July 2017

GIANT MINE REMEDIATION PROJECT

Baker Creek Diversion: Alternatives Evaluation

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REPORT

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The detailed evaluation was completed during the MAA Evaluation Workshop attended by representatives of INAC, PSPC, AECOM, and Golder, in consideration of existing GMRP-specific information. Results of this evaluation process were further reviewed by members of Golder's fish and fish habitat, water quality, construction, and traditional studies facilitator team and refined as applicable and as noted in the preceding text.

Based on this MAA process, the Handle Lake – North Route diversion alternative was evaluated as the lowest ranked alternative, below both on-site alternatives, primarily from its footprint within undisturbed areas requiring additional land, temporary infrastructure during construction, and permanently increasing the potential for human and wildlife interaction with the diversion. The PDR Reach 3 - Option A diversion alternative was evaluated slightly higher than the PDR Reach 3 - Option C diversion alternative, primarily influenced by its lower footprint and excavation requirements, and GMRP assumptions.

The objective of this MAA process, in consideration of requirements of Measure 11, was to determine the final alignment corridor of the Baker Creek, whether on site or off site. This evaluation showed that off-site diversion should clearly be discarded from future consideration, and the final alignment of Baker Creek is therefore recommended to remain on site. The location of the final on-site alignment, whether following the PDR Reach 3 - Option A, PDR Reach 3 - Option C, or other proposed on-site alignment based on refinements of the two, is beyond the scope of Measure 11, and should be subject to further evaluation once the GMRP design is better defined, and assumptions from this study, pertaining to pit and sediment remediation, and fish passage, can be confirmed or revisited. Neither the closure material balance, which could affect the ratings of the two on-site alternatives, nor management alternatives of Baker Creek Reach 6, were considered in this study.

This document is intended to be reviewed by independent technical reviewers and then provided to the Giant Mine Oversight Board and the Giant Mine Working Group for review. Public engagement on various diversion options was completed during the SDE Process. The results of this MAA, namely the selection of an on-site Baker Creek diversion alternative, will be discussed in upcoming public meetings. Once the review and engagement is complete, further engineering of the on-site alignment alternatives (Option A versus Option C) will be initiated; this will include consideration of the GMRP closure material balance and Baker Creek flood hazard assessment.

Table of Contents

TABLES

FIGURES

APPENDICES

TABLE OF ACRONYMS

Acronym	Definition
CCME	Canadian Council of Ministers of the Environment
DAR	Developer's Assessment Report
GMRP	Giant Mine Remediation Project
GNWT	Government of the Northwest Territories
INAC	Indigenous and Northern Affairs Canada
ISQG	Interim Sediment Quality Guidelines
MAA	Multiple Accounts Analysis
MVEIRB	Mackenzie Valley Environmental Impact Review Board
PDR	Preliminary Design Report
PEL	Probable Effects Level
PSPC	Public Services and Procurement Canada
SDE	Surface Design Engagement
TDS	Total Dissolved Solids

1.0 INTRODUCTION

1.1 Scope of Work

In recent years, the Giant Mine Remediation Project (GMRP) considered multiple alternatives for the diversion of Baker Creek, including on-site and off-site alignments. These alternatives were based on a range of considerations, including, but not necessarily limited to, flood risk, fish habitat, and contaminated sediments. However, these alternatives were not previously evaluated on a consistent scale to identify a preferred final closure alternative. This report is intended to address that gap.

The requirement for a final closure diversion alternative was formalized under Report of Environmental Assessment Measure 11 (Measure 11) from the final decision letter on the recommendation contained in the Mackenzie Valley Environmental Impact Review Board's (MVEIRB) Report of Environmental Assessment and Reasons for Decision (Minister of Aboriginal Affairs and Northern Development Canada 2014):

The Developer, with meaningful participation from the Oversight Body and other parties, will thoroughly assess options for, and the environmental impacts of, diversion of Baker Creek to a north diversion route previously considered by the Developer or another route that avoids the mine site and is determined appropriate by the Developer. Within one year of the Project receiving its water license, a report outlining a comparison of options including the current on-site re-alignment will be provided to the appropriate regulatory authorities, the Oversight Body and the public.

