June 4, 2004

Hugh Copland, Project Manager
Energy, Mines and Resources
Abandoned Mines Project Office
Box 2703
Whitehorse, Yukon Y1A 2C6

privileged and confidential
draft for discussion

Dear Mr. Copland:

Re: 23-669 – Mt. Nansen Mine Site, Brown McDade Pit Hydrogeological and Geochemical Investigation –Draft Report

We are pleased to present you with six copies of our draft report entitled "Brown McDade Pit Hydrogeological and Geochemical Investigation". Please review at your earliest convenience and contact me to discuss your comments and revisions. We anticipate that a final report can be produced within a few weeks of receiving your comments.

Please do not hesitate to contact me at ext. 24 should you have any questions. We thank you for the opportunity to work on such an interesting project and look forward to finalizing the report.

Yours very truly,
GARTNER LEE LIMITED

Martin Guilbeault, M.Sc., P.Eng (ON)
Hydrogeologist
MG:mg

June 4, 2004

Hugh Copland, Project Manager
Energy, Mines and Resources
Abandoned Mines Project Office
Box 2703
Whitehorse, Yukon Y1A 2C6

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Dear Mr. Copland:

Re: 23-669 – Issuance of Draft Reports

A DRAFT is a rough copy of a report. The intent in issuing it is to allow other knowledgeable people associated with the project an opportunity to review the style and content prior to final issuance.

Since the FINAL report may differ from the draft, we think it only prudent to collect all of the DRAFT reports prior to issuance of the FINAL report.

We would appreciate it if you would see that all copies of the DRAFT are returned to us and then we will issue our FINAL report.

We thank you in advance for your cooperation.

Yours very truly,
GARTNER LEE LIMITED

Grant Anderson

E. Grant Anderson, P.Eng.
President

EGA:mm
Attach.

privileged and confidential
Draft for discussion

Mt. Nansen Mine Site – Brown McDade Pit Hydrological and Hydrogeological Investigation

prepared for:
Energy, Mines and Resources
Abandoned Mines Project Office

prepared by:
Gartner Lee Limited

In association with:
Northwest Hydraulic Consultants Ltd.
Lorax Environmental Services Ltd.

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6 Energy, Mines and Resources
2 Gartner Lee Limited

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Photographs of Site and Field Activities

Appendix B

Pit Water Balance Calculations

(Electronic Copy – Final Report)

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1. Introduction

The mine site at Mt. Nansen, located 60 km west of Carmacks, YT (Figure 1) was owned in part or in whole by BYG Natural Resources Inc. from 1985 to 1999. BYG conducted mining and milling operations between October 1996 and February 1999 when environmental concerns forced BYG to cease operation of the mine. An interim receiver, appointed in March 1999, subsequently abandoned the mine in July 1999. Following abandonment, Indian and Northern Affairs Canada, Water Resources Division assumed responsibility for the site and began care and maintenance operations. As part of the devolution of federal government responsibilities in Yukon, the Government of Yukon took over on April 1, 2003 and continued care and maintenance operations and also began the process of closure planning. Gartner Lee Limited (GLL) was retained to assist the Government of Yukon (YG) in determining and assessing final closure options specifically as they related to the Brown McDade open pit. The focus of the study was to develop an understanding of the pit water elevation behavior and the associated water quality. This information is critical to help provide confidence and/or guidance in the development and assessment of environmentally sound pit management and closure options. The purpose of this report is to summarize what is presently known about the site and provide the necessary guidance to ultimately achieve these goals.

1.1 Site History – Nature of the Problem

The Mount Nansen Mine is an abandoned gold-silver mine located 60 km west of Carmacks. The Mount Nansen area has been subject to mining and exploration since 1943 (Conor Pacific, 2000). The site consists of a 5,300 hectare parcel of land within the Little Salmon/Carmacks First Nations traditional territory (Connor Pacific, 2000) (Figure 2). Open pit mining of the Brown-McDade deposit commenced on October 16, 1996 and ceased in January 1999 (Conor Pacific, 2000). The final depth of the pit extended approximately 10 m below the elevation permitted by the water license and into a sulphide rich zone of the bedrock. This deposit was originally mined through underground workings accessed from the Pony Creek Adit. As a result of excavating the pit through these underground workings, two mine drifts, which paralleled the main ore body, now extend a few meters into the northern pit wall. The main Pony Creek Adit however, is now exposed along the western pit wall.

Higgs (1994) developed a water balance prior to development of the open pit and predicted, given the metrological, and pit catchment areas at the site, that dewatering activities would likely not be required during mining activities, which subsequently proved to be true. Individuals involved during open pit mining activities reported no significant accumulation of water in the pit bottom and consequently, dewatering activities were never required (Bill Mann, Robert Stroshein, pers. comm. 2004).

Following pit abandonment in 1999, water began to accumulate in the north end of the pit. Given the location and geometry of the pit and the underground adits, it is believed that if pit water levels are allowed to increase, the Pony Creek Adit could provide a conduit for direct flow out of pit water into Pony Creek. Additionally, given the nature of the host rock material within the pit and the potential for poor pit water quality, it is possible that if pit water is discharged into Pony Creek (a critical surface water receptor) significant environmental impacts could occur.

Figure 1. Mt Nansen Mine Site Location Map

Figure 2. 2004 Mine Site Layout and Study Area

1.2 Study Goals and Approach

Water levels in the pit are expected to rise until steady-state hydrologic and hydrogeologic conditions are achieved. Management intervention (summers of 2001 and 2002) was needed to ensure that water levels did not rise past the Pony Creek Adit shortly after the open pit mining activities stopped in 1999. It is therefore likely that steady-state water levels in the pit will be higher than the base of the Pony Creek Adit. This underlines the importance of developing a good technical understanding of the pit water budget components, dynamic pit water chemical behavior and physical transport processes. This information will help develop a scientifically based long-term pit management strategy and closure plan. It should be noted that the data compiled to date is limited and long-term steady state pit lake water chemistry and pit water balance model has not been developed as part of this project. However the approach used in this study was designed to provide a greater understanding of the various controls and constraints on the overall pit lake chemistry and hydrogeological behavior. This report concludes with a summary of the pertinent findings and provides a number of recommendations for future work and data compilation needed to develop a better understanding of the pit hydrogeology and geochemistry.

A staged approach consistent with time constraints and winter site conditions during the study period was developed to determine the hydrology, hydrogeology and geochemistry of the pit. Existing information was reviewed to establish background conditions. Site reconnaissance was then completed to photograph and ground-truth the catchment and surficial drainage areas delineated from available maps and aerial photographs. Post-operational detailed surficial mapping, and a detailed survey of the pit (prepared by others) were combined with existing water level monitoring and meteorological data from the site to develop a spreadsheet-based analytical water balance model for the pit. This model was used to predict a range of potential pit filling rates for both average and extreme metrological conditions. Pit water quality samples were collected through the ice at different locations and depths to examine geochemical stratification. Pit walls that were not snow covered were also examined for evidence of staining and seepage. In the absence of compositional water quality data (i.e. chemistry of seepage, pit runoff, etc.) this recent depth-discrete data provided a basis for the development of a conceptual model for pit water chemistry.

2. Brown McDade Pit Water Balance

2.1 Introduction

In general, the main components of the water balance include direct precipitation onto the pit lake surface, surface runoff, evaporation from the pit lake surface, and net changes in surface water and groundwater inflow/outflow. These different components are illustrated in Figure 7. An important consideration for the water balance of the Brown-McDade pit is the incorporation of local meteorological information. Additionally, effects pertinent to a northern setting were also considered. These considerations include the formation of pit surface ice during winter, accumulation of snow within the watershed and the presence of discontinuous permafrost within the study area. Subsequently, these factors affect infiltration rates of precipitation, groundwater flow and surface hydrology.

To provide accurate estimates for each component of the water balance, detailed mapping of the study area and an accurate post-operational survey of the pit were essential. This allowed calculations of land slope, ground cover, pit geometry, surficial drainage patterns, catchment areas, pit volumes and relative elevations of water levels, nearby water bodies and land formations. In the analysis of the pit water balance, it was also essential to consider the impact of the de-watering management activities 2001 and 2002.

2.2 Background Information

2.2.1 Previous Water Balance

A water balance was first completed for the mine site in 1994 as part of the mine project planning process (T.W. Higgs, 1994 and T.W. Higgs, 1995). It was predicted that the bulk of the water input would be absorbed by broken rock and removed by truck to either the waste dump or mill, without additional pit de-watering requirements. As predicted, pit de-watering was not required during the period of mine operations (H. Copland, personal communication). The Higgs water balance analysis was based on long-term climate data from the Carmacks weather station augmented with a limited amount of site-specific metrological data collected during site exploration actives between 1985 and 1988. This study however has incorporated site-specific data including post-operational water levels of the pit lake, a 2004 detailed pit survey, digital site mapping, and recent meteorological data collected from the Mount Nansen Site meteorological station.

2.2.2 Historical Occurrence of Pit Water

Underground mining occurred within the Pony Creek Workings previous to the development of the open pit. During this time, subsurface water was encountered only within the end portion of a drift, constructed off the Pony Creek Adit, which ran north and parallel to the main ore body (pers. comm. Stroshein, 2004). The end of this drift is now exposed along the northern face of the pit. Stroshein (2004) stated that the volume of water seeping into this area did not result in significant accumulation and consequently, dewatering of the underground workings was not needed. It was also noted that the water in this area appeared to leak into the drift from the ceiling, and subsequently leak out through the drift floor. This suggests that the regional groundwater table within the bedrock in the area is lower than the drift elevation, and that the water likely seeped from an overlying water source.

Additionally, the only observed groundwater seeps within what is now the excavated pit, occur in the same location (i.e. along the north pit face). The seeps appear to flow continuously during non-frozen periods (pers. comm. Bruce Wheeler, 2004), however during winter months, seepage stops after large icicles form. Photographs are included in Appendix A. The seeps along the north pit face appear to emanate primarily from the toe of the fist bench below the north pit rim. This is consistent with the elevation of seepage observed during the underground mining. Water from these seeps flows over the first bench and cascades downward into the pit. Again, this suggests that leakage likely occurs from an overlying water source and that the pit lake surface does not represent a local or regional groundwater table. No other seeps into the pit have been identified.

To help investigate the source of the seepage water along the north face of the pit, a detailed elevation survey of the site was conducted by Underhill Geomatics of Whitehorse, YT. In part, this survey was used to determine if nearby Pony Creek could be leaking through the weathered upper bedrock subsurface and be providing the source of water that has long been observed in this area. Pony Creek runs tangential to the northern pit rim just 64 m from the pit rim (). It would be reasonable to assume that that seepage from Pony Creek was not considered by Higgs (1994) during the completion of the pre-mining water budget, as this water source technically is from outside of the pit catchment area (i.e. Pony Creek catchment area).

Significant volumes of water did not accumulate in the base of the pit during mining operations (pers. comm., Robert Stroshein, 2004). Therefore, it can be assumed that the pit was relatively dry until 1999 and water began accumulating shortly after mining activities ceased. For the purpose of better understanding post-mining operations and the potential environmental effects of pit water accumulation, pit water elevations have been monitored. This was done by the Yukon Government, Department of Environment, Water Resources Section, since late fall of 2001, using a vented Stevens multi-logger and data logger. All available data has been corrected to elevations surveyed in 2004 (Figure 3). A review of the pit water elevation data shows that water levels rise in the pit from April through to mid November and decrease during the winter months. However water levels appear to increase yearly, indicating an overall net gain in pit water volume.

The water levels during the winter months (December through March) drop at an average rate of approximately 0.27 m /month. This process becomes apparent in the spring, when a large void beneath the ice is created and the overlying frozen ice collapses during spring thaw (per comm Bruce Wheeler, 2004). Therefore, the decrease in pit water elevations during winter months suggests that groundwater seepage out of the pit represents an active component of the annual pit water balance. This might also represent a seasonal drop in the regional groundwater table.

2.2.3 Historical Pit Dewatering Events

The following accounts of pit de-watering activities are based on personal communications with Robert Stroshein, 2004, who was involved at the site during mining activities and after closure of the Brown McDade pit in 1999. Pit water was first pumped and treated in the summer of 2001. It is believed that above average rates of precipitation during the summer months caused the water level in the pit to reach the bottom of the pit ramp which provides road access into the pit from the western pit rim. The pit was dewatered to prevent potential impacts to nearby surface water sources (i.e. via Pony Creek Adit, into Pony Creek). Once the pit water was pumped lower than the toe of the ramp, a road and small turn around area were constructed northward approximately 100 m along the base of the west pit wall. From the turn around area, (which now provides access to the northern and deepest section of the pit), water was once again pumped and levels were lowered approximately 2.5 m below the road surface. Although it cannot be confirmed as water levels in the pit were not monitored, it appears that the maximum pit water level prior to this dewatering event was likely above the base of the Pony Creek Adit (per com Stroshein, 2004). However, leakage through the Pony Creek Adit into Pony Creek could not be confirmed (per com Stroshein, 2004). A more detailed discussion is provided in section 2.4.

A net increase in pit water elevation of approximately 1 m reportedly occurred between the summers of 2001 and 2002 prompting a second de-watering management episode. An interview with Bruce Wheeler (2004) revealed that by late summer 2002, water levels in the pit were once again approaching the level of the Pony Creek Adit. The pit was pumped over a period of 8 days. (These events are identified on Figure 3).

Figure 3. Post-operational Pit Water Level Fluctuations (2001 – 2004)

It should be noted that pit lake water elevations prior to and following the dewatering events could not be confirmed as water level data unfortunately was not collected during the summer months of 2001 and 2002. Additionally, YTG Water Resources was contacted to provide volume estimates of the treated water that was pumped during each event, however they were unable to provide the project team with this information.

A more detailed discussion regarding the behavior of the pit water elevations, as well as the behavior of the seepage into and out of the pit, in the context of the overall pit water balance, is provided in the following sections.

2.3 Site Visit

Gartner Lee personnel visited the Mt. Nansen site on February 9th and 10th, 2004 to examine and photograph the site and to collect water quality samples from the Brown-McDade open pit. Although winter conditions were not ideal for performing fieldwork or observing many land features within the pit and surrounding area, a visit during frozen conditions was extremely useful for observing seepage patterns and allowed several key observations about the hydrology and hydrogeology of the site. The presence of ice on the pit lake also facilitated the collection of depth-discrete pit water quality samples and in-situ chemical profiling of water quality.

Hugh Copeland of the YG type II mines office met the field crew at the site on February 9th and provided a tour and overview of the site. GLL personnel also met with Bruce Wheeler, the caretaker for the mine, to discuss his observations of seasonal fluctuations of site hydrology (i.e. pit water levels, flow in creeks at the site, site drainage patterns, etc.). A total of eight water quality samples (including one duplicate) were collected from different depths at three locations in the pit. Photographs of the site field visit are included in Appendix A. The pit walls that were not snow-covered, were visually inspected to assess the fractured nature of the rock as it relates to groundwater flow. Pit wall seeps were identified at the north end of the pit. These seeps were completely frozen and therefore could not be sampled. No other seeps or visual oxidation staining, indicative of groundwater flow, were visible. Small rock falls were also identified within the pit, suggesting freeze/thaw-weathering processes are occurring.

The areas surrounding the pit were inspected for surficial drainage patterns (i.e. ditches, creeks, land slope) and catchment areas were delineated to determine the land surface area that could potentially contribute surface runoff into the pit. The pit water level was also surveyed using a level transit against two prominent benchmarks within the pit (the ground level beneath the data recorder and a drill hole in the western pit wall near to the data recorder). This was done to ensure that water levels measured using the level logger could be related to elevations of benchmarks established later during a detailed pit and site survey.

A visual inspection of the entrance to the Pony Creek Adit, from the Pony Creek side, suggests that the adit has caved in. Historical accounts also indicate that the adit is sloped upwards from Pony Creek towards the pit. The entrance to the adit is also located at least 3m above Pony Creek and therefore the chance of reverse flooding of Pony Creek into the pit is minimal. Within the excavation, the Pony Creek Adit could not be located or visually inspected as it was covered in snow, however it was noted by Bruce Wheeler (2004) that during snow free periods, the adit within the pit is likely caved in. Further investigation of this adit is warranted, particularly in snow free conditions, as it represents a significant potential hydraulic feature.

2.4 Detailed Pit Survey and Site Mapping

Surficial mapping of the area was completed by EBA, 1994. Previous studies also conducted some surveying and mapping of the site prior to and during mining activities. However, post-operational mapping was not found in the reviewed materials or known to exist at the time of this study. In order to provide reasonable estimates of drainage areas, surficial topography and existing site infrastructure (buildings, roads, rock dumps, tailings pond, etc.), a regional scale digital elevation model (DEM) was produced using aerial photography. Figure 2 was produced using this recent mapping data.

In order to provide accurate estimates of the pit geometry for the water balance and to address potential concerns identified during the field visit, a detailed site survey was completed. Conducted by Underhill Geomatics of Whitehorse, YT in February, 2004, it measured the elevation of: Pony Creek, adits/drifts within the pit, pit water levels; pit seepage faces/benches, etc. The detailed survey of the pit is shown on Figure 4.

The Brown-McDade open pit is elongated in a north-west, south-east direction (Figure 2). An access ramp to the pit leads down from the west side to a turn around area, which is where the pit water level logger is located. This location is at an elevation of 1184.4 masl, which was 2.2 m above the February 10^{th}, 2004 pit water levels. The ramp separates the pit into two areas referred to as the “southern end” and “northern end” (Figure 4). The northern end of the pit is approximately 23 m deeper than the southern end and has a depth of approximately 40 m from ground surface at the northern pit rim to the pit lake bottom. The elevation of the northern pit bottom is approximately 1170 m-asl. The deepest point within the southern end of the pit is 1193.3 m asl, which is only 5.2 m below the southern pit rim (at about 1198.5 m-asl). No water has been observed to accumulate in the southern end of the pit (Hugh Copland, Bruce Wheeler, pers. comm. 2004).

