March 2001. *Summary Report Arctic Gold and Silver Tailings Site Remediation Near Carcross Yukon* unpublished report for Public Works and Government Services Canada.

EBA Engineering Consultants Ltd. July 2001, *Research of Low Permeability Cover Performance, Arctic Gold and Silver Mine Site, Carcross, Yukon*, published report in MERG.

Konrad, Jean Marie and Martin Samson, February 2000, Influence on Hydraulic Conductivity of Silty Clay, Journal of Geotechnical and Geoenvironmental Engineering.

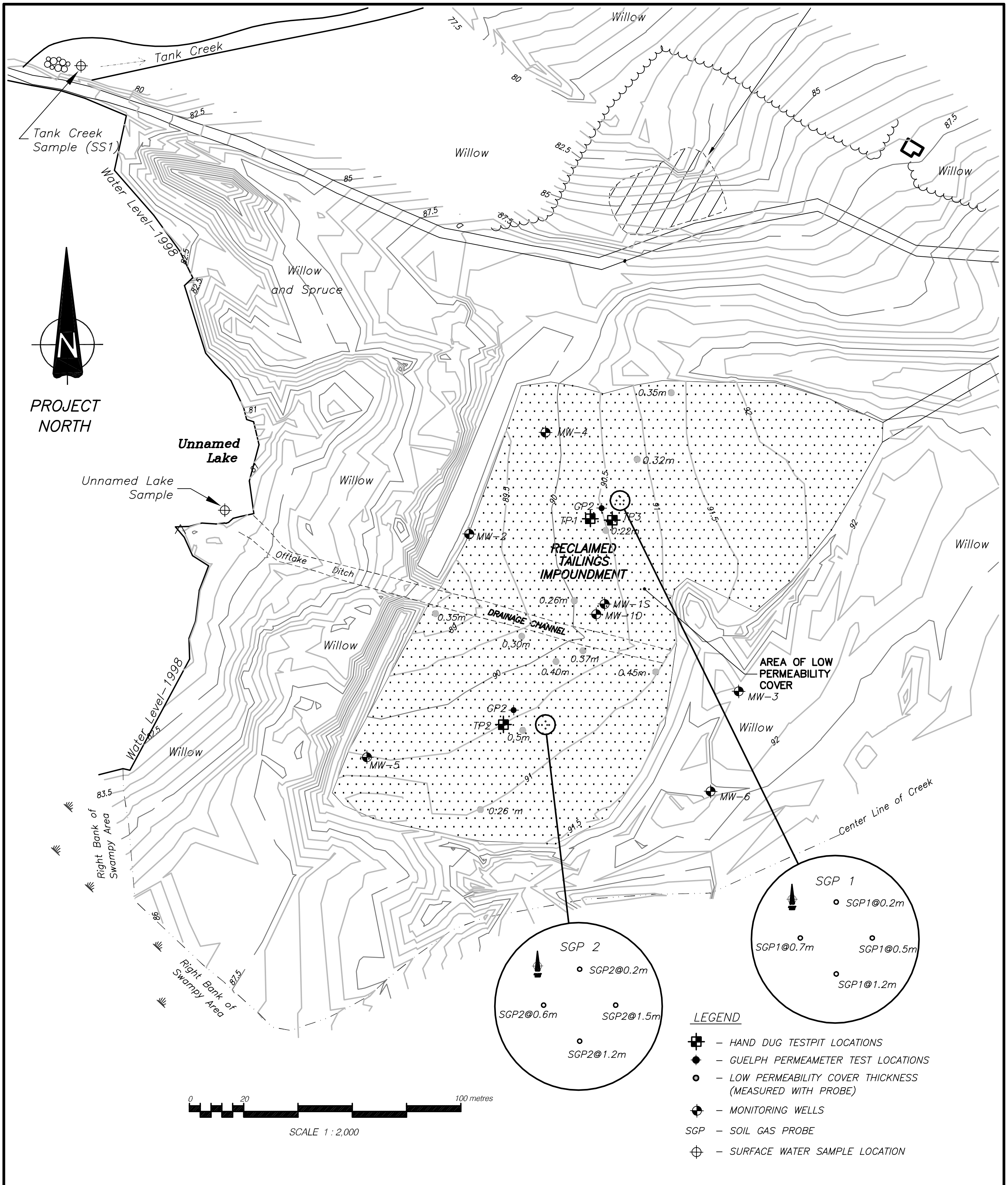
Nolan, Davis and Associates (N.B.) Limited. May 1993. *Field Procedures Manual, Gas Transfer Measurements, Waste Rock Piles, Heath Steele Mines, New Brunswick* published report in Mine Environment Neutral Drainage (MEND), Program Report 1.22.1a.

Othman M.A. et al. 1993. *Laboratory Testing to Evaluate Changes in Hydraulic Conductivity of Compacted Clays caused by Freeze Thaw*, ASTM STP 1142.

Norwest Mine Services Ltd. July 1998. *Acid Mine Drainage Behaviour in Low Temperature Regimes-Thermal Properties of Tailings*, published report in MEND 1.62.2.