Once informed by the advice of the Oversight Body and regulatory authorities, the Developer will determine and implement the preferred option. In doing so, the Developer will consider the advice of the Oversight Body, regulatory authorities, and the public, and will ensure that the primary considerations in selecting an option are to:

- *a) minimize the likelihood of Baker Creek flooding and entering the arsenic chambers, stopes and underground workings, and*
- *b) minimize the exposure of fish in Baker Creek to arsenic from existing contaminated sediments on the minesite, surface drainage from the minesite or tailings runoff. If off-site diversion is selected, the Developer will seek required regulatory approvals to implement the diversion within five years of receiving its initial water license.*

Expanding on Measure 11, the final Baker Creek alignment, whether on-site or off-site, must be determined based on a detailed evaluation of diversion alternatives informed by regulatory authorities, the Giant Mine Oversight Board, and the public, in consideration of potential risks of flooding to the arsenic chambers, stopes and underground workings, and potential risks of exposure of fish to arsenic.

Public Services and Procurement Canada (PSPC) retained Golder Associates Ltd. (Golder), on behalf of Indigenous and Northern Affairs Canada (INAC), to complete a comprehensive evaluation of diversion alternatives for Baker Creek and recommend a final alignment to comply with the requirements of Measure 11 and accommodate input from the Giant Mine Oversight Board and stakeholders. It was understood that this work would be done to support a future Closure and Reclamation Plan for the mine.

The evaluation was done using a Multiple Accounts Analysis (MAA), a recognized decision-making process based on a comprehensive evaluation of alternatives, suitable for this study (See Section 5.0 for further detail). Stakeholder, public engagement, and input from regulators and the Giant Mine Oversight Board informed the evaluation criteria (See Section 1.3).

This report is organized as follows:

- A review of the background of Baker Creek during and after the Environmental Assessment (Section 1.2)
- A review of stakeholder engagement related to the Baker Creek diversion (Section 1.3)
- An overview of the Baker Creek watershed (Section 2.0)
- A summary of investigations into Baker Creek diversion alternatives (Section 3.0)
- Descriptions of the Baker Creek diversion alternatives (Section 4.0)
- A summary of the standard MAA process and components (Section 5.0)
- Development of the MAA matrix (Section 6.0)
- MAA and results (Section 7.0)
- Conclusions, recommendations and next steps (Section 7.3)

1.2 Background

A summary of the background on and timeline of considerations for Baker Creek closure options in the Environmental Assessment and Post-Environmental Assessment phases is provided below.

1.2.1 Remediation Plan and Environmental Assessment (2010-2013)

It is recognized that Baker Creek is a major risk at Giant Mine (INAC 2010) and remediation is required to mitigate this risk. In its current alignment on site, Baker Creek is a risk to the underground mine and associated infrastructure such as pumps, potentially risking a major release of contaminated water to Great Slave Lake. Without management, Baker Creek has the potential to overtop its banks and flow toward the open pits and openings to surface and enter the underground mine and potentially affect the arsenic chambers and infrastructure. It could also create thermal and mechanical permafrost issues on surface (MVEIRB 2013). These risks could occur, without active management, during flood conditions, with the presence of anchor ice in the stream, or under the influence of beaver dams (MVEIRB 2013).

This risk was reviewed during the Environmental Assessment process for the Giant Mine Remediation from 2010 to 2013 (Figure 1). The Developer's Assessment Report (DAR) and its draft Giant Mine Remediation Plan proposed that the risk of flooding of Baker Creek could be managed through design of the creek to withstand a 1:200 year flood event (INAC 2010). Stakeholders and the MVEIRB concluded that the creek design as outlined in the DAR was inadequate to mitigate the risk of flooding, given uncertainties in design and model predictions related to climate. MVEIRB commented that Baker Creek posed unacceptable risk to the GMRP and the downstream environment.