Two prominent benches have been excavated into the pit walls for stability, each approximately 10 to 15 m in height (Figure 4). Pit wall angles are generally greater than 60 degrees. Depth measurements taken at 6 locations beneath the pit lake ice during the 2004 field visit revealed water depths ranging from approximately 8 m to only a few meters. At one location a rock was hit with the auger within only a few cm of the ice surface. The data from beneath the ice was incorporated into the detailed pit survey presented in Figure 4.

Unfortunately, the base of the Pony Creek Adit within the pit could not be identified during the site visit or during the detailed pit survey due to snow cover. However based on conversations with Bruce Wheeler, (pers. comm. 2004), it is suspected that the elevation of the adit floor is approximately 0.5 m above the road level where the data logger is located (i.e. 1184.4 masl). This estimated elevation (1184.9 m-asl) seems realistic given that the elevation of the Pony Creek Adit entrance, some 170 m away, is 1183.4 masl corresponding to a downward adit slope of approximately 1% from the pit out towards Pony Creek. It is interesting to note, given the account of the 1st dewatering event provided in section 2.2 (pers. comm. Stroshein, 2004), that the water level in the pit lake had reportedly risen to the toe of the pit access ramp by late summer 2001.

The elevation of the toe of the ramp can be estimated at between 1184.4 and 1186.9 m-asl based on the recent survey. Given that the base of the Pony Creek Adit is estimated at 1184.9 m-asl, it would be reasonable to assume that pit water levels at this time may have risen above the base of the Pony Creek Adit. Leakage through the adit into Pony Creek however could not be confirmed (per com Stroshein, 2004). Pit water level data were not collected by YG at this time. Furthermore, the precise elevation of the Pony Creek Adit has not been confirmed. Unfortunately, it could not be determined if the Pony Creek Adit is a pathway for water out of the pit and into Pony Creek. The Pony Creek Adit therefore must still be considered a likely exposure pathway from the pit lake into Pony Creek until otherwise demonstrated.

Based on the 2004 survey, pit area and pit volume were expressed as a function of pit elevation (Figure 5). The Average Area Method was applied using Autodesk Land Development Desktop software to calculate the surface area of the pit lake and pit water volumes for a variety of pit water elevations. This data was plotted and mathematical functions were applied so that pit volumes and pit surface areas could be calculated as part of the overall water balance spreadsheet model (Appendix B). These curves are valid for pit water elevations ranging from 1174 m asl. (the deepest point identified during the field visit) up to an elevation of at least 1191 m asl (well above the elevation where the pit intercepts the Pony Creek Adit).

A number of pertinent cross-sections have been developed based on data collected during the detailed elevation survey. These figures are presented in the appropriate section pertaining to the water balance and pit hydrology/hydrogeology.

Figure 4. Brown-McDade Open Pit Survey (March 2004)

Figure 5. Pit Lake Elevation / Surface Area Curve for Brown-McDade Open Pit

2.5 Surficial Drainage

The Brown McDade pit is located on a local topographical high and the entire mine site is located quite high within the watershed (Figure 2). The property is located within the Dawson Range with the surrounding terrain consisting mainly of rounded ridges and shallow valleys with small trees (EBA, 1994). The area is drained by the Nisling River to the west that drains into the Yukon River via the Donjek and White Rivers. Several small streams drain the area in the immediate vicinity of the mine and the Brown-McDade Pit. Dome Creek runs southward in the valley to the west of the pit and is diverted around the tailings impoundment. Pony Creek is a tributary of Back Creek and flows through a small catchment area located to the north-east of the pit. At its' closest location, Pony Creek flows within 64 m of the northern edge of the pit rim. The gradient of Pony Creek increases significantly as it passes eastward by the northern pit rim and heads toward its' confluence with Back Creek (Figure 6).

As discussed in section 2.2, the only observed groundwater seeps within the pit have been identified along the north pit face. The seeps appear to flow continuously during non-frozen periods, however during the site visit in February 2004, the seeps were completely frozen and no "active" liquid water was identified. Photographs are included in Appendix A. Given the close proximity of the north pit seepage face and Pony Creek, a section of Pony Creek closest to the pit rim was inspected during the field visit. Similar to the frozen seeps observed within the pit, the entire depth of Pony Creek was also frozen (more than 0.3 m). Photographs of a hole augured through ice and down to the frozen streambed of Pony Creek are included in Appendix A.

This observation would support the hypothesis that the source of water seeping into the pit is from Pony Creek, and is likely seeping through the upper weathered bedrock surface. If the source of seepage were from a deeper location, it might be expected that seepage would occur through the winter. However the icicle growth observed within the pit did not appear to be active.

Figure 6 shows the drainage areas that were delineated and used in the water balance. Each area is discussed in the following sections.

Figure 6. Surficial Drainage and Catchment Areas

2.6 Development of Pit Water Balance Model

The water balance model developed for the Brown McDade Pit, is a spreadsheet based analytical model designed to be used as a tool to help provide a greater understanding of the various water components and fluxes that affect the behaviour of the pit lake. These insights were then used to assist in developing a conceptual model and qualitative assessment of pit water chemistry. Based on the information obtained during the site visit, and information collected during the historical workings of the mine (both open pit and underground), the conceptual model describing the various components of the water budget is presented in Figure 7.

As discussed in section 2.4, using elevation data collected as part of the detailed pit survey, mathematical functions were developed which relate pit lake elevations to pit lake volumes and pit lake surface areas. Monthly time steps were selected for the model, as this time frame was consistent with the time increment of available meteorological data (i.e. snowfall, evaporation, rainfall). The following sections provide details regarding the various components of the water balance model, including information about input data, model calibration procedures and overall modeling results.

Figure 7. Conceptual Model of Pit Water Balance Components

2.6.1 Pit Catchment and Runoff

Pit catchment areas were delineated based on 2004 mapping and site visit information (Figure 6). The area of the pit defined by the outermost extent of the pit rim that would contribute water to the northern end of the pit, is approximately 34, 360 m^2. This area is referred to as "Zone 1 – Drainage Area Inside Pit Rim". The ground surface of this catchment area consists primarily of fractured bedrock. The next zone outside of Zone 1, is referred to as "Zone 2 - Drainage Area outside of Pit Rim" and consists mainly of slightly sloping gravelly and rocky terrain as well as a small, vegetated slope along the eastern pit edge. Zone 2 occupies approximately 53,450 m^2 (depending on pit lake size). The water balance accounts for changes in the surface area of the pit lake with pit water level. The pit lake surface area (Zone 3) was approximately 2,000 m^2 at the time of the field visit.

Runoff coefficients (defined as the ratio of runoff to precipitation) were applied to Zones 1 and 2, based on the calibration process of fitting modeled data to actual observed water levels in the pit. Typical runoff coefficients are discussed in Appendix C and a detailed discussion of the calibration process is provided in section 2.6.4. It should be noted that runoff coefficients usually relate to storm events and therefore, there may be some slight variation between runoff coefficients for heavy rainfall events as opposed to the average values that were calculated. For the purposes of this study, it was assumed that the runoff coefficients used were representative of average precipitation.

It should be noted that seasonal water ponding has not been identified in the south end of the pit (Hugh Copland, pers. comm. 2004). Therefore, this catchment area has been excluded from the pit model and it has been assumed that any water from runoff or direct precipitation into this section either evaporates or is lost to groundwater seepage and does not report to the northern end of the pit. Visual observations and measurements during non-frozen conditions may indicate otherwise or suggest that water from this end of the pit reports as groundwater to the northern, lower point of the pit.

2.6.2 Meteorological Data

A meteorological station was installed by YG Department of Environment, Water Resources Section at the Mt. Nansen site following closure in 1999. Available data from the site is summarized in a report by NHC (Appendix C). A statistical analysis of data from meteorological stations in Carmacks and Pelly Ranch (collected over a much longer period of time) was performed by NHC. Mean and extreme values were then transferred to the Mt. Nansen site. Statistical procedures used to estimate average snowfall, precipitation, rainfall and evaporation rates for the Mt. Nansen site are described in Appendix C.

Rainfall

Rainfall estimates for the Mt. Nansen site calculated based on actual 2000 to 2003 site data and Carmacks data (MET Sta. 2100300), are included in Table 1. These site specific data were used to calibrate the water balance model to the water levels measured in the pit over the corresponding time periods. Estimated mean and extreme precipitation events were used for fill rate prediction.

Table 1. Estimated mean annual to 100-year rainfall for Mt. Nansen

Month	Distribution	Mean annual	5 year	10 year	20 year	50 year	100 year
	%	211 mm	254 mm	285 mm	312 mm	348 mm	372 mm
Jan	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Feb	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mar	0.1	0.2	0.2	0.3	0.3	0.3	0.3
Apr	0.9	1.8	2.2	2.4	2.7	3.0	3.2
May	11.5	24.3	29.2	32.8	35.9	40.0	42.8
Jun	17.6	37.2	44.8	50.2	55.0	61.2	65.5
Jul	28.6	60.3	72.6	81.4	89.3	99.3	106.2
Aug	22.3	47.0	56.6	63.4	69.6	77.4	82.8
Sep	15.8	33.5	40.3	45.1	49.5	55.1	58.9
Oct	3.1	6.5	7.9	8.8	9.7	10.7	11.5
Nov	0.2	0.3	0.4	0.5	0.5	0.6	0.6
Dec	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note:

Estimates from LogNormal frequency analysis of Carmacks (MET Sta. 2100300) rainfall data of 1964-2002 by Northwest Hydraulics Consultants Ltd. and increased by 10% based on comparison of data collected at Carmacks and Mt. Nansen (supplied by Glenn Ford of Yukon Environment) for 2000-2002.

Snowmelt

Snow thickness and corresponding snow water equivalent (SWE) depth for 2000 – 2003 for the Mt. Nansen site are provided in Table 2. Table 3 contains mean to 100 year snowfall estimates calculated by NHC. Based on climatic data, it was assumed that most of the snowmelt occurs at the site during the months of April and May. Therefore, snowmelt, as snow water equivalent, was delivered to the water balance model at this time. The snow water equivalent data measured during 2000 through to 2003 (Table 2) were used to calibrate the water balance model to actual observed water levels in the pit lake.

Table 2. Snow Water Equivalent (SWE) at the End of March for Mt. Nansen

Year	Depth (cm)	SWE (mm)
2000	38	68
2001	36	52
2002	45	71
2003	31	50

Notes: Summary of data (by North West Hydraulics) supplied by Rick Janowicz of Yukon Environment, Hydrology)

Table 3. Estimated Mean Annual to 100-Year Snow Water Equivalent at the end of March for Mt. Nansen

Return Period (years)	Snow Water Equivalent
Mean Annual	73
5	87
10	97
20	106
50	118
50	126

Notes: Estimates (by North West Hydraulics) from LogNormal frequency analysis of Mt. Nansen (Sta. 09CA-SC01) data of 1976-2003, supplied by R. Janowicz of Yukon Environment

Pit Lake Evaporation

Pit lake evaporation rates were estimated from the Pelly Ranch lake evaporation data record (MET Sta. 2100880). These data show that lake evaporation occurs from May to September and most evaporation occurs during June and July. Pit lake evaporation is an important component of the water balance. The effects of evaporation on the runoff components from the pit walls and catchment areas are accounted for by the runoff coefficients discussed in section 2.6.3. Therefore, pit lake evaporation values were applied only to the surface area of the pit lake. Site specific values for pit lake evaporation are not available for the Mt. Nansen site. Therefore, the data in Table 4 were used for both the water balance model calibration and the long-term model predictions.

Table 4. Estimated Mean Annual to 100-Year Lake Evaporation for Brown McDade Pit at Mt. Nansen

Return Period	Pit Evaporation	Monthly Mine Pit Evaporation (mm)				
years	(mm)	May	June	July	August	September
Percentage Distribution		**23.0**	**26.5**	**24.5**	**17.6**	**8.3**
Mean annual	369	85	98	90	65	31
5	38	89	103	95	68	32
10	39	92	106	98	70	33
20	408	94	108	100	72	34
50	419	96	111	103	74	35
100	426	98	113	104	75	35

Notes: Estimates from LogNormal frequency analysis (by North West Hydraulics) of Pelly Ranch (MET Sta. 2100880) lake evaporation data of 1965-1995 and reduced by 19% to account for the 800 m higher elevation of the Brown McDade Pit and Mt. Nansen

2.6.3 Pit Seepage

As discussed in section 2.2, the major, if not only source of groundwater seepage into the pit occurs at the toe of the top bench in the northern end of the pit. Based on observations discussed in section 2.2, it can be assumed that this seepage is the only significant source of groundwater into the pit. This rate of seepage is perhaps the biggest unknown variable in the water balance as there was no means of measuring the flow rate during the frozen period when the site visit occurred. As a result, this parameter was included into the water balance during non-frozen periods. Seepage rate estimates, defined as “Pony Creek Seepage” for the purpose of this model, were used to help calibrate the water balance to the actual observed water levels in the pit. The source of seepage is inferred to be Pony Creek from visual observations, however, without groundwater instrumentation or water quality data, it is not possible to confirm this.

Cross sections provided in Figure 8 and Figure 9 and that shows the elevation of Pony Creek relative to the Brown McDade Pit. Based on relative elevations and the observed seepage occurring along the north pit face, this cross section suggests that Pony Creek is a very likely source of the seepage water. As a “check” to assess if the Pony Creek catchment could provide the estimated seepage rates that were used during model calibration, average monthly precipitation rates were applied over the Pony Creek Catchment area (95 Ha). It was found that the estimated seepage into the pit typically could represent less than 1% of the available water in the catchment during any non-frozen month. Therefore this finding suggests that the estimated seepage rates used in the water balance are properly bounded.

On average, the pit water levels during the winter months (December through March) dropped at a rate of approximately 0.3 m /month. This process becomes apparent in the spring, when a large void beneath the ice is created and the overlying ice collapses during spring thaw (per Comm Bruce Wheeler, 2004). It was assumed that during these winter periods, groundwater leakage out of the pit represents the only active component of the pit lake water balance. Based on the following observations and assumptions, all other inputs or outputs from the pit were considered negligible (i.e. zero) during this time.

1. The seeps identified at the north end of the pit freeze during the winter months, and did not appear active (i.e. no flowing water observed).
2. The surface of the pit lake freezes so evaporative losses are assumed to be zero.
3. All precipitation during the winter is considered to be in the form of snow, and therefore cannot be part of the active pit lake water budget until it melts.

Seepage rates measured from the negative slope portion of the pit lake elevation curves (Figure 3) were used to help calibrate the model. Pit lake elevation curves based on the three winter months data was collected, appears to be quite linear. The daily slope of this negative portion of the curve was calculated for each winter and multiplied by 30 days. Given the range of pit lake elevations, this generated an estimated monthly seepage rate that was applied across the entire year. For example, pit seepage rates measured from December 2001 through to March 2002 indicate a slope of 0.0076 m/day which equates to a seepage rate of 0.23 m / month. Given the range of observed pit elevations for this same period, an average seepage rate of 470 m^3 / month was calculated. This seepage rate, assumed to be constant, was then applied during both frozen and none frozen months from December 2001 through to December 2002. Overall the seepage rates between the three consecutive winters data sets were found to be very similar (i.e. for 2001, 2002, and 2003 the seepage rates were 540, 470 and 600 m^3/month respectively). An average seepage rate out of the pit (535 m^3/month) was used for simulating future pit water elevations. It should be noted however that seepage out of the pit could change through time and will likely depend on the pit lake elevation. As discussed, it would be expected that as the pit lake elevation increases, the expected permeability and or flux out of the pit bottom would likely increase as more fractures are encountered, including the Pony Creek Adit. However, this could change through time as a result of pit lake sedimentation, and a corresponding reduction in fracture permeability. Also, the driving head would likely increase when the water level in the pit is higher, resulting in a higher flux out of the pit based on Darcy's law.

The net loss of water from the pit during frozen periods can occur only through the submerged portion of the pit (i.e. through fractures), suggesting that the formation below the lake surface is somewhat permeable and unfrozen. The rocks within the deeper sulfide deposit (i.e. the deepest part of the pit) have been characterized in previous studies as being more "massive" or "less permeable" than overlying rock which are characterized as being more weathered and fractured. However, as indicated by the seasonal winter decline in water levels, it is very likely that small fractures within the massive bedrock are providing significant groundwater outflow.

Based on the observations to date, it is hypothesized that the regional water table is likely lower than the pit bottom. As discussed, this is not unreasonable as the Brown McDade pit is located on a topographic high locally and overall the site is quite high within an Alpine watershed. Consequently, within the vicinity of the pit, it would be expected that the regional water table is likely quite deep and would correspond with the lower part of the pit or lower in some parts, however no monitoring wells exist nearby to confirm this hypothesis.

Figure 8. Longitudinal Cross Section Profile of Brown McDade Pit

Figure 9. Cross Section Showing the Elevation of Pony Creek as it Flow East of the Pit

2.6.4 Pit Water Balance Model Calibration

The pit water model was calibrated to the available pit water level-elevation data for October 2001 to March 2004. Table 5 provides a summary of the various components of the analytical spreadsheet water balance model for the Brown McDade Open Pit, including a description of each step within the model. In combination with the pit volume / pit surface area curves, and associated catchment areas, actual meteorological data collected from the Mount Nansen Mine Site meteorological station was used to conducted an initial calibration of the water balance model. The corresponding observed pit lake elevations (Figure 3) were used to assess the accuracy of the model's prediction. This methodology provided a means of assessing which variables in the model play a significant role in the overall water balance of the pit. It also provided a method of confirming the magnitude of the estimated runoff coefficients and seepage inputs.