SRK Robinson, February 1999. *Final Report Assessment of Remedial Measures for Arctic Gold and Silver Tailings Site*, Contract Report for Public Works and Government Services Canada.

University of Waterloo. March 1992. *Development of Laboratory Methodologies for Evaluating the Effectiveness of Reactive Tailings Covers*, published report in MEND 2.2.1.1.



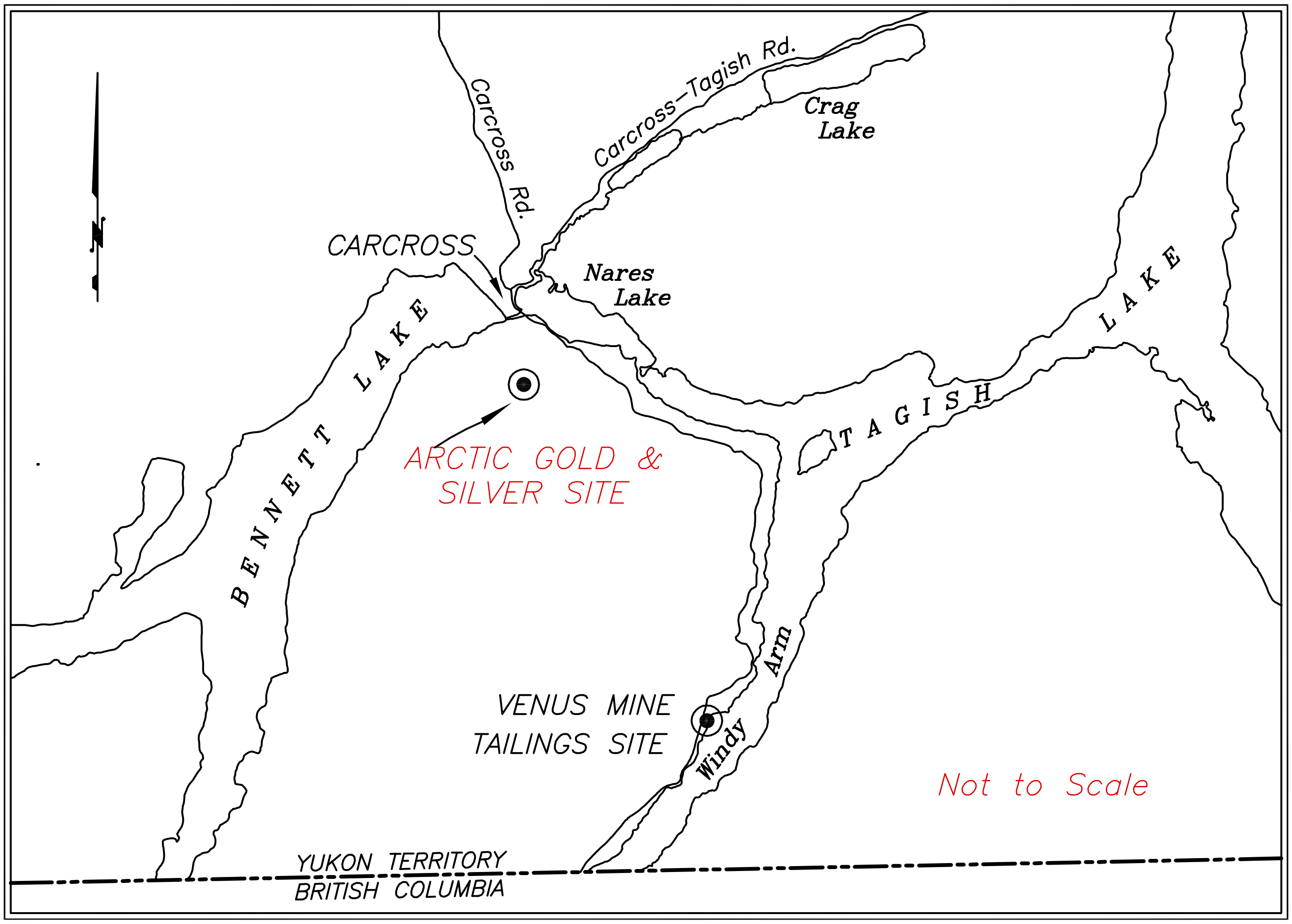
EBA Engineering Consultants Ltd.

PROJECT
EVALUATION OF LOW PERMEABILITY COVER
ARCTIC GOLD & SILVER TAILINGS POND - CARCROSS, YT.

CLIENT
MERG/DIAND

TITLE
SITE PLAN SHOWING
SAMPLING LOCATIONS

DATE	May, 2002	DWN.	JSB	CHKD.	RMM	FILE NO.	0201-00-14535001	DRWG.	FIGURE 2



EBA Engineering Consultants Ltd.

CLIENT MERG/DIAND	PROJECT EVALUATION OF LOW PERMEABILITY COVER ARCTIC GOLD & SILVER TAILINGS POND - CARCROSS, YT.
DATE JULY, 2001 · DWN. RMM · CHKD. RMM	TITLE SITE LOCATION
	FILE NO. 0201-00-14535 · DRWG. FIGURE 1

APPENDIX A

ALS LABORATORY ANALYTICAL RESULTS