2011

◆ Baker Creek Sediment Release

2010 – 2014 Environmental Assessment Review

EA Review Process

- Project continues to investigate Off-site diversion alternative such as the North Diversion.
- Preliminary studies on the North Diversion begin but are not finalized during EA period
- Mackenzie Valley Environmental Impact Review Board (MVERIB) rules Baker Creek poses an unacceptable risk, and subsequently issues linked Measures 11 (north diversion or other possible routes), 12 and 13.
- MVEIRB recommends an investigation into an Off-site diversion

2012

2011 – 2015 Investigative Studies

- Review of multiple diversion options:
  - Investigations into north diversion bathymetry, geophysical
  - Third party development of alternate diversions (Stantec 2014
  - Model assessment of predicted water quality for the North Diversion (Golder 2015)
  - Investigation of ecological and human health risk of sediments in Baker Creek on-site

2013

◆ Baker Creek becomes managed fishery

◆ Human Health and Ecological Risk Assessment of Baker Creek Water and Sediment

2012 – 2016 Regional Studies (Water and Sediment Quality)

- Originally thought that diverting Baker Creek Off-site would result in improved water quality
- Findings from regional studies were that water and sediment quality impacted regionally from historical operation of Giant Mine

2014

◆ Highway 4 Diversion to bypass Giant Mine

2015

2015-2016 Surface Design Engagement

- Stakeholder engagement on closure options for Giant Mine
- Included is a review of Baker Creek On site vs Off-site, Open-pits vs Filled pits
- Outcomes:
  - o Splitting contaminant loads and contaminating new areas was deemed undesirable
  - o Filled pits desired due to safety concerns

2016

2016-2017 Workshop, Incorporation of Stakeholder Input, Continued Monitoring and Modelling

2017

- Sufficient information to formally address Measure 11
- Screening criteria developed, including stakeholder input and

Alternatives to this design for Baker Creek were considered, including diverting the creek off-site. An off-site diversion was rejected as an option in the DAR because even if Baker Creek was diverted, the channel would remain on site to drain the mine site catchments, albeit with lower flows. However in 2011, during the Environmental Assessment process, the GMRP outlined that an off-site diversion was again a possible alternative'. This included a possible 'North Diversion' that would route Baker Creek north through Trapper Lake, Gar Lake and Shot Lake, discharging to Yellowknife Bay near Yellowknife River (see Section 4.2 for details). The GMRP outlined that more thorough review as a contingency was underway, but that work was preliminary.

Stakeholders and regulators could not review possible diversion alternatives, given that no conceptual design for an alternative was available at the time. It was on this basis that MVEIRB issued Measure 11: requiring the GMRP to evaluate diverting the creek away from the mine site to minimize flood risk and to evaluate options to minimize exposure of fish to arsenic through contaminated sediment, site runoff, and tailings (see Section 1.1).

1.2.2 Additional Regulatory Considerations (Measures 12 and 13) (2013-2014)

The Report of Environmental Assessment included three linked measures related to Baker Creek: Measure 11, Measure 12, and Measure 13 (MVEIRB 2013; AANDC 2014). Collectively these measures relate to the routing of Baker Creek and water quality objectives for discharge from the former Baker Creek channel as well as any new off-site alternative.

> **Measure 12**: *To prevent significant adverse impacts on Great Slave Lake from contaminated surface waters in the existing or former channel of Baker Creek, should it be re-routed to avoid the mine site, the Developer will ensure that water quality at the outlet of Baker Creek channel will meet site-specific water quality objectives based on the CCME [Canadian Council of Ministers of the Environment] Guidance on the Site-Specific Application of Water Quality Guidelines in Canada.*
>
> **Measure 13**: *The Developer will design and, with the applicable regulators, manage the Project to ensure that, with respect to arsenic and any other contaminants of potential concern, the following water quality objectives are achieved in the vicinity of the outlet of the existing or former channel of Baker Creek, should it be re-routed to avoid the mine site, excluding Reach 0:*
>
> *a) Water quality changes due to discharge from Baker Creek will not reduce benthic invertebrate and plankton abundance or diversity;*
>
> *b) Water quality changes due to discharge from Baker Creek will not harm fish health, abundance or diversity;*
>
> *c) Water quality changes due to discharge from Baker Creek will not adversely affect areas used as drinking water sources;*
>
> *d) Water quality changes due to discharge from Baker Creek will not adversely affect any traditional or recreational users; and,*
>
> *e) There is no increase in arsenic levels in Great Slave Lake due to discharge from Baker Creek beyond the parameters described in Measure 12.*

Measure 12 and Measure 13 influence the Baker Creek diversion options in that improved water quality and the protection of aquatic life and traditional users was required. These measures required the GMRP to verify that water quality at the outlet of the Baker Creek channel remaining on site to meet site-specific water quality objectives. An investigation to the water quality of a potential off-site diversion and the channel remaining on site was initiated (See Section 3.0 for results).