During the model calibration process, the runoff coefficients recommended by Northwest Hydraulics Consultants (NHC) (2004) for Zone 1 (0.2 to 0.3) and Zone 2 (0.8 to 0.9), were found to produce pit lake elevations significantly higher than actual observed levels. In particular during spring months (i.e. April, May and June) the model produced pit levels that were significantly higher than the actual recorded levels. This suggests that very little water within the catchment area is actually arriving into the pit, and that the associated run-off coefficients, recommended by NHC, are potentially over estimated. It might also suggest that losses to the ground water system are larger in summer than the rates calculated for the winter months. However, no data exists to verify this latter explanation. It may be possible that groundwater losses are lower during winter months because of frozen conditions. Observation of possible groundwater discharge at surface during non-frozen conditions (i.e. along the Dome Creek Watershed downgradient of the pit) could provide evidence that seepage rates may vary depending on frozen vs. non-frozen soil conditions. In the absence of supporting evidence, it was assumed that groundwater seepage rates out of the pit were constant. Therefore, the run-off coefficients were decreased (see Table 5), which allowed the model to more accurately reproduce the observed pit lake elevations. Although this procedure worked well in the spring, it became apparent by summer and early fall that precipitation directly on the pit and within the pit catchment area could not account for the observed increase in pit levels.

Up until this time in the model calibration process, the observed seepage along the north pit face had not been included in the water balance. As discussed, the observed increase in pit levels could not be accounted for by precipitation alone, therefore it became apparent that including a seepage component into the model, particularly during the non-frozen periods when seeps were known to be active, provided a means of producing a reasonable match between observed and modeled data (Figure 10). As discussed, a calculation was conducted and found to that the Pony Creek catchment could indeed provide the estimated seepage rates used during model calibration. It is essential however, that the seepage rates used in calibration be validated with field data (i.e. direct measurement of seepage rates) during the active season to provide confidence in model simulations.

Table 5. Description of Pit Water Balance Model

Figure 10. Calibrated Pit Water Balance Results

2.6.5 Modeling Results

Figure 11 presents a summary of the various components of the model that was calibrated using 2003/2004 meteorological data. This diagram suggests that seepage water into the pit along the north pit face is contributing the largest component of water, while groundwater seepage out of the pit, represents the largest component of water loss. At this elevation, the net total of all water balance components results in a yearly surplus of water in the pit and leads to a net rise in pit lake elevation.

The calibrated model was used to estimate the rate at which the pit would fill using a series of average monthly precipitation events. One 10-year precipitation event was also included in the simulation to examine the effect of pit filling during high rainfall/snow fall years. The results of this simulation (Figure 12) show that a high precipitation event plays a negligible role on the overall pit filling rate. This is consistent with the fact that the seepage into the pit, which is the largest input component, is not a function of precipitation. The limited data available prior to this study and the lack of site-specific measurements or observations of seepage make it impossible to infer any relationship between seasonal fluctuations in precipitation and changes in seepage flow rates.

The water levels also rise more quickly within the first few years when the water level is below an elevation of approximately 1184.5 m and subsequently rise more slowly beyond this level. Closer inspection of modeling results and pit geometry reveal that the pit lake surface area increases significantly beyond an elevation of 1184.5 m (see Figure 5). This corresponds roughly to the top of the flat area where the access road and ramp are located. When the water level reaches this point, there is a significant increase in the volume of water lost to evaporation resulting in a larger deficit between direct precipitation onto the lake surface and evaporation.

Based on these key observations, the assumptions associated with the model, and the limited data available, the model predicts that the pit lake elevation rise to an elevation approximately equal to the base of the Pony Creek Adit (inferred to be 1184.9 m) within 6 to 8 years before stabilizing.

In order to improve the level of confidence and accuracy of the model, the following data must be validated by field measurements:

- The position of the water table between Pony Creek and the pit, as well as on the far side of the pit must be ascertained to determine the permanent water table position. This will help assess the direction of flow to or from the pit and also help calibrate the amount of flow that might be leaving the pit by establishing lateral hydraulic gradients. This can be done with a few strategically placed groundwater monitors.

- The fluctuations in seepage rates into the pit are unknown at this time. The model assumes a constant seepage rate into and out of the pit, however, it is unknown if large precipitation events will change the rate of the seepage entering the pit.

- Seepage rates out of the pit are likely a function of water level. Given the current data set, changes in seepage rate out of the pit at higher water levels are unknown at this time. Additionally, the rate of leakage out of the pit may change seasonally and into the future. As observed, leakage from Pony Creek cascades into the pit, and may contribute, in the long term, to sediment accumulation in the base of the pit lake, which could reduce permeability and outward seepage rates. Conversely, as pit lake levels increase, and waters interact with the more fractured nature of the upper bedrock surface or potentially with the Pony Creek Adit, a greater seepage capacity out of the pit may occur. The effects of these processes are unknown at this time.

- The exact elevation of the base of the Pony Creek Adit must be confirmed.

- Field qualitative observations of the timing of spring thaw, ice melt, snow runoff, seepage thaw and freeze up must also be quantified.

Figure 11. Contribution of Individual Components of Water Balance

Figure 12. Projection / Simulated Pit Lake Elevations up to 2016

3. Pit Water Quality

3.1 Historical Review / Background

Gartner Lee retained Lorax Environmental Services Ltd. (Lorax) to assist in assessing the chemical nature of the lake forming in the McDade pit at the abandoned Mt. Nansen mine site. Most of the following sections have been taken with permission directly from their report included in Appendix D. The reader is encouraged to read the full report for more complete details and information. This mine was developed to extract gold and silver ore. A detailed report by Lorax is included in Appendix D. The report provides the assessment of the existing lake and, given the available data, constrains the potential controls on lake chemistry and dynamics. The paucity of existing pit and pit lake data makes quantitative predictions of future evolution of pit lake water quality extremely difficult. Accordingly, an important component of this study is the recommendations for filling data gaps and establishing the geochemical nature of the individual water balance components. The following sections provide a summary of the 2004 pit water quality sampling by Gartner Lee as well as the background information relevant to understanding the dominant controls on pit lake water quality. The following provides a summary of key issues discussed in detail by Lorax in Appendix D.

As discussed previously, the quality of the pit lake water is of particular concern due to potential off-site impacts such as the discharge of pit water into the Pony Creek watershed through the Pony Creek adit if water levels rise above the entrance to the adit within the pit. Also, the potential discharge of contaminated groundwater to streams or rivers downgradient of the pit is also of concern.

The main water quality issues are potential Acid Rock Drainage (ARD) and Metal Leaching (ML) from the pit floor and walls. As outlined in section 1.1, the pit intersects mostly oxide material which has been shown to have a low ARD/ML potential. However, pit mining continued to an elevation of approximately 10 m below the oxide zone and into the sulphidic zone. The latter has a relative high potential for ARD/ML as it contains various sulphide minerals, including pyrite, arsenopyrite, sphalerite, galena, bornite, stibnite and chalcopyrite.

3.2 Available Data

The following is an overview of the data available for the assessment and prediction of the pit lake water quality:

- The most recent data (February 9, 2004) on the chemistry of the pit lake water was collected by Gartner Lee as part of this study (section 3.6.1). The water samples were taken at the depths indicated in the following table.

Table 6. Pit Lake Water Quality Sample Depths

Station	**SP1**	**SP2**	**SP3**
Depths	1 m, 4 m, and 8 m	1 m, 3.5 m	1 m, 3 m

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- The recent pit lake water balance developed for this study: $\Delta S = (P\text{-}EP) + R_{ca} + R_{pw} + (G_i\text{-}G_o)$

  -with monthly inputs: P = precipitation onto lake surface

  R_{ca} = runoff from catchment area

  R_{pw} = runoff from pit walls/benches

  Gi = groundwater seepage into pit

  -with monthly outputs: EP = lake evaporation

  G_o = groundwater seepage out of pit

- Other chemical data of the pit lake water are obtained from 6 water samples collected at different times in the period from July 27, 1998 to September 10, 2002.

- Other potentially useful data include incomplete pit lake water chemistry data (E5) reported in Table 3.3-4 of the Conor Pacific Report (2000) that refer to samples collected (1) between October 22, 1998, and June 27, 1999 (2) on September 28, 1999. The complete data sets (incl. pH, alk, SO_4) were unavailable at the time of this study.

- Chemistry data are also available for surface waters (*e.g.* Dome Creek, Pony Creek) and adits (*e.g.* lower Huestis adit) collected by:

- Norecol on October 11, 1985, March 4, 1985, June 9, 1986, July 4, 1987, August 28, 1987 and May 27, 1988
- EPS (Environment Canada) in July and August of 1988
- P. Melling on September 12, 1994
- Conor Pacific on August 28, 1999

- representative precipitation chemistry data

3.3 Approach

At present, it is not possible to model the pit lake water chemistry given the paucity of compositional data for the individual components of the water balance. In particular, more information on the chemistry of water balance components R_{pw} (runoff from pit walls/benches), G_i (seepage into pit) and G_o (groundwater seepage out of pit) would improve the prediction of pit lake water chemistry by a simple mass-balance model. Some particular pit lake and tailings pond data of the Conor Pacific Report could be used as estimates for the water chemistry of some of the water balance components. The most valuable data, however, are those collected recently by Gartner Lee on Feb. 9th, 2004. These data form the basis for the development of the conceptual model described later.

This report serves as an assessment of the existing pit lake and, given the available data, identifies the potential controls on lake chemistry and dynamics. Once more representative data can be collected and better quantitative predictions of the pit lake evolution can be made. Accordingly, an important component of this report is the recommendations for filling data gaps.

The following sections describe the field methodology used to collect the samples and summarizes the key points which are discussed in detail in Appendix D. The following includes:
(1) a summary of background information relevant to an understanding of the dominant controls on pit lake dynamics;
(2) (2) an interpretation of the McDade pit lake data and a conceptual model that describes the observed behaviour, and ;
(3) (3) a summary of the findings and recommendations for better constraining our understanding of this system.

3.4 Physical and Chemical Characteristics of Pit Lakes

As outlined in Appendix D, the manner in which a pit lake behaves chemically is ultimately governed by the composition of water which fills it, in addition to its physical characteristics, specifically the way in which it mixes. . Because pit lakes are typically deep and steep-sided, they are resistant to wind-induced vertical mixing. Thermally induced spring and fall turnover do occur but may not always result in complete mixing and oxygenation of water at all depths. If the pit is subject to inflows of water with high concentrations of TDS then chemical stratification may occur, or may reduce the tendency for lake mixing. This characteristic imparts a geochemical framework upon the water column, which can be used to advantage in mine closure. Specifically, a pit lake can be created in which the natural physical tendencies are towards stability and the chemical inclinations involve metal removal. The following section describes briefly the physical and chemical characteristics of pit lakes generally and describes how these characteristics can be used to develop a system conducive to long-term chemical stability. A more detailed discussion is included in Appendix D.

3.4.1 Physical Behavior and Mixing

Pit lakes are typically steep-sided and deep; accordingly, the lake surface is often small relative to its depth. The small fetch (*i.e.*, length of lake surface exposed to wind-energy), deep water column and in some cases, topographic sheltering from strong winds, results in a limited transfer of wind energy to depth and limited vertical mixing. These characteristics cause pit lakes to behave very differently from most natural lakes. While the Brown McDade pit lake is not particularly deep, it shares some of these characteristics with its deeper counterparts.

In the absence of any salinity gradients, deep lakes typically host two layers: a deep layer (hypolimnion), whose waters are seasonally isolated from the atmosphere (and sometimes perennially stagnant), and an upper stratum of water (epilimnion), which actively circulates via wind mixing. A zone in which temperature changes rapidly with depth, the thermocline, typically defines the boundary between the upper and lower strata. This intermediate layer is characterized by a marked change in temperature with depth, which represents the depth interval over which maximum changes in density are observed. This region of maximum density change is referred to as the "pycnocline", the nature of which governs the characteristics of lake mixing. As discussed in Appendix D, large density contrasts across the pycnocline can result in the virtual elimination of mixing of surface waters with those at depth. This leads to the inhibition of oxygenation of deep waters which fosters anoxic conditions and an environment with fundamentally different chemical and biological traits to oxic waters above.

Vertical mixing in most lakes occurs via wind action and through thermal turnover when the temperature, hence density difference between upper and lower lake water layers diminishes making water layers easier to mix. Vertical mixing in most temperate lakes occurs via wind action and through thermal turnover, typically in the fall and spring.

The density structure is complicated slightly in some pit lakes, where the water column receives waters derived from runoff over the pit wall or other potential sources of salts (such as the Pony Creek Seepage). Under such circumstances, it is possible that salinity gradients can be established in the water column, which in turn influence the manner in which the lake mixes (Appendix D). Density increases with increasing concentrations of dissolved salts. As a result, salinity changes such as those that could be typically observed in a pit lake (*i.e.*, on the order of hundreds to thousands of mg/L) have a similar effect on density compared to changes in temperature. While pit lakes do not always salt-stratify, it is often possible for salinity gradients to influence the density structure of the water column. Accordingly, salinity can be viewed as an important parameter in the management of pit lake closure and is likely very important to the Brown-McDade pit.

3.4.2 Biological Controls on Metals in the Water Column

Primary productivity, or the life cycles of phytoplankton, exists in the surface waters of virtually all lacustrine systems. Even in nutrient-starved and heavily contaminated lakes, unicellular algae grow and die. The remains of these organisms sink through the water column to the lake floor. This process has two important ramifications on lacustrine biogeochemistry: first, sinking organic matter represents an important factor controlling metal transport from surface waters to the sediments (Hamilton-Taylor and Willis, 1990); and second, decomposing organic matter consumes oxygen and drives the water column and sediments to chemically reducing conditions (Balistrieri and Murray, 1992).

Consequently, a highly productive lake which hosts large algal populations (the Brown McDade pit does not) will be more likely to scavenge or remove metals from the surface waters to the sediments. Since most pit lakes tend to be oligotrophic (*i.e.,* poorly productive; Forsberg, 1989; Fukushima *et al.,* 1989), it is likely that the influence of such a scavenging mechanism would be small in an unmanaged system. However, the oligotrophic nature of such systems affords an opportunity to passively manage the chemistry of the system through "fertilization" in the form of direct or indirect nutrient addition (discussed in Appendix D).

3.5 Geochemical Controls on Metals in the Water Column

A detailed discussion about the nature of the density structure of stratified lakes and the profound influences on the chemical and biological processes that occur in both the water column and sediments is included in Appendix D. In summary, oxidation of organic matter processes that occur throughout the water column can result in the depletion of oxygen in the bottom waters. This process is further enhanced in the absence of deep water mixing (as in stratified lakes). The development of anoxic (*i.e.*, no oxygen) bottom waters can greatly influence the behaviour of heavy metals. Specifically, the development of anoxia can lead to the removal of metals via sulphide precipitation. Once oxygen is depleted, other electron acceptors are utilized to oxidize the organic matter. This consumption sequence and the resulting steady-state distributions of the respective oxidants are illustrated schematically in Figure 2 in Appendix D.

In summary, through processes described in Appendix D, the development of anoxia in the saline bottom waters of stratified lakes can lead to sulphate reduction and the commensurate generation of alkalinity. As a result, when ample sulphate exists, such lakes can be characterized by significant production of hydrogen sulphide (H_2S) in the bottom waters (Perry and Pedersen, 1993). Many trace elements (Fe, Co, Ni, Zn, Cd, Pb, *etc.*) react rapidly with sulphide to precipitate as relatively insoluble sulphide minerals. Consequently, the precipitation of metal sulphides, and their subsequent settling to the lake floor, can provide an effective removal mechanism of heavy metals from the water column (Green *et al.*, 1989), as has recently been done in the pit at the Colomac Mine in the NWT.

3.6 Results and Discussion

3.6.1 2004 Pit Water Quality

Water samples for chemical analysis were collected by Gartner Lee Limited during the February, 2004 field visit. Samples were collected through the ice at 3 locations (SP-1, SP-2 and SP-3) (Figure 4) and at two to three depths at each location (Table 6) to obtain a profile of water quality. Water quality results are included in Table 7.

Table 7. Pit Water Quality Results – February 2004

Field Sampling Procedures and Equipment

Water samples were collected using a Kemmerer depth-discrete sampler. Photographs of the sampler are included in Appendix A. Samples were collected by lowering the device slowly to the sample depth and allowing enough time to minimize disturbance prior to sampling. The samples were collected in plastic sampling bottles and an additional volume of water was used to record field parameters. Field measurements were recorded for pH, Electrical Conductance (EC), Specific Conductance (SC), and temperature. Field data have been incorporated with the analytical laboratory data for the sampling event (Table 7).

The pH was measured using a Hanna Phep5 handheld combination temperature and pH probe with an accuracy of 0.01 pH units and 0.1 degrees C. Specific conductance was measured using a YSI Instruments model 30 combination SC and temperature probe. All SC measurements were automatically compensated by the instrument for groundwater temperatures and are reported as for a sample at 25°C. Photographs of the field measurement apparatus can be found in Appendix A. Field probes were calibrated daily prior to the start of the sampling event and at the end of the day using new pH and conductivity calibration solutions.