1.2.3 Post-Environmental Assessment (2013-2017)

Once the Environmental Assessment process concluded in 2013-2014, further investigations related to on-site and off-site diversions of Baker Creek were initiated to address Measure 11, including the water quality modelling noted above, a geophysical investigation, validation of north diversion and local drainage concepts, and a gap analysis of alternative diversion routes. A separate study on sediment in Baker Creek, initiated in 2011, was finalized in 2013 to understand the potential for effects from contaminated sediments in Baker Creek on aquatic life and human health (Golder 2013). These are discussed in Section 3.0.

During the post-Environmental Assessment period, three additional factors influenced the options for diverting Baker Creek:

1) In 2014, the Government of the Northwest Territories (GNWT) re-routed the territorial highway that bisected the Giant Mine site (Highway 4, Ingraham Trail). The new routing avoids the mine site. The highway previously complicated routing of Baker Creek on-site. In relation to re-alignment of the highway, a power sub-station for the mine underground workings and the C-shaft, located east of the highway, were also removed. Without a public access highway and the power substation, options for widening Baker Creek to address flood risk were simplified.

2) In 2013, the mouth of Baker Creek became a managed fishery under the Northwest Territories Fisheries Regulations. The creek is closed to Arctic Grayling fishing from April 1 to June 15 each year to reduce the potential effects of sportfishing on Arctic Grayling. This constrained an off-site diversion as the upstream flow supporting Arctic Grayling spawning and rearing could potentially be reduced/absent if the creek were diverted.

3) At the same time the GMRP was reviewing off-site diversion options for Baker Creek, the GNWT, Natural Resources Canada and various universities partnered to conduct water and sediment sampling in a radius around Yellowknife, off-lease from Giant Mine. Results published in 2015 showed that water quality in lakes surrounding Yellowknife contained higher levels of metals than lakes away from the Yellowknife area (Palmer et al. 2015). More specifically, lakes surrounding the mine that were downwind of the Giant Mine roaster stack contained elevated concentrations of arsenic.

   These regional studies of water quality significantly influenced the assessment of Baker Creek diversion alternatives. It was originally thought that diverting Baker Creek off-site would result in improved water quality to the Baker Creek diversion. New regional water quality data now suggested this assumption may not be valid and further water quality modelling of off-site diversion was then necessary to evaluate this. In 2014, a north diversion scenario was modelled, to determine the influence on water quality in Yellowknife Bay near the Yellowknife River (Section 3.0).

1.3 Engagement

1.3.1 Environmental Assessment Technical Session (2011)

Potential Baker Creek north diversions were first discussed with stakeholders at the Giant Mine Technical Session in October 2011, approximately one month after the draft report on diversion alternatives (Golder 2011) was completed. The transcript of the Technical Session (MVEIRB 2011) notes that 54 people attended on October 18, the day that the north diversion was on the agenda.

During the Technical Session, aspects of the north diversion were presented and question from participants were taken and responses were provided.

1.3.2 Surface Design Engagement (2015-2016)

In 2015 and 2016, the GMRP team engaged stakeholders in a Surface Design Engagement (SDE) process. The purpose of the engagement was to provide an opportunity for stakeholders to voice concerns, identify objectives and provide direct input into the planning of the Giant Mine surface remediation and to provide input on the EA Measures (INAC 2015). Baker Creek was a specific item identified by stakeholders as an area for input as well as the remediation of the open pits, both of which are related to risk of flooding the mine. The SDE process included the following opportunities for engagement:

- **June 16-18, 2015 (Dettah, NT) Initial Scoping Session:** The consultation program was initiated with a large meeting of stakeholders at the Chief Drygeese Centre. The consultation session was hosted by INAC, with technical support provided by numerous consultants. The initial session was intended to describe the key issues and alternatives with respect to surface design; and to frame the consultation program.
- **September 22-24, 2015 (Vancouver, BC):** Following the compilation of the feedback gathered during the initial scoping session, SRK and INAC hosted a technical team meeting for the purposes of reviewing feasible closure options/strategies. The purpose of this meeting was to assess the engineering aspects of the various surface design features identified in the initial scoping session.
- **December 8-10, 2015 (Yellowknife, NT) Risk Review Meeting:** Following the feedback from both the initial scoping session and the technical review session; SRK developed ten remedial options for Giant Mine closure. The purpose of this meeting was to engage a small group of stakeholders (primarily First Nations and local government representatives) in the identification and assessment of risks associated with each option.
- **February 16-19, 2016 (Dettah, NT) Options Evaluation Workshop:** Over 75 participants gathered to an Options Review workshop representing Yellowknives Dene First Nation, North Slave Métis Alliance, Alternatives North, the City of Yellowknife, the GMRP Team, Environment Canada, Health Canada, GNWT Department of Lands, and GNWT Department of Industry, Tourism and Investment), other users of the site (Mining Heritage Society and Fly Kids), and technical experts.

Participants in the Options Evaluation workshop were divided into groups. With regards to Baker Creek and open pits, the groups reviewed an on-site option with widened channel/ versus an off-site diversion and an option to leave the pits open or fill the pits. The off-site diversion outlined to the groups was a 'North Diversion' since it was a possible route with technical information to support it. It was noted that other routes were possible but detailed information was not available for the workshop.

Baker Creek: None of the groups supported the off-site diversion as outlined, using the proposed North Diversion (SRK 2016b). The major concerns included:

- splitting the arsenic load reporting to Great Slave Lake into 1) the mouth of Shot Creek entering Yellowknife Bay in the new diversion channel and 2) the mouth of Baker Creek in the channel remaining on site;

- contaminating other surface water bodies along the diversion route;
- potential effects to wildlife in previously, uncontaminated areas;
- fish living in the contaminated water in the diversion channel; and
- spending a lot of money for limited risk reduction.

In addition, there was strong resistance from multiple groups to the proposed discharge location of the North Diversion near the mouth of the Yellowknife River. Some groups indicated that they might consider a diversion that either discharged further south along the shoreline or followed another route, but without more information, groups were uncertain whether that would change their overall conclusion (SRK 2016b).

Groups were also concerned about contaminated sediments in Baker Creek and how contamination would be spread from Baker Creek to new areas. The GMRP committed to removing or capping sediments in the reaches of Baker Creek on site to ameliorate these concerns.

Open Pits: Most groups chose to fill the pits and place a non-vegetated cover on the pits. This was chosen to address public and worker safety risk of injury of falling into an open pit, reduce risk of Baker Creek flooding to the underground and provide storage space for contaminated material. The GMRP agreed to review this option but that the type of fill for each pit would undergo review.

The fisheries value of Baker Creek was not expressly discussed during SDE. In general though, stakeholders and regulators have differing perspectives on fish in Baker Creek. Aboriginal groups do not want fish exposed to contaminants that may affect traditional users. As noted above, Fisheries and Ocean Canada protected Arctic Grayling at the mouth of Baker Creek through recent legislation. Further review of fish and fish habitat will occur once a Baker Creek alignment is finalized and is not thought to be critical to the review of diversion alternatives.

In summary, the input from the SDE process influences the screening and evaluation criteria for the alternatives for a possible diversion of Baker Creek. Refer to Section 5.0 and Section 6.0, where the rationale and weighting of the criteria are described in detail.

1.3.3 Engagement on MAA Evaluation Criteria (2016)

Screening and evaluation criteria for the MAA were initially developed by Golder and then were further reviewed and refined during a Giant Mine Expert Support review meeting, including representatives from Fisheries and Oceans Canada, Environment and Climate Change Canada, Health Canada and the Giant Mine Oversight Board, held on 26 October 2016 at Golder's Edmonton office. This is discussed in more detail in the Section 5.0.

1.4 Summary

The issues surrounding the location of Baker Creek at Giant Mine are complex. An options review of alternatives for Baker Creek was initiated to address Measure 11, incorporate input from the SDE process and new regional studies of water quality and to move forward on the design of the Giant Mine Closure and Reclamation Plan. Given the level of interest in Baker Creek, a robust review process using an established method, the MAA was undertaken. A brief overview of Baker Creek watershed and investigations into diversions is provided prior to the detailed methods of the MAA.

2.0 BAKER CREEK WATERSHED OVERVIEW

To provide context for the importance of Baker Creek locally and regionally and to help inform the evaluation criteria, an overview of the Baker Creek watershed is outlined below.

2.1 Regional Setting

Baker Creek is located in the North Slave region, north of Great Slave Lake in the Taiga Shield ecozone (Figure 2), characterized by shallow, coarse soils, discontinuous permafrost, and open, stunted forest. Glacial scouring of the landscape has created many waterbodies that influence the hydrological regimes of these watersheds. This area includes the Snare, Wecho, Yellowknife, McCrea, Cameron, Beaulieu and Waldron river watersheds, all of which drain to Great Slave Lake, as well as smaller named and unnamed streams. Communities in the North Slave region include Yellowknife, Detah, N'Dilo, Behchokǫ̀, Wha Tì, Gamètì and Wekweètì (INAC 2003).

Runoff hydrographs of streams in the North Slave region generally exhibit a subarctic nival regime, with the greatest discharges during spring snowmelt runoff, storage in ice starting at freeze-up and lowest flows in late winter (INAC 2003). Recent precipitation and temperature trends may be contributing to a shift to a combined nival/pluvial runoff regime, particularly in smaller watersheds, due to warmer conditions and more frequent autumn rainfall (Spence et al. 2011). Mean annual water yields of gauged streams in the North Slave region / Taiga Shield ecozone range from approximately 50 to 150 millimetres (mm).

2.2 Baker Creek Watershed

2.2.1 Climate

The Giant Mine site is located approximately 5 kilometres (km) northeast of the Yellowknife Airport climate station (Station 2204100; Environment Canada 2017). Climate normals for the period 1981-2010 indicate monthly mean air temperatures ranging from -25.6 degrees Celsius (°C) in January to 17.0°C in July. The extreme low temperature measured at the Yellowknife Airport was -51.2°C on February 1, 1947, and the extreme high temperature was 32.5°C on July 16, 1989.

Climate normals indicate mean annual rainfall of 171 mm, mean annual snowfall of 158 centimetres (cm), and mean annual precipitation of 289 mm. The station reports a mean March snow depth of 38 cm, with an extreme snow depth of 81 cm on March 5, 1958. The greatest reported daily rainfall was 82.8 mm on August 15, 1973.

2.2.2 Hydrology

Baker Creek is a small, intermittent stream located near Yellowknife, originating at Duckfish Lake, approximately 25 km northwest of Giant Mine (Figure 3). It flows southeast to its discharge point in Yellowknife Bay, Great Slave Lake. The final two kilometres of the lower reaches of Baker Creek flow through the Giant Mine site (Figure 4). The watershed has a drainage area of 121 square kilometres (km^2) at the outlet of Lower Martin Lake, where Water Survey of Canada station 07SB013 has operated since 1983. This WSC station, combined with a previous station (07SB009; 124 km^2, 1968-1982) located just above the Giant Mine site, together provide more than 40 years of record with which to characterize the flow regime. Its annual hydrograph is the product of an arid, sub-arctic climate, spring snowmelt, summer lake evaporation and summer/autumn rainfall events.