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3.6.2 Quality Assurance and Quality Control

All groundwater samples submitted for analyses were collected in pre-cleaned bottles supplied by the analytical laboratory. The following sampling and preservation methods were used:

- Samples submitted for dissolved metal analyses were collected in 250 mL high density polyethylene (HDPE) bottles and were preserved in the field (pH < 2) using laboratory-supplied and measured aliquots of nitric acid. Samples were filtered in the field using 0.45 micron filters.

- Samples submitted for general parameters (i.e. pH, alkalinity) and nutrient analyses (nitrate) were collected unfiltered into 1-L HDPE laboratory-supplied bottles.

Following sample collection, all samples were kept in a cool, dark environment and transported by courier to the laboratory within the allotted transport periods. ALS Environmental of Vancouver, BC (ALS), a member of the Canadian Association for Environmental Analytical Laboratories (CAEAL), conducted all water analyses.

To assess analytical variability, a set of laboratory replicates was used to calculate the relative percent difference (RPD) on a laboratory replicate. RPD is defined as the following:

$$\%RPD = \frac{2(X_1 - X_2)}{(X_1 + X_2)} * 100$$

Where: X_1 = The concentration of the first sample;
X_2 = The concentration of the second sample (i.e., the replicates).

Laboratory variability was also calculated in lab duplicates and found to have RPD values of less than 5% (calculated only for parameters that had concentrations greater than two times the method detection limit).

Field Variability (i.e., repeatability of data between simultaneous grab samples) was also assessed with the collection and analysis of one field replicate. The RPD for all parameters from the field replicate was less than 17% showing relatively low variability between simultaneous grab samples. In summary, these findings indicate acceptable levels of data reliability.

3.6.3 ARD/ML Assessment

A detailed review of acid rock drainage (ARD) and metal leaching (ML) work done at the site and an interpretation of the results was done by Lorax (Appendix D). The first assessments of the ARD and ML characteristics of the ore, wasterock and tailings from the Huestis, Webber and Brown McDade Zones were conducted in 1985, 1989 and 1994 (Higgs, 1994; Conor Pacific, 2000). Most samples from the McDade Zone were from the upper portion defined as the oxide zone. The samples were characterized by low sulphide content and mostly positive net neutralization potential (NNP). Distilled water leaching test results suggested that the waste rock did not contain appreciable leachable metals.

Additional ARD/ML assessment work was conducted in 1996 (during operation) and in 1999 (Conor Pacific, 2000). In November 1996, 13 rock samples were collected from the walls of the McDade pit and analyzed by the modified ABA procedure. All samples were again taken from the upper oxide zone. During the 1999 site assessment by Conor Pacific (after closure), 6 rock samples were taken from the lower areas of the pit floor to assess the ARD/ML potential of the pit floor and lower pit walls. Apart from ABA tests, the samples were also tested by a modified Special Waste Extraction Procedure (SWEP) method using distilled water to determine the readily soluble metals. The results from the ARD/ML assessment studies in 1996 and 1999 are discussed below.

The data found in Table 1 and Figure 4 of Appendix D indicate that many of the 1996 and 1999 samples are either *likely* or *possibly* acid generating. The nature of acid generation in these samples appears to be related more to their relatively low neutralization potential rather than their high acid potential. The significance of this observation has to do with the amount of acidity generated by the exposed pit walls. While the residual sulphides in the exposed oxide regions of the pit wall may be acid-generating now or in the future, the amount of acidity will be relatively low owing to the low sulphide contents.

The metal leaching characteristics of the 1999 samples are shown in Table 2 of Appendix D along with dissolved metal concentrations in samples of pit lake water. Except for the sample of a foliated diorite (MN-PF-TP03-01) with an extremely high acid potential, the concentrations of *readily soluble* metals in the leachates from the samples are generally low although some exceptions do exist for Zn, Cd and Mn in a few samples. Only arsenic concentrations are relatively high, especially in samples that are likely or possibly acid generating.

A comparison between metal concentrations in the leachates and pit lake waters shows similarities and discrepancies (Table 2 of Appendix D). Most metal concentrations appear to be highest in pit lake water samples that were sampled immediately after closure (*e.g.* October 22, 1998 – September 28, 1999) after which they decrease in pit lake water with time. Although metal concentrations in the leachates are dependent on the solid:water ratio used in the tests, it is interesting to note that the concentrations of metals vary greatly. Whereas arsenic (As) concentrations in the leachates are higher than those in the pit lake water, the opposite applies to the concentrations of Cd, Cu and Zn.

The observed discrepancies in metal concentrations indicate that the chemistry of the lake water cannot simply be predicted from the results of a metal leaching test and subsequent dilution; *in situ* geochemical transformations are known to significantly influence metal concentrations. Moreover, the bedrock exposed to metal leaching is highly heterogeneous in composition and ARD potential. Perhaps more importantly, other input sources (*e.g.* seepage from the Pony Creek watershed) may contribute substantively to the chemistry of the pit lake water.

3.6.4 Evolution of Pit Lake Water Chemistry

Over the period from July 27, 1999 to February 9, 2004, several surface water samples were collected from the McDade pit lake; the data are presented in Table 3. In contrast to the apparent acid generating potential of the pit walls, the lake water has remained comparatively alkaline hosting pH values between 7.8 and 8.1 with commensurately high alkalinities up to approximately 250 mg/L ($CaCO_3$ equivalent).

Since the first sampling, the conductivity of the water has dropped from 4,200 µS/cm and now appears to fluctuate between 1,400 to 2,000 µS/cm. As the dominant anion in the lake water, the trend in the SO_4 concentration is similar to that of conductivity. Both trends may reflect changes in the pit lake water balance due to variations in the contributions from the different water balance components. This potential effect of the water balance on the pit lake water chemistry was examined by Lorax and is discussed in detail in Appendix D.

Using data from the latest water balance calculations and data shown on Figures 6 to 8 in Appendix D, there doesn't appear to be an evident correlation between any of the major parameters (conductivity, sulfate or zinc) and the relative inputs from water balance components (e.g. increases in seepage or direct runoff do not correspond to increase of these parameters). The apparent lack of correlation between changes in pit lake chemistry over the years and changes in the monthly averages of the various water balance components may be due to several reasons. First, the hydrological conditions on the sampling days in various years do not necessarily reflect the long-term monthly averaged conditions depicted in the water balance. Still, a better correlation between short-term and long-term hydrological conditions would be expected. Secondly, major chemical inputs to the pit lake water chemistry may be from water balance components that are relatively small. Additional information on the chemistry of the different water balance components would enable the use of a mass balance to identify the major chemical sources among the different water balance components. Thirdly and perhaps most importantly, changes in the chemistry of the water at the surface of the pit lake may be more related to the chemistry of the entire water column and its dynamics than to the various input and output of the water balance. This would apply to a situation where the pit lake water column is either temporarily or permanently stratified.

Sampling of the pit lake water column at different depths has only occurred during the last sampling by Gartner Lee Limited on February 9, 2004. The results of the chemical analyses are shown in Table 7. Depth profiles of several important chemical characteristics of the pit lake water column are presented in Figure 9 of Appendix D.

The conductivity and the SO_4 concentration of the pit lake water appear to increase (linearly) with depth. Values for both parameters near the bottom of the pit (8 m) appear to be of similar magnitude as in the surface water sample collected on 27/7/'99, probably at the beginning of the pit lake development.

The dissolved concentration profiles of both Cd and Zn show marked increase in concentration near the bottom of the pit presumably in association with ARD from initial pit filling. However, the concentration profiles of NO_3, Mn and Cu are of particular interest because redox processes in the pit lake appear to affect their concentrations. The concentrations of NO_3 and Mn(II) decrease and increase, respectively with depth suggesting that both nitrate and Mn oxides are being utilized as oxidants in the progressive oxidation of organic matter and that the redox potential of deep waters is sub-oxic at the very least (see Figure 2 of Appendix D). The fact that Cu is seen to decrease in concentration with depth may be interpreted to suggest that sulphate reduction is also occurring but not to the extent that either sulphate, Fe or any of the other trace metals are visibly impacted. Thus, while surface waters appear fully oxygenated, the deep layer resides somewhere in the sub-oxic to anoxic geochemical regime.

3.6.5 Conceptual Model

While a predictive mass loading model is impossible to produce given the data limitations, the existing ARD/ML and water chemistry data allow the development of a conceptual model.

During the final stages of the operations in the Brown McDade pit, mining proceeded into the sulphide zone where it exposed bedrock with a high potential to generate ARD. Accordingly, the initial filling stage of the pit, ARD from the lower part of the pit generated high concentrations of sulphate and trace metals in the shallow pit lake. However, the relatively high pH and alkalinity of this water suggests that an independent water source contributed abundant neutralizing capacity to the lake. This is seen in the chemical composition of the pit lake water collected on July 27, 1999 and the deepest water samples (8 m) in the pit lake (Table 3 of Appendix D).

During subsequent filling stages of the pit, ARD release from lower pit walls would have ceased and comparatively fresh water would constitute the upper layer of the lake. After the initial filling stage of the pit, little mixing would have occurred between the highly concentrated water in the bottom of the pit and the relatively fresh water added during successive filling stages. While it seems unusual that so little mixing would have occurred in such a shallow pit lake, the persistence of lake stratification is strong evidence for the lack of substantive mixing. In other words, despite the shallow nature of the system and its potential for wind mixing, there are at least two distinct layers separated by strong physical and geochemical gradients. Indeed, the salinity contrast between surface and deep water is large and likely capable of preventing open-water mixing. However, this salt-stratification will likely degrade with time to the extent that the lake will eventually mix throughout its water column, unless it is allowed to deepen significantly.

The bottom layer is high in solutes dominated by sulphate. The concentration profiles of NO_3 and Mn in the water column suggests that the redox state in the bottom layer is gradually evolving to more strongly reducing conditions. These data also support the notion that the stratification is persistent as the data suggest that the lake is oligotrophic and incapable of producing seasonal episodes of anoxia.

Except for Mn and Zn, which are highest in concentrations in the bottom layer, dissolved metal concentrations are comparable to those in the overlying water layer(s). The top layer is characterized by a much lower solute concentration than the bottom layer and in addition to sulphate, calcium and magnesium appear to dominate its chemical composition. Redox conditions are oxidizing. Without any detailed CTD-profiling of the water column, it is impossible to delineate the extent or resistance to mixing of the two water layers in the pit lake.

Over the short term, the bottom layer will likely remain isolated from surface waters and redox conditions will gradually become more reducing. However, with time, the stratification will likely erode through the progressive loss of salt by diffusion to the surface layer, to the extent that seasonal turn-over may become a regular event. Under such conditions, the water column will likely remain oxygenated year-round. It is possible that deep water loss to groundwater seepage will decrease the thickness of the bottom layer; however, the break-down of stratification is probably the more dominant process. In either case, the lake should evolve towards a uniform composition.

The chemical composition of the upper layer and ultimately, the pit lake as a whole, will largely be determined by chemical loadings from the different components of the water balance. To predict the chemical composition of the top layer, at least the chemical loadings need to be established. These loadings will be from the runoff from the catchment area, the pit walls and the benches, as well as seepage flowing over the top bench in the north end of the pit from the Pony Creek catchment.

Without more information on the chemical composition of the major input and output sources in the water balance, it will be very difficult to predict the chemical composition of the pit lake. However, in the absence of these data, and given the existing structure of the lake, it is not unreasonable to suggest that future water quality will be similar to that presently seen in surface waters.

Water quality in the pit is also representative of the water quality of groundwater leaving the pit. Based on recent data, it is reasonable to assume that there is potential for a plume of contaminated groundwater to emanate from the pit. There exists the possibility that groundwater of poor water quality may be discharging to surface water bodies downgradient of the pit. The direction of groundwater flow near the pit and the magnitude of vertical hydraulic gradients near the pit can not be determined without local water table measurements from wells. This would depend on initial groundwater quality leaving the pit, geochemical conditions in the subsurface and travel times along flow pathways. For the purposes of this preliminary study, a detailed groundwater investigation focussing on groundwater quality was not warranted without first understanding the controls on the pit lake water balance and pit lake water quality. Consequently, this should be an important consideration when developing future investigations at the site. Potential siting of groundwater wells near the pit to examine physical flow characteristics should also aim to examine groundwater quality.

4. Conclusions and Recommendations

Despite the nature of field conditions during this study and the limited data available, sufficient data has been compiled to allow identification of the potential issues related to water quality and quantity management for the Brown McDade Pit. The following recommendations were developed to offer guidance on the best approach to acquiring data and information which will be key to developing a full understanding of the issues identified. There is insufficient water quality and water flow data collected thus far that would enable a quantitative prediction of final water quality for the Brown McDade Pit. (For example what is the water chemistry of each contributing source of water into the pit). Furthermore, several uncertainties associated with the prediction of final pit water levels remain. In particular, is the pit lying below the regional water table, or is it simply leaking down to the water table much further below? It is recommended that the best approach, for more accurately predicting final pit water quality and allowing for better confidence in the water balance model, would be to delay any direct management intervention such as pit de-watering. This would prevent any modification to pit lake quality, and allow proper monitoring of seasonal pit lake fluctuations, pit water balance component interactions, and pit lake chemistry evolution, until substantial data has been collected. This approach would ensure that the most cost-effective and scientifically based pit lake management and/or abandonment plan be developed. Based on the findings of this work and the goals set out in the Statement of Work, the following conclusions and recommendations have been made.

4.1 Conclusions (Pit Water Balance)

The historical review of pit lake water levels, on site observations and the analytical spreadsheet based water balance model developed for the McDade pit lake allowed the following conclusions to be drawn:

- Seepage water into the pit along the north pit face (likely from Pony Creek) is contributing the largest positive component of water balance. No other evidence of seepage into the pit was observed.

- Groundwater seepage out of the pit, represents the 2nd largest component, as a water loss.

- The Pony Creek seeps are reported to occur during all non-frozen months however no direct measurements were possible due to frozen conditions at the time of this study to confirm the rates estimated using the model.

- The contribution of precipitation within the pit catchment area likely represents a small component of the water budget.

- Underground mining, within the Pony Creek workings prior to the excavation of the pit, encountered subsurface water only at the end portion of a drift, constructed beneath what is now the northern face of the pit. It was noted by Stroshein (2004) that the water in this area appeared to leak into the drift from the ceiling and leak out through the drift floor suggesting that seepage into the pit occurs mostly from the Pony Creek seepage along the north bench.

- Seepage into the pit appears to stop during winter months and large icicles form along the pit face. Icicle growth does not appear active during the frozen months. Pony Creek to the north, appears to freeze completely into the stream bed during the winter. Pony Creek crosses to the north of the pit approximately 65 m away, and is significantly higher in elevation than the base of the pit. In fact, the elevation of the seepage face on the first bench of the pit corresponds reasonably well to the elevation of the creek.

- The pit is located quite high topographically. Collectively, this evidence combined with the lack of seepage into the pit from sources other than the north end of the pit suggests that the pit lake surface does not reflect a regional groundwater table, and that the water table is likely lower or close to the pit bottom elevation. No monitoring wells in the area are present to confirm this hypothesis.

- Based on the assumptions associated with the model, and the limited data available, the model predicts that the pit lake elevation rise to an elevation approximately equal to the base of the Pony Creek Adit (inferred to be 1184.9 m) within 6 to 8 years before stabilizing. Based on the pit geometry, this elevation represents a point where the pit lake surface becomes very large, allowing for evaporation rates during summer months to greatly increase, and cause equilibrium type conditions.

- Fluctuations in seepage rates into and out of the pit and seasonal, physical (i.e. the effect of Pony Creek seepage cascading over the side-walls causing sediment accumulation at the bottom of the pit, reducing outward seepage rates), and climactic influences (i.e. increases in precipitation) on these seepage rates could not be estimated or predicted given the available data.

- Pit lake evaporation becomes an important component of water loss from the pit when the water level in the pit reaches the level of the flat platform area at the toe of the ramp. This results from the significant increase in Pit Lake surface area that occurs at this point.

- Unfortunately, it could not be determined during this study if in fact Pony Creek Adit is a preferential pathway for water out of the pit and into Pony Creek. It is believed this adit has caved in, however until otherwise demonstrated, it is unknown if this will provide a pathway for seepage.

4.2 Conclusions (Pit Water Quality)

From the interpretation of the Acid Rock Drainage and Metal Leaching (ARD/ML)assessment and a review of recent and historical water chemistry data of McDade pit lake the following conclusions can be drawn:

- There are insufficient data to generate a rigorous pit lake model as there are few source water compositional data.
- The water column of McDade pit lake is stratified, consisting of a more saline bottom layer and a top layer with relatively fresh water. Considering the differences in chemical composition between the two layers and the reducing conditions established in the bottom layer, the stratification of the water column appears to have persisted since closure. The similarity between the 1999 data (immediately post closure) and the deep samples (8 m) supports this notion.
- Stratification of the water column probably originates from ARD generated from the exposed sulphide zone during the initial filling stages of the pit. ARD generation caused the formation a (saline) bottom layer with a high sulphate concentration, which was topped by a layer with fresh water during successive filling stages.
- An independent source of alkalinity to the filling lake has allowed the pH to remain in the slightly alkaline range (pH ~8). The Pond Creek seepage (on the north wall) is a potential candidate but cannot be confirmed without compositional data.
- Despite the shallow lake depth, substantive wind mixing between the two layers has not occurred. The lake configuration (pit shape, wind-shielding effect of local topography) and the disparity between fresh water inflow and ARD-influenced deep waters likely contributed to a lack of mixing between the two layers during filling.
- At present the generation of ARD from the sulphide zone at the bottom of the pit lake is non-existent, given permanent water cover and the existing reducing conditions. Hence, the chemical composition of the bottom layer is not expected to worsen due to its isolation and the lack of inputs. The chemical composition of the bottom water will be affected by the prevailing redox conditions, which will become more reducing with time. However, ongoing seasonal mixing is anticipated to gradually erode the salt stratification such that seasonal, whole lake mixing may occur in the future.

- The chemical composition of the surface layer is largely determined by the various input sources of the water balance. Among these, inputs from runoff have the largest impact on the lake water composition. At present, the loading associated with runoff is unknown, making it difficult to predict the chemical evolution of surface waters. However, the current surface water composition appears to be a reasonable first approximation to eventual pit lake water quality.

4.3 Recommendations (Pit Water Balance)

Considering the paucity of existing pit water balance component data, especially those related to estimating Pony Creek seepage and groundwater outflow seepage and evaluating seasonal fluctuations in these major water balance components, additional studies are recommended to better constrain the understanding of the controls on the pit lake water balance. Accordingly, the following recommendations are offered:

- Continuous monitoring of pit lake water levels using the existing level logger system should be continued as well as the collection of site specific meteorological data.

- Installation of 2 to 3 ground water monitoring stations to determine the depth of the regional ground water table and to assess the potential for seasonal inflow/outflow of ground water to/from the pit. These should be installed in non-winter conditions, and at a minimum monthly monitoring of water levels pursued. Installation of long-term data acquisition devices (i.e. level-loggers) at these stations would be useful to monitor seasonal trends.

- Key observations of exact timing of snowmelt, ice collapse, pit-wall runoff, qualitative observations of seepage rates and seep locations within the pit, surface runoff patterns (during and following rainfall events) should be noted, recorded and photographed whenever possible by mine site personnel (e.g. Bruce Wheeler) and YG personnel (e.g. Glenn Ford) to provide qualitative validation and refinement to the water balance model.

- The occurrence of seepage runoff out of the Pony Creek adit should be monitored to confirm that no seepage occurs into the adit from the fractured rock within the adit (and not from rising water levels in the pit)

- A qualitative and/or quantitative observation of the state of the Pony Creek adit should be made to establish the possibility that water from the Pit could leak out through the Pony Creek drift (i.e. there could exist a way to test if the adit provides a direct conduit such as pumping water into the adit and examining the response at the exit although this may be logistically complicated). This may also allow an opportunity to monitor seepage quality from the Pony Creek Adit.

- Flow in Pony Creek and any other major drainage feature at the site such as ditches or seeps into the pit should be measured and monitored seasonally (using a combination of stream gauging and weirs) to provide better estimates of each component and also establish flow patterns around the pit. Water samples of the creek and the seepage into the pit should be analyzed for water quality parameters to assist in the confirmation of this source of water to the pit.

- The elevation of the Pony Creek adit within the pit (which could not be located due to snow cover during the survey and study period) should be determined. This may involve the use of historic mine documents coupled with a detailed inspection of the open pit mine face.

- The occurrence of pit wall staining indicative of groundwater seepage into the pit should be examined to validate observations made during a period of partial snow-cover.

- An instrument should be installed at the site to allow direct measurement of pit lake evaporation for the Brown-McDade Pit.

- The preliminary water balance model should be updated and further calibrated with site specific measurements and data that has been collected since March 2004.

4.4 Recommendations (Pit Water Quality)

Considering the limited pit lake data, especially those required to predict the chemical evolution of the pit lake water, additional studies are recommended to better constrain the understanding of the controls on the pit lake. Accordingly, the following recommendations are offered:

- Collect detailed information on the conductivity, temperature with depth profiles (CTD) of the pit lake water column at several locations of the pit lake. The information is necessary to determine the vertical density structure and corresponding volumes of water in each of the stratified layers.

- Repeat the CTD profiling in different seasons to verify that pit lake stratification is not seasonal. Also, repeat the sampling of the different water layers for chemical analysis to complement the limited, existing water chemistry data.

- Collect water quality samples from all substantive inflows including the Pony Creek seepage on the north wall.

- Measurements of pit lake water quality should also include dissolved oxygen (DO), pH, Eh and Temperature in addition to conductivity.

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5. Acknowledgements

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- Robert Stroshein, Bill Mann
- Glenn Ford and Ric Janowicz, Department of the Environment, Yukon Government,
- UnderHill Geomatics
- Lorax Environmental Services Ltd.
- Northwest Hydraulic Consultants Ltd.

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Hugh Copland (personal communication, Feb 9, 2004)

Bruce Wheeler (personal communication, Feb 9-10, 2004)

Robert Stroshein (personal communication Feb 24, 2004)

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Appendix A: Photographs of Site and Field Activities

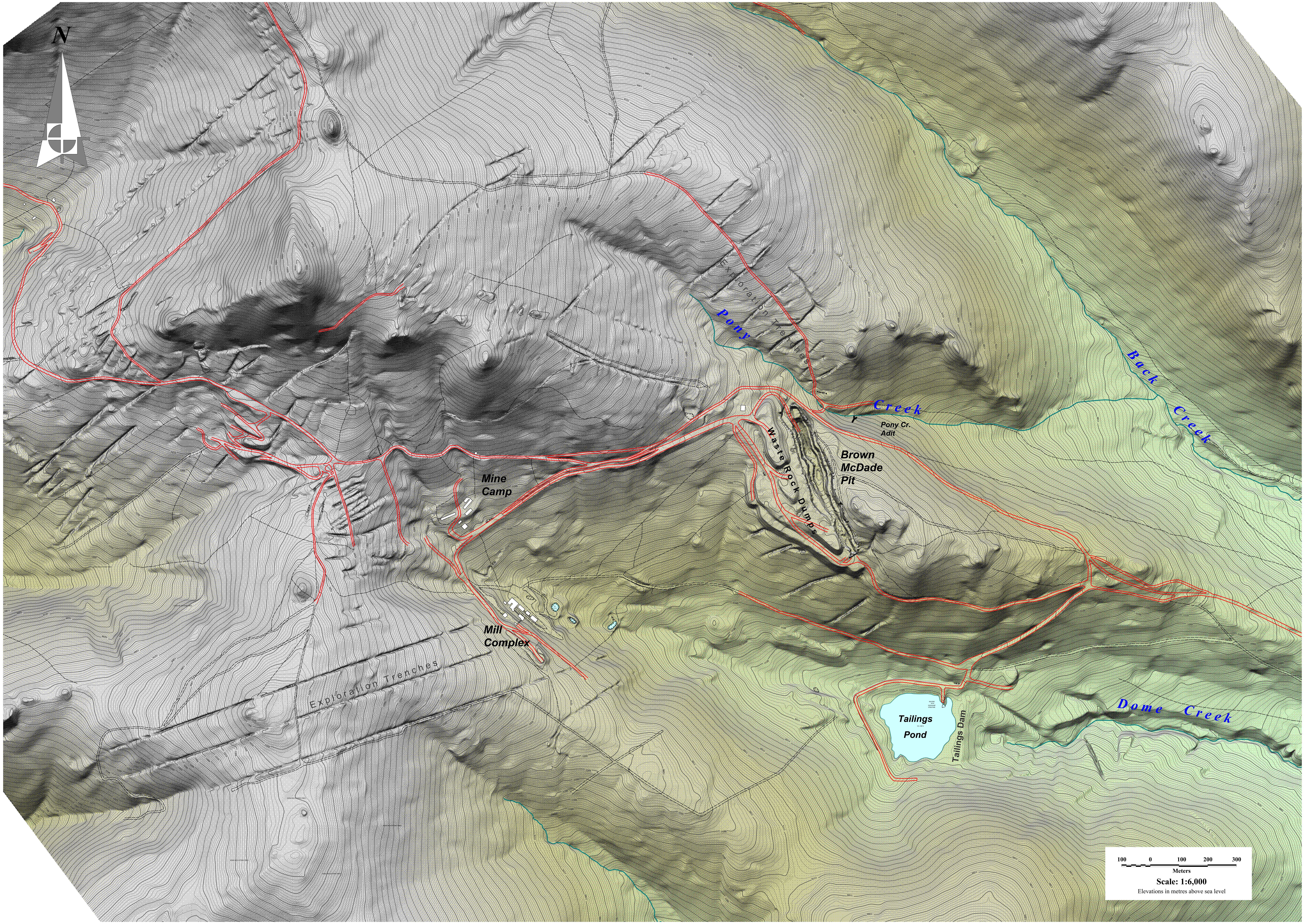
Appendix B: Pit Water Balance Calculations (electronic)

Appendix C: 2004 Pit Water Balance Input Parameters Report by NHC Ltd.

Appendix D: 2004 Pit Water Quality Evaluation Report by Lorax Environmental Services Ltd.

Appendix E. Official Water Quality Reports

Site Name: Brown McDade Pit	YTG - Energy Mines and Resources	Project No: 23-669
File Name: 23669_fig1.WOR	Brown McDade Pit Water Balance Mount Nansen, Yukon	Date Issued: Mar. 2004
Gartner Lee Scale: 1: 6,000,000	**Project Location Map**	**Figure 1**



LEGEND:

- Index Contour (5 m)
- Intermediate Contour (1 m)
- Pit Contour (2.5 m)
- Large Stream
- Waterbody
- Road
- Trail
- Building

SOURCES OF DATA:

Orthoshop, 2004. Based on 1998 aerial photography at 1:50,000 scale
Pit Survey by Underhill Geomatics Limited, 2004.

DRAWING INFORMATION:	
DRAWN BY:	FKP
REVIEWED BY:	MG
DATE ISSUED:	MAY 2004
PROJECT NO.:	23-669
FILE NAME:	23669-F2.WOR
REVISION:	0
DATA PROJECTION:	UTM ZONE 8, NAD 83

ABANDONED MINES PROJECT OFFICE
ENERGY, MINES & RESOURCES
BROWN MCDATE PIT HYDROGEOLOGICAL & GEOCHEMICAL INVESTIGATION

MOUNT NANSEN MINE PROJECT OVERVIEW MAP

Gartner Lee

FIGURE NO. 2

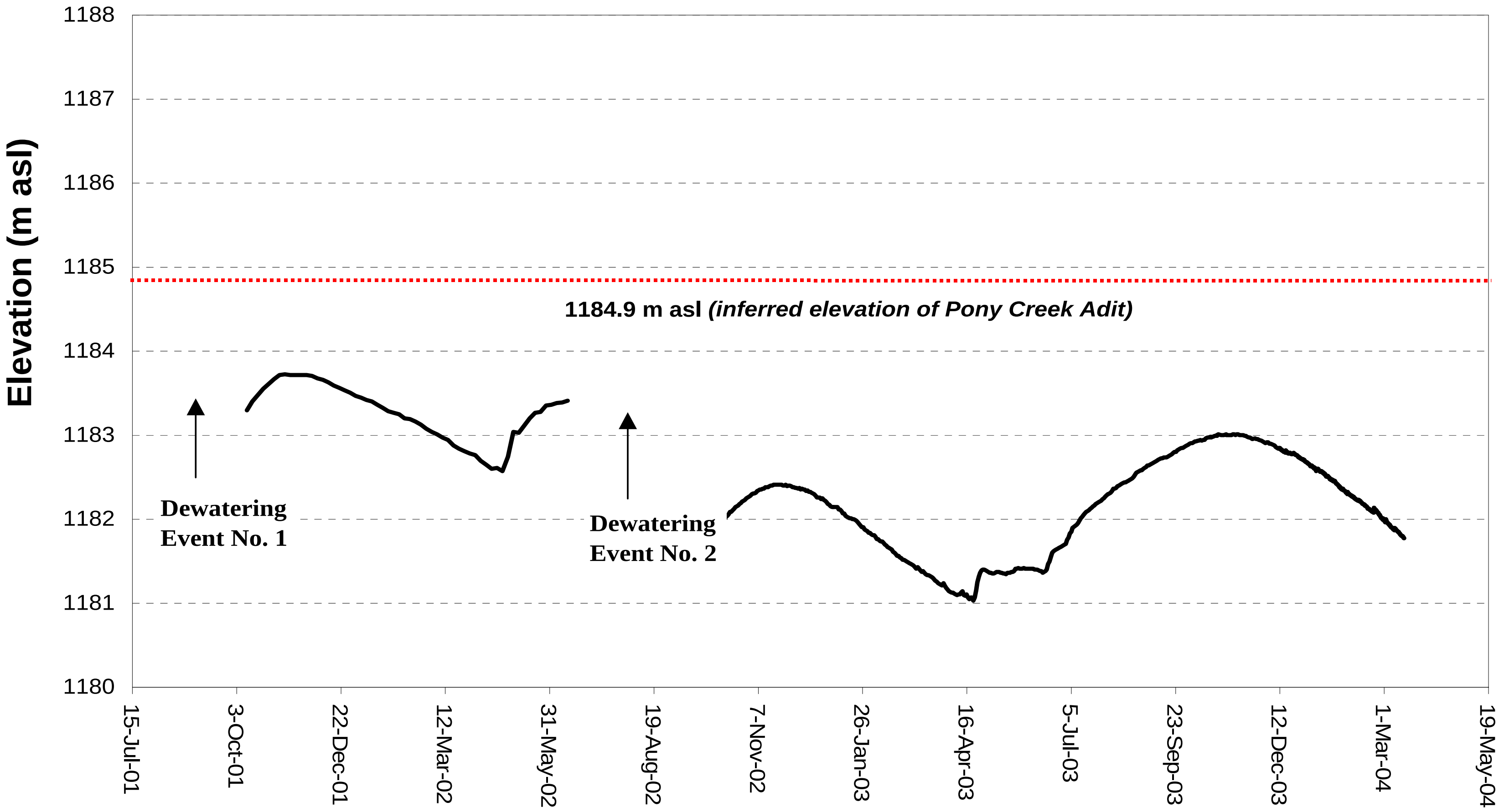
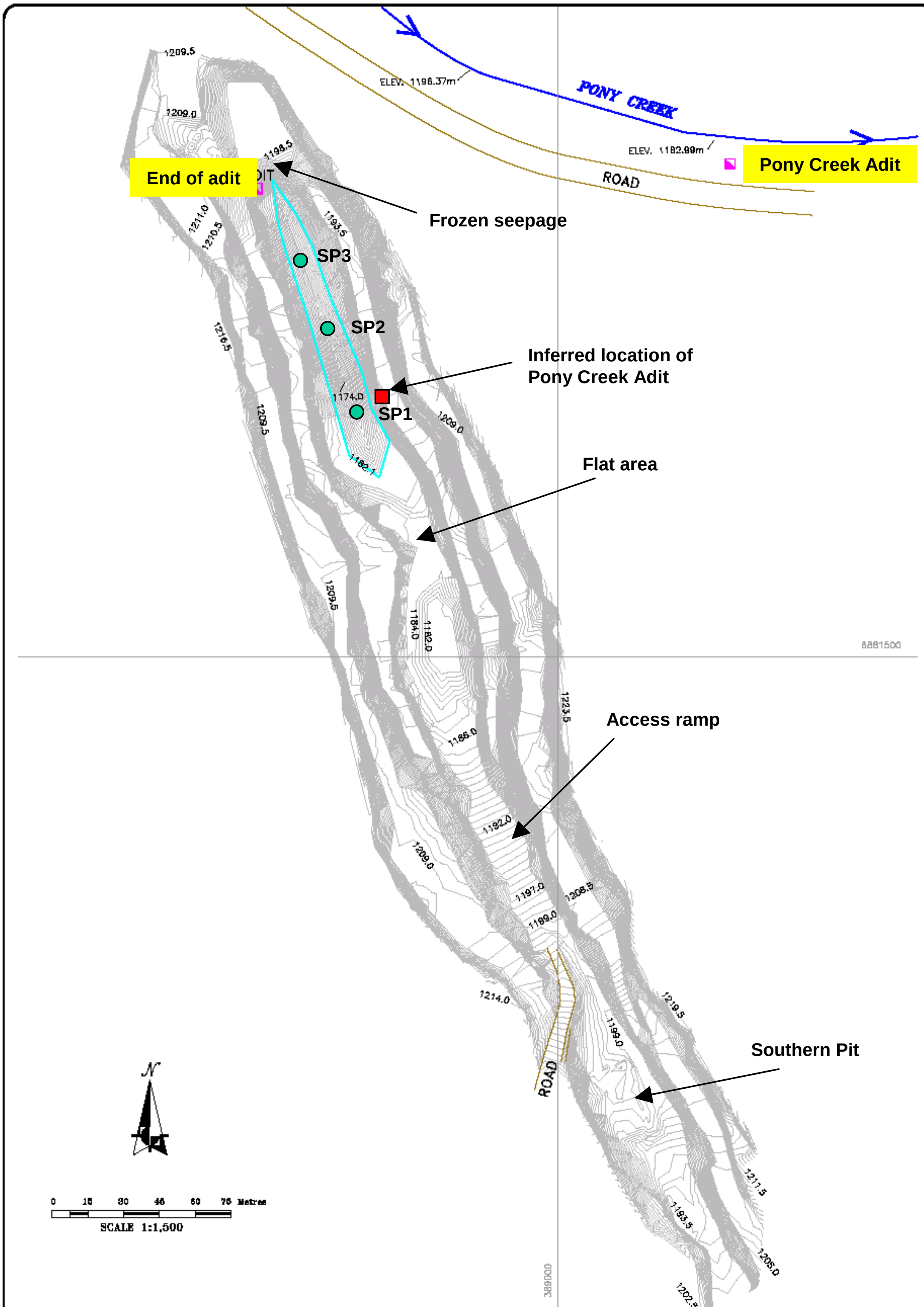


Figure 3. Post-operational Pit Water Level Fluctuations (2001-2004)

Gartner Lee

Project Number: 23-669
Date: May, 2004



LEGEND:

- CREEK
- GROUND SURFACE CONTOUR (mASL)
- LEVEL OF ICE (MARCH, 2004)
- ADIT
- 2004 Sampling Points

SOURCE OF DRAWING: SURVEY BY UNDERHILL SURVEYORS CONDUCTED IN MARCH, 2004 CONTOURS IN mASL NAD 83 ZONE 8	Project: HYDROGEOLOGICAL AND GEOCHEMICAL INVESTIGATION Location: MT. NANSEN MINE SITE, BROWN MCDADE PIT Client: ENERGY MINES AND RESOURCES, ABANDONED MINES OFFICE
REVIEWED BY: MG DRAWN BY: PW DATE ISSUED: JUNE, 2004 PROJECT NUMBER: 23-569 FILE NAME: 23569-2D-01.DWG REVISION: 0	**BROWN MCDADE OPEN PIT SURVEY (March 2004)** Gartner Lee FIGURE NO 4

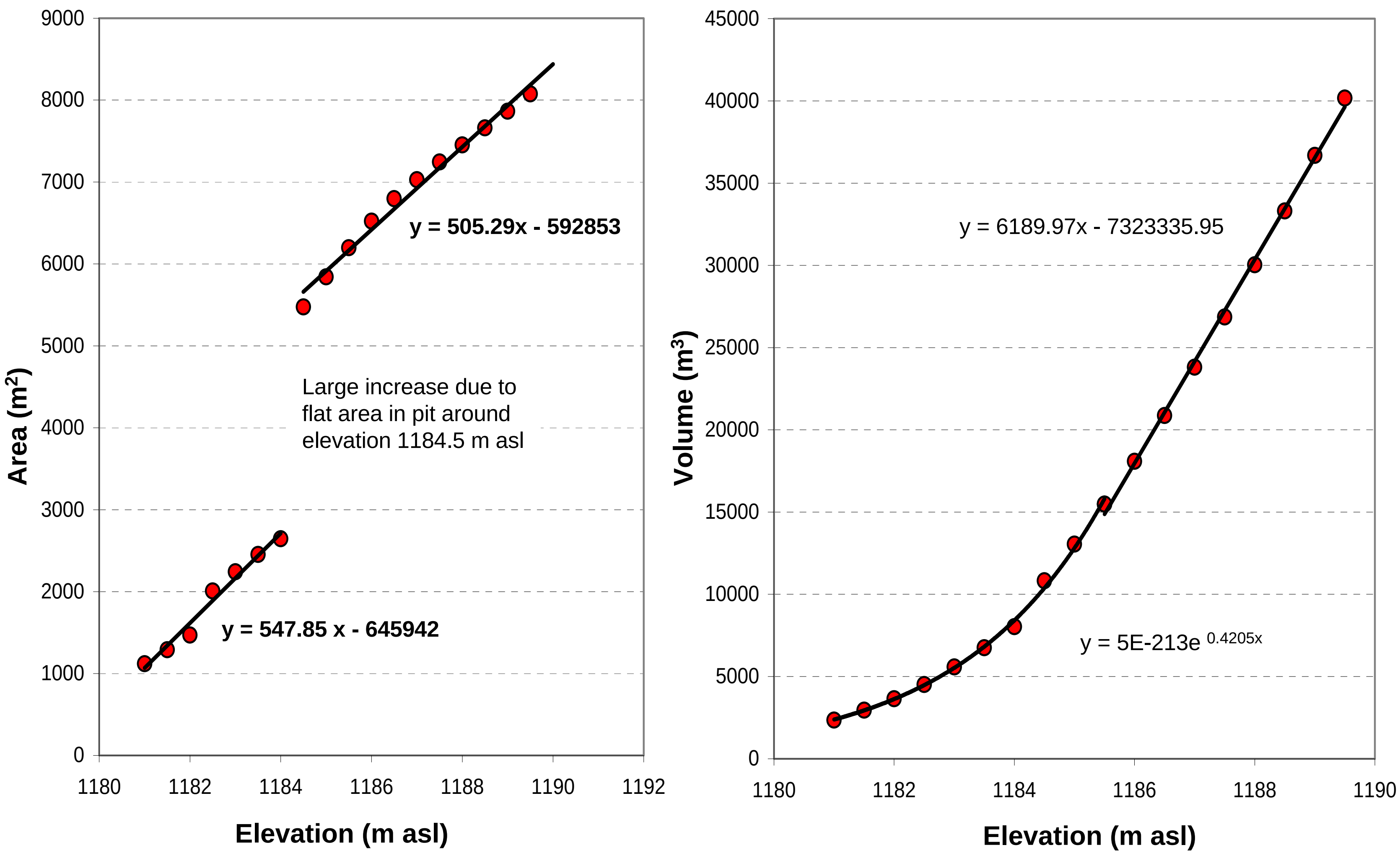
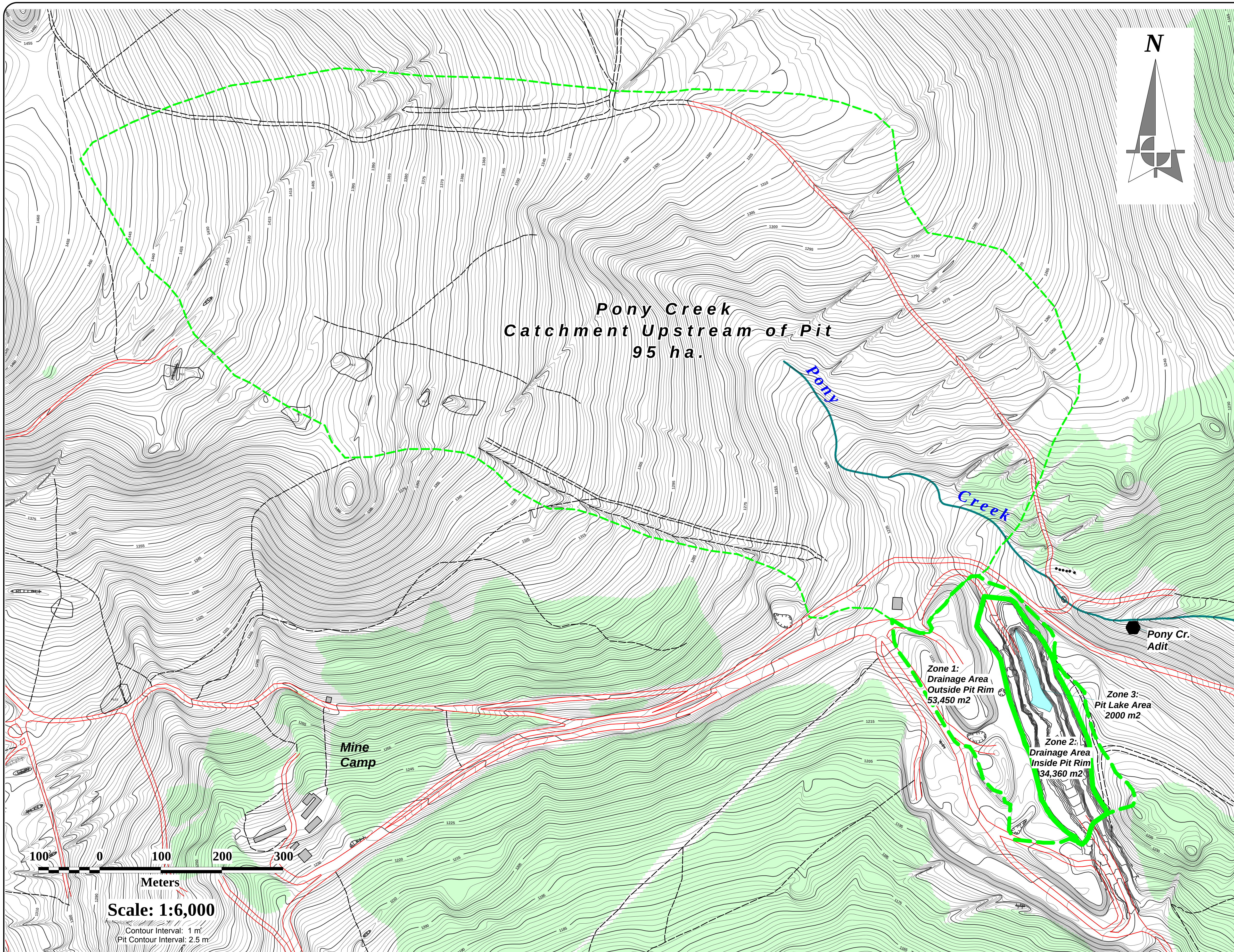


Figure 5. Pit Lake Elevation Volume/Area Curves and functions Used for Water Balance (based on detailed pit survey, 2004)

Project Number: 23-669
Date: May, 2004

Gartner Lee



LEGEND:

SOURCES OF DATA:
Orthoshop, 2004. Based on 1998 aerial photography at 1:50,000 scale.
Pit Survey by Underhill Geomatics Limited, 2004.

DRAWING INFORMATION:

DRAWN BY:	FKP
REVIEWED BY:	MG
DATE ISSUED:	MAY 2004
PROJECT NO.:	23-669
FILE NAME:	23669-F3C.WOR
REVISION:	0
DATA PROJECTION:	UTM ZONE 8, NAD 83

ABANDONED MINES PROJECT OFFICE
ENERGY, MINES & RESOURCES
BROWN MCDADE PIT HYDROGEOLOGICAL & GEOCHEMICAL INVESTIGATION

BROWN MCDADE PIT CATCHEMENT AREAS

Gartner Lee

FIGURE NO.

6

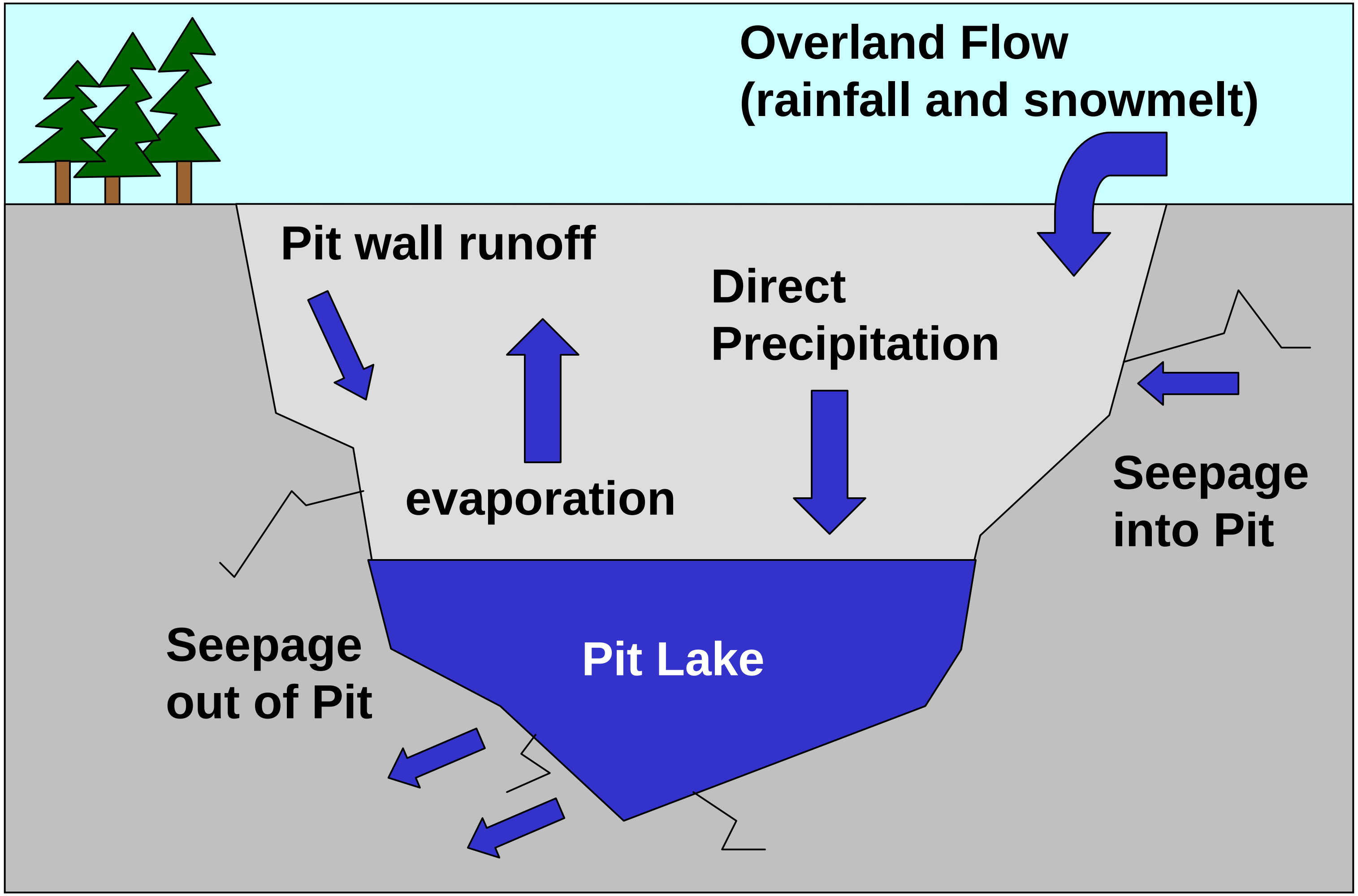
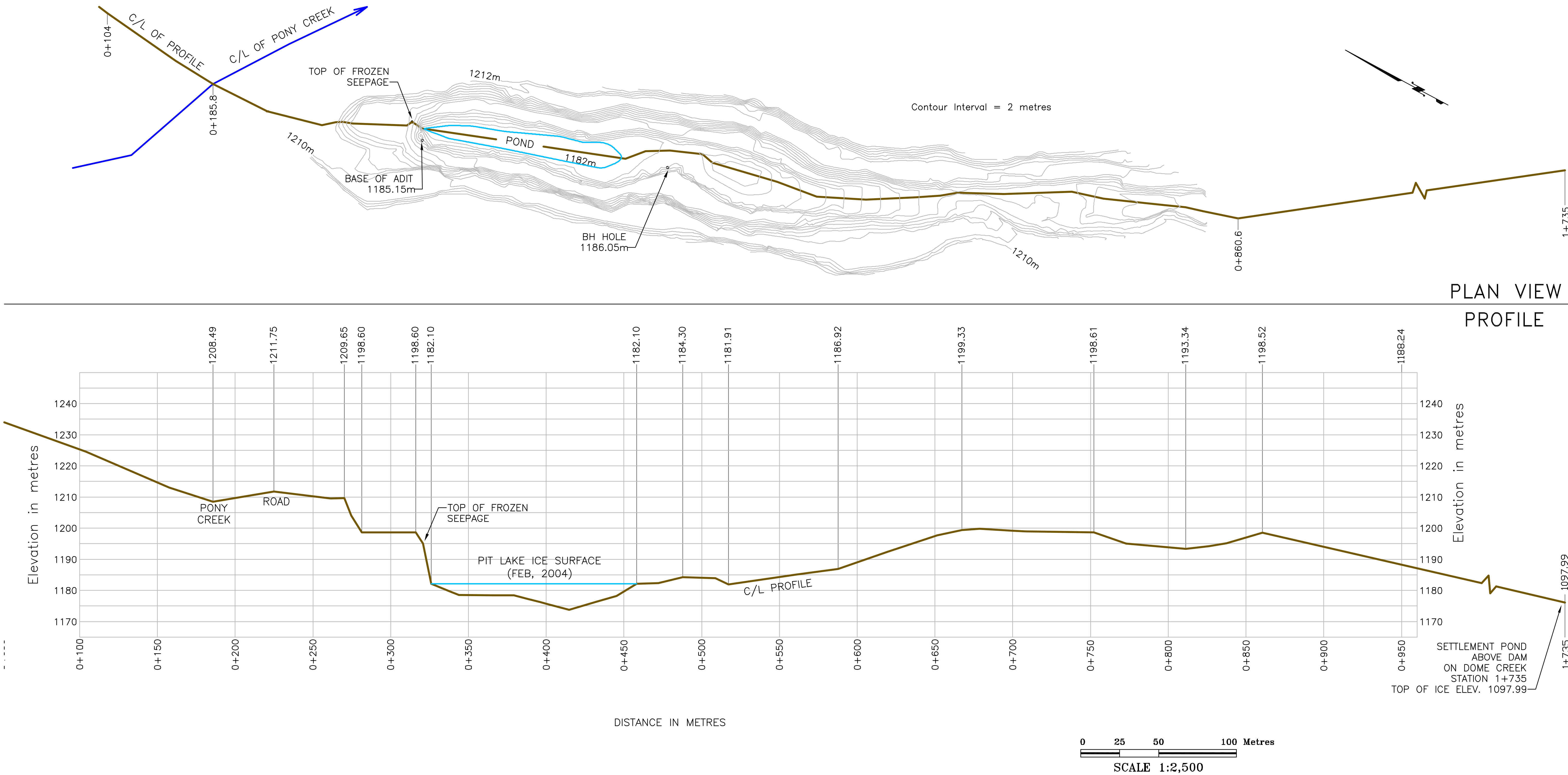


Figure 7. Conceptual Model of Pit Water Balance Components

Gartner Lee

Project Number: 23-669
Date: May, 2004



LEGEND:

SOURCE OF DRAWING:
SURVEY BY UNDERHILL SURVEYORS CONDUCTED IN MARCH, 2004

CONTOURS IN mASL
NAD 83 ZONE 8

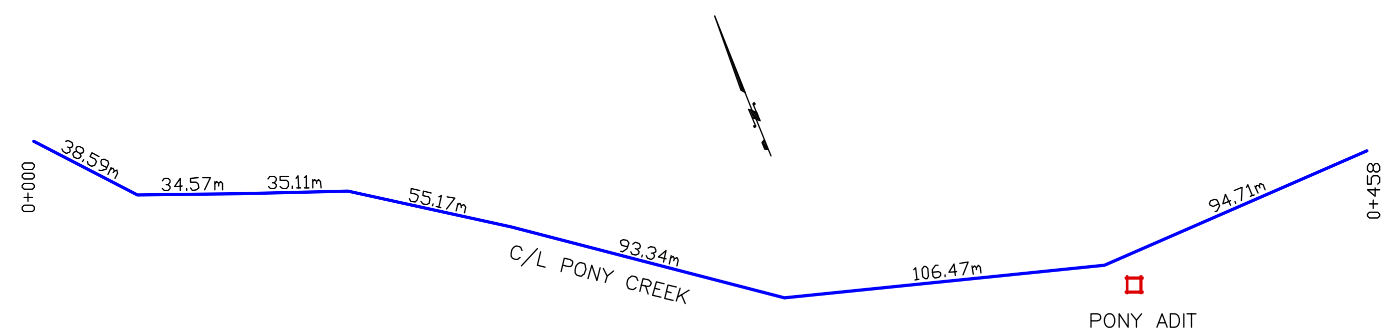
REVIEWED BY:	MG
DRAWN BY:	PW
DATE ISSUED:	JUNE, 2004
PROJECT NUMBER:	23-669
FILE NAME:	23669-2D-02.DWG
REVISION:	0

Project: HYDROGEOLOGICAL AND GEOCHEMICAL INVESTIGATION
Location: MT. NANSEN MINE SITE, BROWN MCDADE PIT
Client: ENERGY MINES AND RESOURCES, ABANDONED MINES OFFICE

LONGITUDINAL CROSS SECTION PROFILE OF BROWN-MCDADE PIT

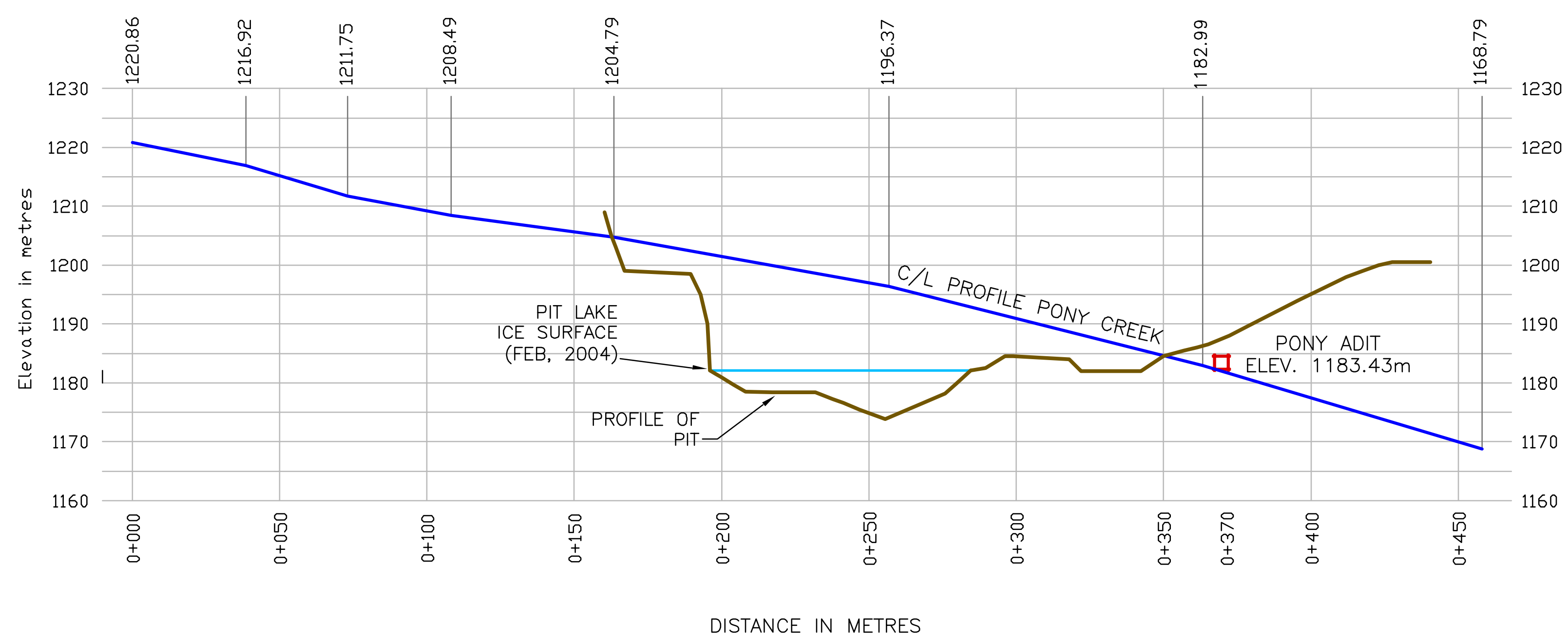
Gartner Lee

Figure No. 8



PLAN VIEW

PROFILE



0 25 50 100 Metres

SCALE 1:2,500

LEGEND:

SOURCE OF DRAWING:
SURVEY BY UNDERHILL SURVEYORS
CONDUCTED IN MARCH, 2004

CONTOURS IN mASL
NAD 83 ZONE 8

REVIEWED BY:	MG
DRAWN BY:	PW
DATE ISSUED:	JUNE, 2004
PROJECT NUMBER:	23-669
FILE NAME:	23669-2D-03.DWG
REVISION:	0

Project: HYDROGEOLOGICAL AND GEOCHEMICAL INVESTIGATION
Location: MT. NANSEN MINE SITE, BROWN MCDADE PIT
Client: ENERGY MINES AND RESOURCES, ABANDONED MINES OFFICE

CROSS SECTION SHOWING THE ELEVATION OF PONY CREEK AS IT FLOWS EAST OF THE PIT

Gartner Lee

Figure No. 9

Table 5. Description of Pit Water Balance Analytical Model Components

Component of Water Balance Model	Description
Month	Monthly time steps were used in the model. Various input and output components of the water balance were calculated on a monthly basis.
Water Elevation at Beginning of Monthly Time Step (m asl)	This elevation represents the starting pit lake elevation used to initiate the calibration process. The model calibration started with data that was collected during October 2001, when the pit lake elevation was measured at 1183.3 masl. All subsequent elevations were generated based on various losses and or gains to the water balance model.
Corresponding Surface Area of Pit Lake (m^2) *Zone 3 –Pit Lake Area*	Based on the Pit Lake Elevation/Pit Lake Surface Area curves generated from the detailed pit survey, a mathematical function was applied to calculate the pit lake surface area for each time step. Water losses such as pit lake evaporation were then applied to this new surface area to more accurately represent evaporative losses (i.e. at a higher pit lake elevation/surface area, there are more evaporative losses)
Pit Wall and Pit Bench Area (34, 360 m^2) *(Zone 2 – Drainage Area Inside of Pit Rim*	This is a fixed area used to calculate volume inputs from direct runoff from precipitation.
Direct rainfall at site (mm/month)	Direct rainfall was applied to appropriate land surface area based on monthly meteorological data (NHC 2004).
Direct rainfall onto pit lake (m^3)	For a given pit lake elevation, the surface area of the pit lake was calculated using the Pit Elevation / Pit Surface Area functions, and direct rainfall estimates (NHC, 2004) were applied.
Direct runoff into pit from catchment (53, 450 m^3) *(Zone 1 – Drainage Area Outside Pit Rim)*	Direct rainfall estimates (NHC, 2004) were applied across Zone 1. Based on the calibration process, it was estimated that approximately 10% of the run-off from this catchment area reaches the pit as surface water.
Direct runoff into pit from sidewalls (m^3)	Direct rainfall estimates (NHC, 2004) were applied to Zone 2. Based on the calibration process, it was estimated that approximately 10% of the run-off from this catchment area reaches the pit as surface water.
Snowmelt runoff from pit walls (34, 360 m^2 – Zone 2) + Snowmelt from Pit Lake Surface	Equivalent snow depth at end of March (Janowicz, YG) was applied to the model in April (Spring melt). Based on the calibration process, it was estimated that 10% of the run-off from this catchment area reaches the pit as surface water.
Snowmelt runoff from pit catchment (m^3)	Equivalent snow depth at end of March (Janowicz, YG) was applied to the model in April. Based on the calibration process, it is estimated that approximately 10% of the run-off from this catchment area reaches the pit as surface water.
Evaporation from pit surface(mm/month)	Evaporative losses were applied to the model for a given month, based on the surface area of the pit lake.
Groundwater Seepage rate out of pit (m^3/month)	Specific seepage rates were calculated based on the actual observed pit lake elevation data and applied to the model to account for seepage loss out of the bottom of the pit. An average value of 535 m^3/day calculated based on the observed decline in water levels during the frozen period, was used for simulations.
Pony Creek seepage into pit (L/s)	Using this variable as a positive component to the water budget, seepage water was added to provide a best fit between actual and modeled pit lake elevations. As would be expected, seepage was required only during non-frozen periods.
Change in Pit Water Volume (m^3)	All water losses or gains included in the model are then summed and an overall change in pit volume was calculated.
Initial Volume in pit based on starting pit water elevation (m^3)	The initial pit lake volume at the start of the monthly time step, was then calculated using the Pit Lake Fill Volume curve, and added to the overall Change in Pit Water Volume
New Volume of water in pit (m^3)	A new pit volume was then calculated based on a sum of the initial pit volume and Change in Pit Water Volume
Corresponding elevation of water in the pit (masl)	The pit Volume/Surface Area curve functions were then applied and a new corresponding pit lake elevation was determined. This elevation was used as the starting point for the proceeding time step.

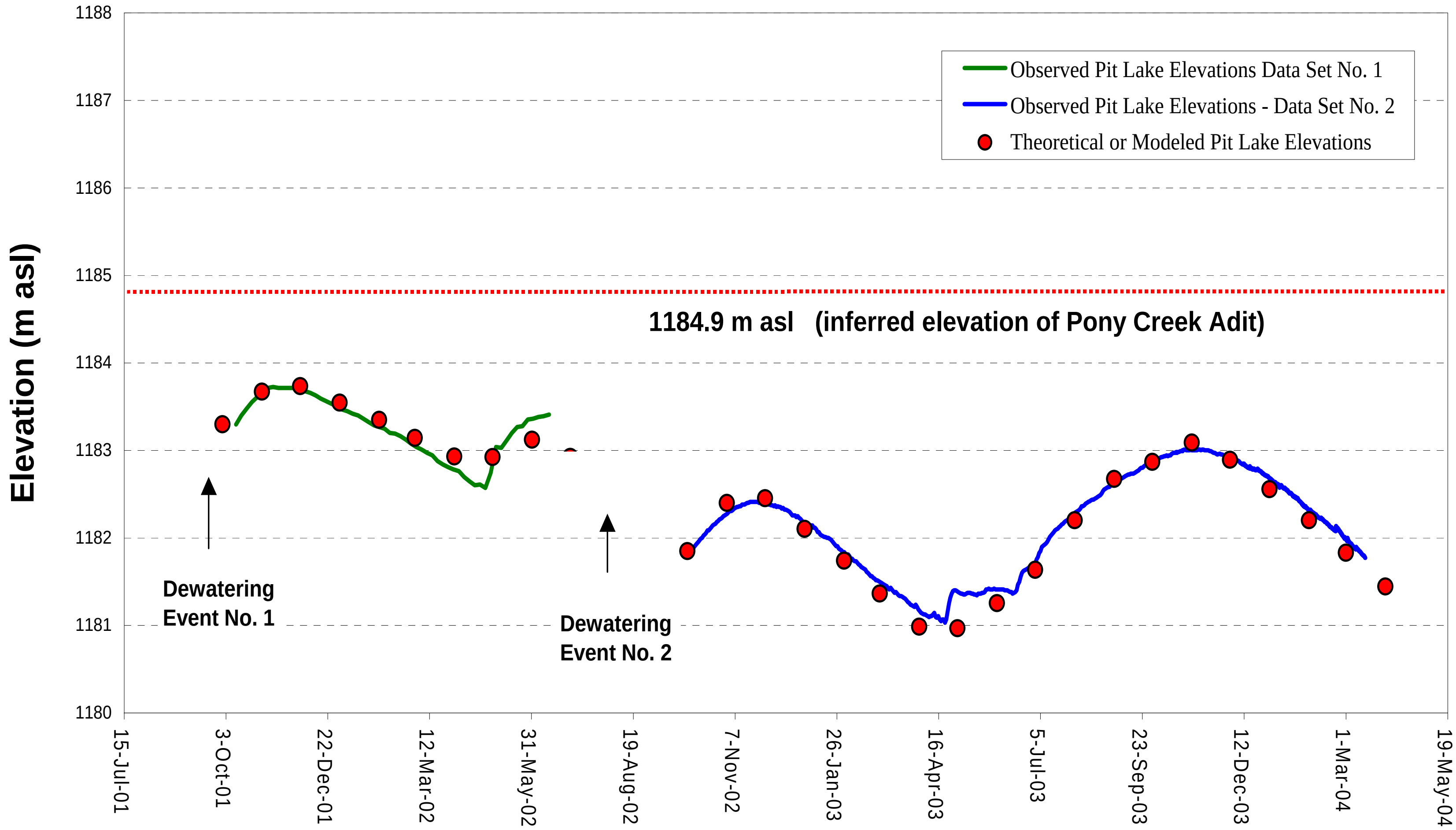


Figure 10. Calibrated Water Balance Results

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Project Number: 23-669
Date: May, 2004

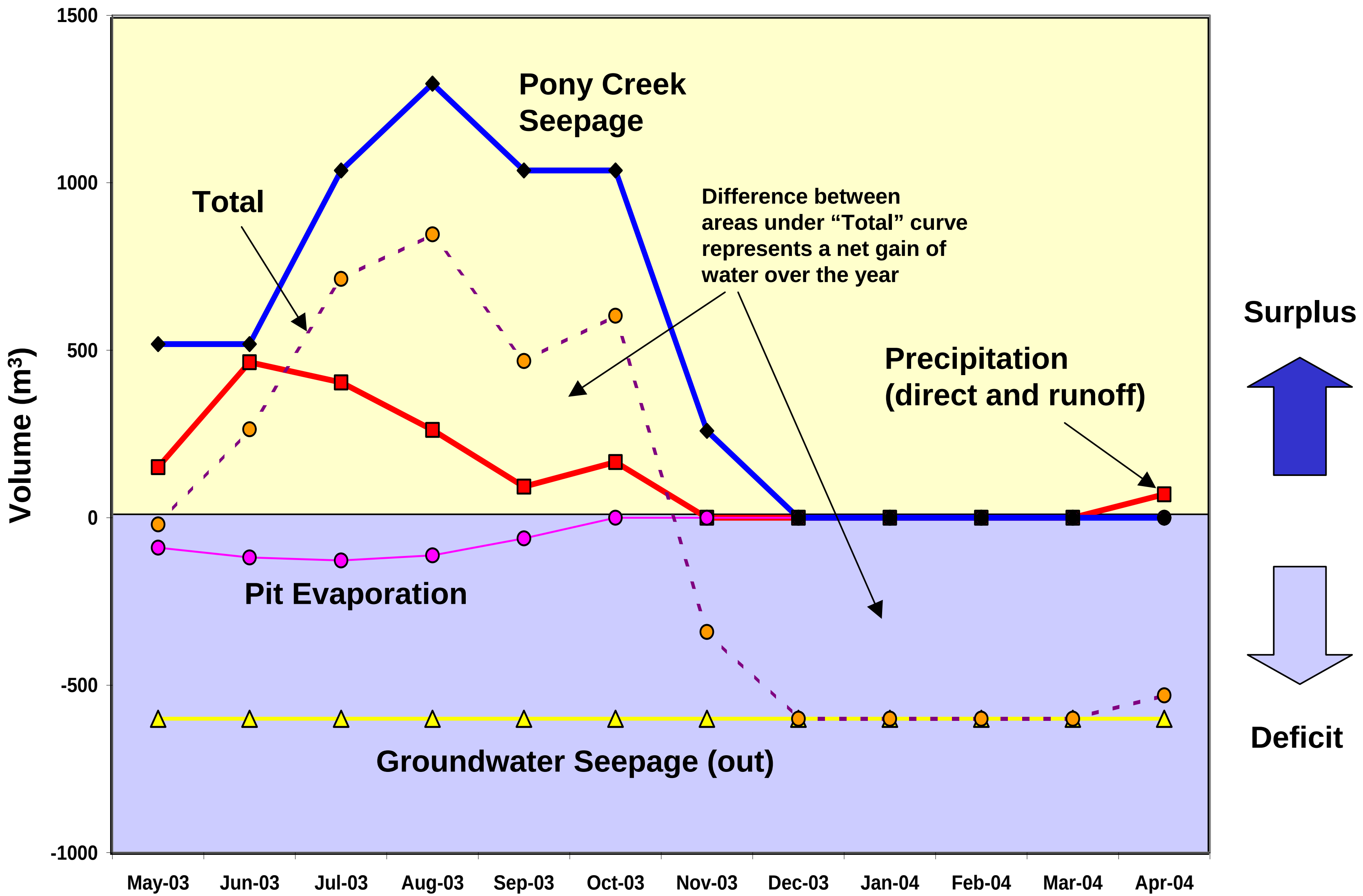

Figure 11. Contribution of Individual Components of Water Balance (based on calibrated model results)

Project Number: 23-669
Date: May, 2004

Gartner Lee

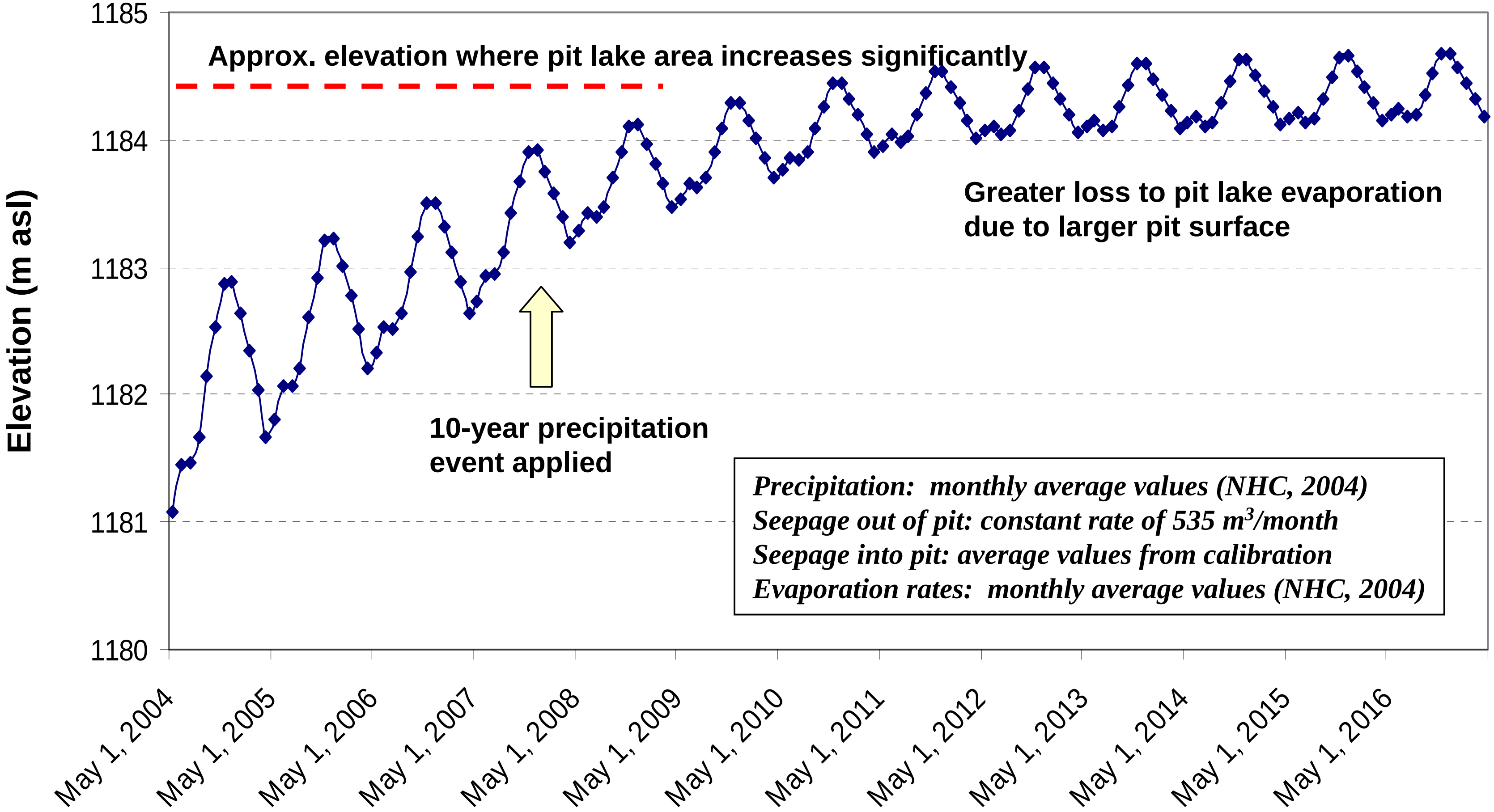

Figure 12. Simulated Pit Lake Elevations up to 2016 Using Average Precipitation Values

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Project Number: 23-669
Date: May, 2004

Table 7 Pit Water Quality Sampling Results - Feb. 2004

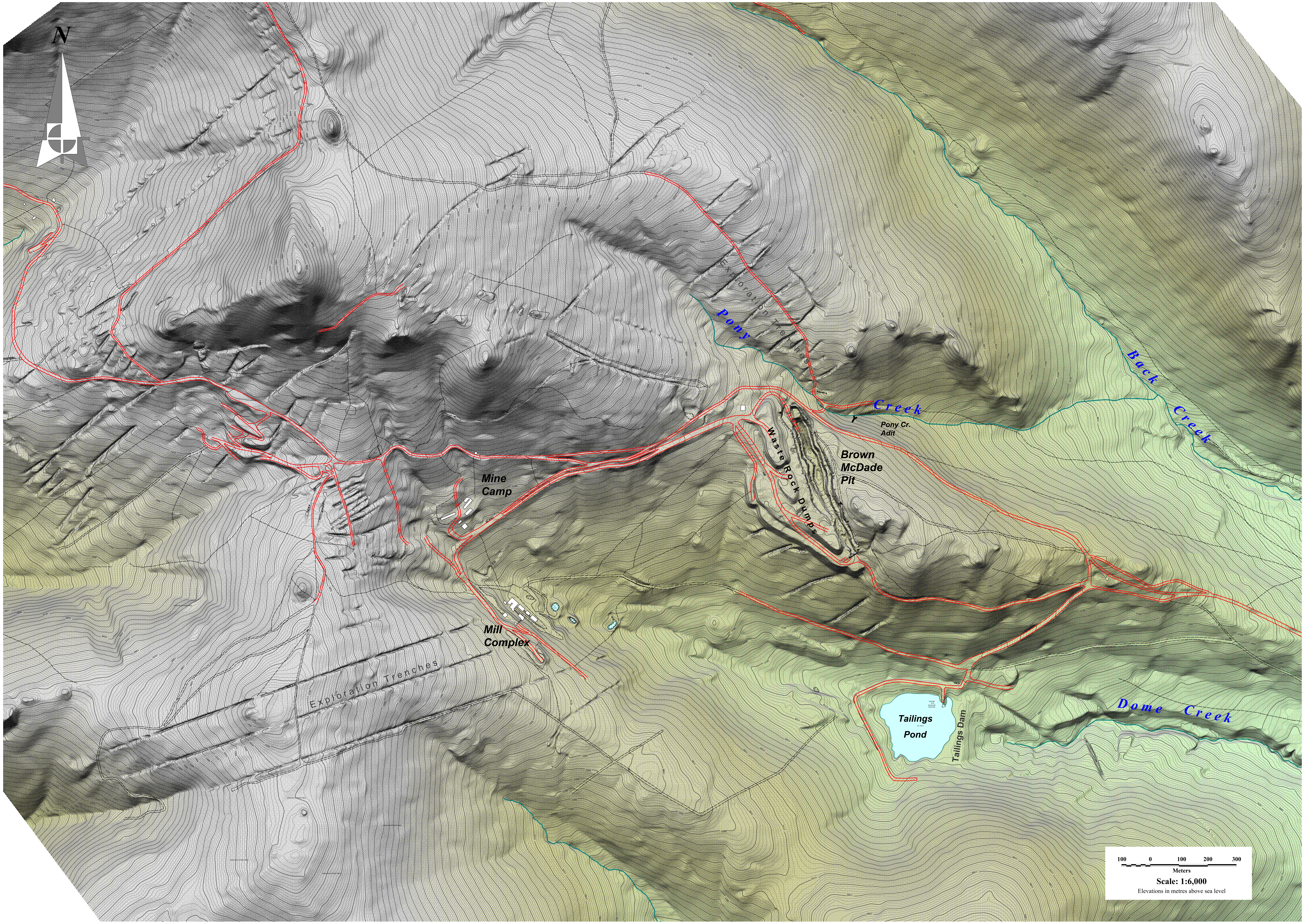
Sample ID	SP1- 1.0m	SP1- 1.0m	SP1- 4.0m	SP1- 8m	SP2- 1m	SP2- 3.5m	SP3- 1m	SP3- 3m
Date Sampled	2/9/2004	2/9/2004	2/9/2004	2/9/2004	2/9/2004	2/9/2004	2/9/2004	2/9/2004
Comment		duplicate						
Field Parameters								
pH	7.44	n/a	7.05	6.5	7.38	6.97	7.45	6.9
Temp (C)	0.5	n/a	3	5.5	0.2	2.6	0.3	3.1
Conductivity (uS/cm)	948	n/a	2519	3653	920	2439	930	1531
Physical Tests								
Conductivity (uS/cm)	1710	1700	2670	3610	1720	2340	1710	2590
pH	8.1	8.03	7.93	7.79	8.1	8.04	8	7.97
Dissolved Anions								
Alkalinity-Total CaCO3	198	199	215	246	213	196	212	211
Bromide Br	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Chloride Cl	1.08	0.99	1.09	1.6	1.11	1.26	0.95	1.73
Fluoride F	0.144	0.145	0.069	0.031	0.146	0.083	0.138	0.092
Sulphate SO4	872	881	1620	2580	891	1360	881	1550
Nutrients								
Nitrate Nitrogen N	6.1	6.15	4.11	0.8	6.26	4.65	6.21	4.28
Nitrite Nitrogen N	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Dissolved ortho-Phosphate P	<0.0010	0.0011	0.0013	<0.0010	0.0012	<0.0010	0.0012	<0.0010
Dissolved Metals								
Aluminum D-Al	<0.050	<0.050	<0.050	0.052	<0.050	<0.050	<0.050	<0.050
Antimony D-Sb	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Arsenic D-As	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Barium D-Ba	0.016	0.015	0.0085	0.0131	0.0183	0.0121	0.0163	0.0107
Beryllium D-Be	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
Bismuth D-Bi	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Boron D-B	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Cadmium D-Cd	0.0081	0.0096	0.0151	0.0283	0.0108	0.0179	0.01	0.0153
Calcium D-Ca	317	303	419	499	348	469	317	422
Chromium D-Cr	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
Cobalt D-Co	<0.0050	<0.0050	<0.0050	0.0155	<0.0050	<0.0050	<0.0050	<0.0050
Copper D-Cu	0.012	0.02	0.013	<0.010	0.022	0.017	0.017	0.012
Iron D-Fe	<0.030	<0.030	<0.030	0.892	<0.030	<0.030	<0.030	<0.030
Lead D-Pb	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Lithium D-Li	0.011	<0.010	0.014	0.025	0.012	0.016	0.011	0.017
Magnesium D-Mg	99.8	94.9	195	420	107	192	97.8	197
Manganese D-Mn	0.334	0.319	0.49	15.6	0.358	0.564	0.296	0.402
Molybdenum D-Mo	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Nickel D-Ni	0.0057	<0.0050	<0.0050	0.0083	<0.0050	<0.0050	<0.0050	<0.0050
Phosphorus D-P	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Potassium D-K	3.5	3.3	5	8.5	3.8	5.3	3.3	5.2
Selenium D-Se	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Silicon D-Si	6.11	5.8	4.07	3.95	6.66	4.87	6.15	3.88
Silver D-Ag	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Sodium D-Na	10.4	9.8	12.2	16.7	11.5	13.1	10.2	12.6
Strontium D-Sr	0.919	0.87	1.15	1.62	1.02	1.27	0.883	1.2
Thallium D-Tl	0.082	<0.030	0.033	<0.030	<0.030	0.04	<0.030	<0.030
Tin D-Sn	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Titanium D-Ti	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Uranium D-U	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Vanadium D-V	<0.030	0.031	0.041	<0.030	0.035	0.04	<0.030	0.039
Zinc D-Zn	1.08	1.18	1.78	3.59	1.36	2.01	1.25	1.92

Notes:
- = refers to parameters not analysed
All results are expressed as milligrams per litre unless otherwise stated
[a] *results obtained from ALS Envionmental Laboratories*

Project Number: 23-669
Date: May, 2004

Gartner Lee

Site Name: Mt. Nansen File Name: HS_plan.WOR Gartner Lee Scale: 1: 6,000,000	**Health and Safety Plan** **Mt. Nansen Brown McDade Pit** **Hydrogeological and Geochemical Investigation** **Mt. Nansen, Yukon** **Project Location Map**	Project No: 23-669 Date Issued: January 2004 **Figure 1**



LEGEND:

- Index Contour (5 m)
- Intermediate Contour (1 m)
- Pit Contour (2.5 m)
- Large Stream
- Waterbody
- Road
- Trail
- Building

SOURCES OF DATA:

Orthoshop, 2004. Based on 1998 aerial photography at 1:50,000 scale
Pit Survey by Underhill Geomatics Limited, 2004.

DRAWING INFORMATION:	
DRAWN BY:	FKP
REVIEWED BY:	MG
DATE ISSUED:	MAY 2004
PROJECT NO.:	23-669
FILE NAME:	23669-F2.WOR
REVISION:	0
DATA PROJECTION:	UTM ZONE 8, NAD 83

ABANDONED MINES PROJECT OFFICE
ENERGY, MINES & RESOURCES
BROWN MCDATE PIT HYDROGEOLOGICAL & GEOCHEMICAL INVESTIGATION

MOUNT NANSEN MINE PROJECT OVERVIEW MAP

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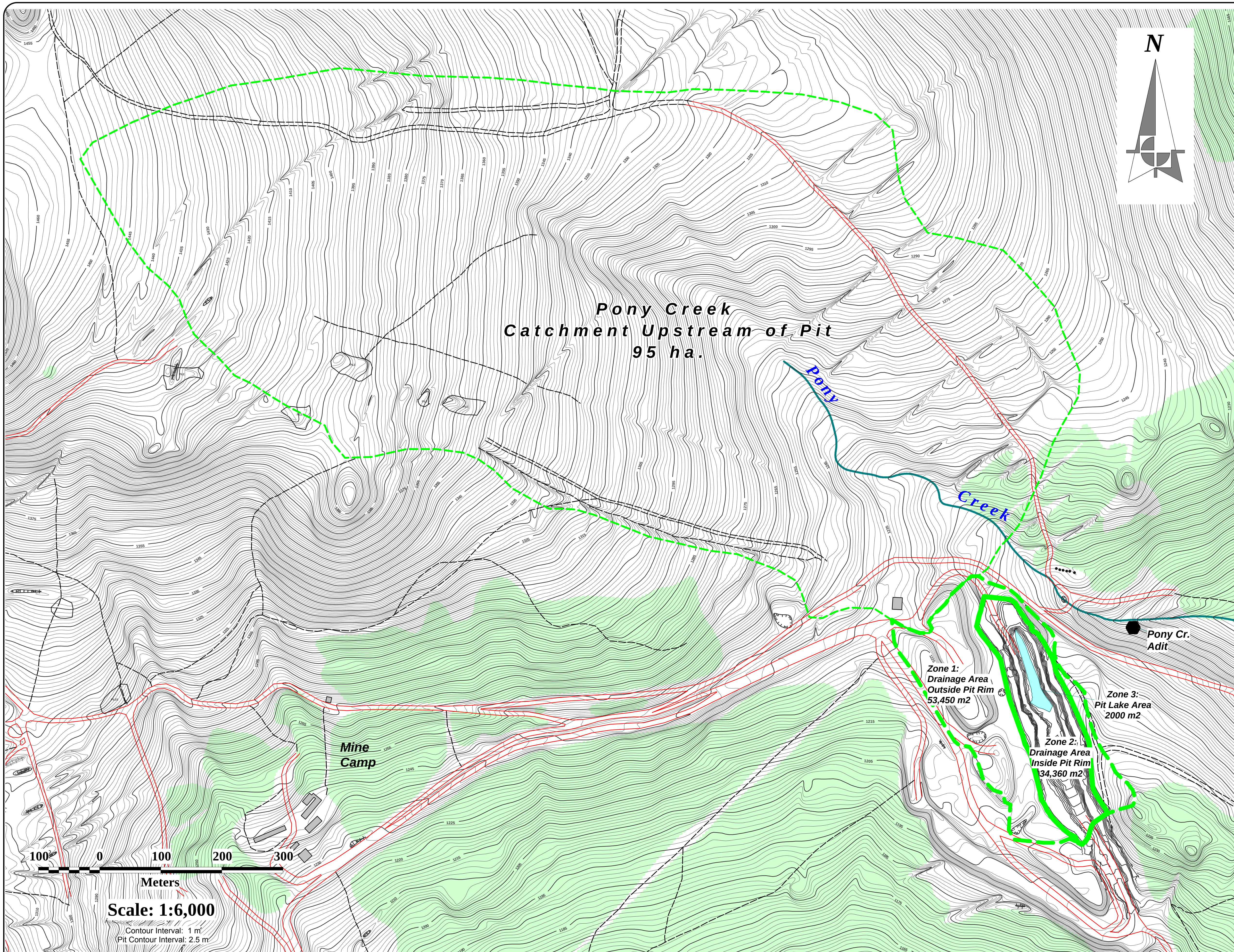
FIGURE NO. 2



LEGEND:

SOURCES OF DATA:
Orthoshop, 2004. Based on 1998 aerial photography at 1:50,000 scale.
Pit Survey by Underhill Geomatics Limited, 2004.

DRAWING INFORMATION:

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REVIEWED BY:	MG
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PROJECT NO.:	23-669
FILE NAME:	23669-F3C.WOR
REVISION:	0
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ABANDONED MINES PROJECT OFFICE
ENERGY, MINES & RESOURCES
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BROWN MCDADE PIT CATCHEMENT AREAS

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FIGURE NO. 3