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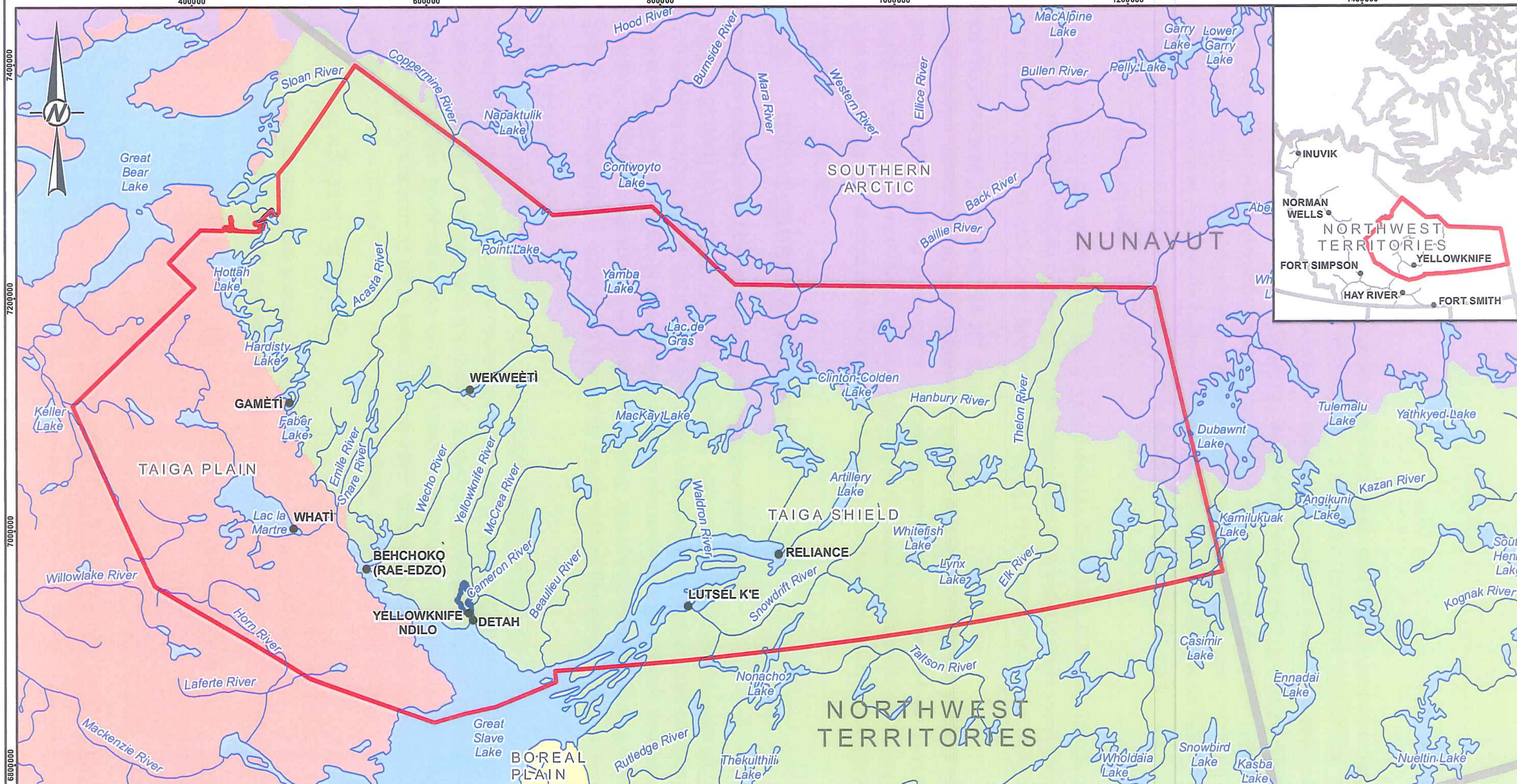

LEGEND

- POPULATED PLACE
- WATERCOURSE
- BAKER CREEK WATERSHED
- NORTH SLAVE ADMINISTRATIVE REGION
- PROVINCIAL/TERRITORIAL BOUNDARY
- WATERBODY

ECOZONES

- BOREAL PLAIN
- SOUTHERN ARCTIC
- TAIGA PLAIN
- TAIGA SHEILD

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PREPARED	AA
REVIEWED	JL
APPROVED	NS

PROJECT
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TITLE
BAKER CREEK SETTING WITHIN THE NORTH SLAVE REGION

PROJECT NO.	CONTROL	REV.	FIGURE
13-1377-0115	15000	0	2

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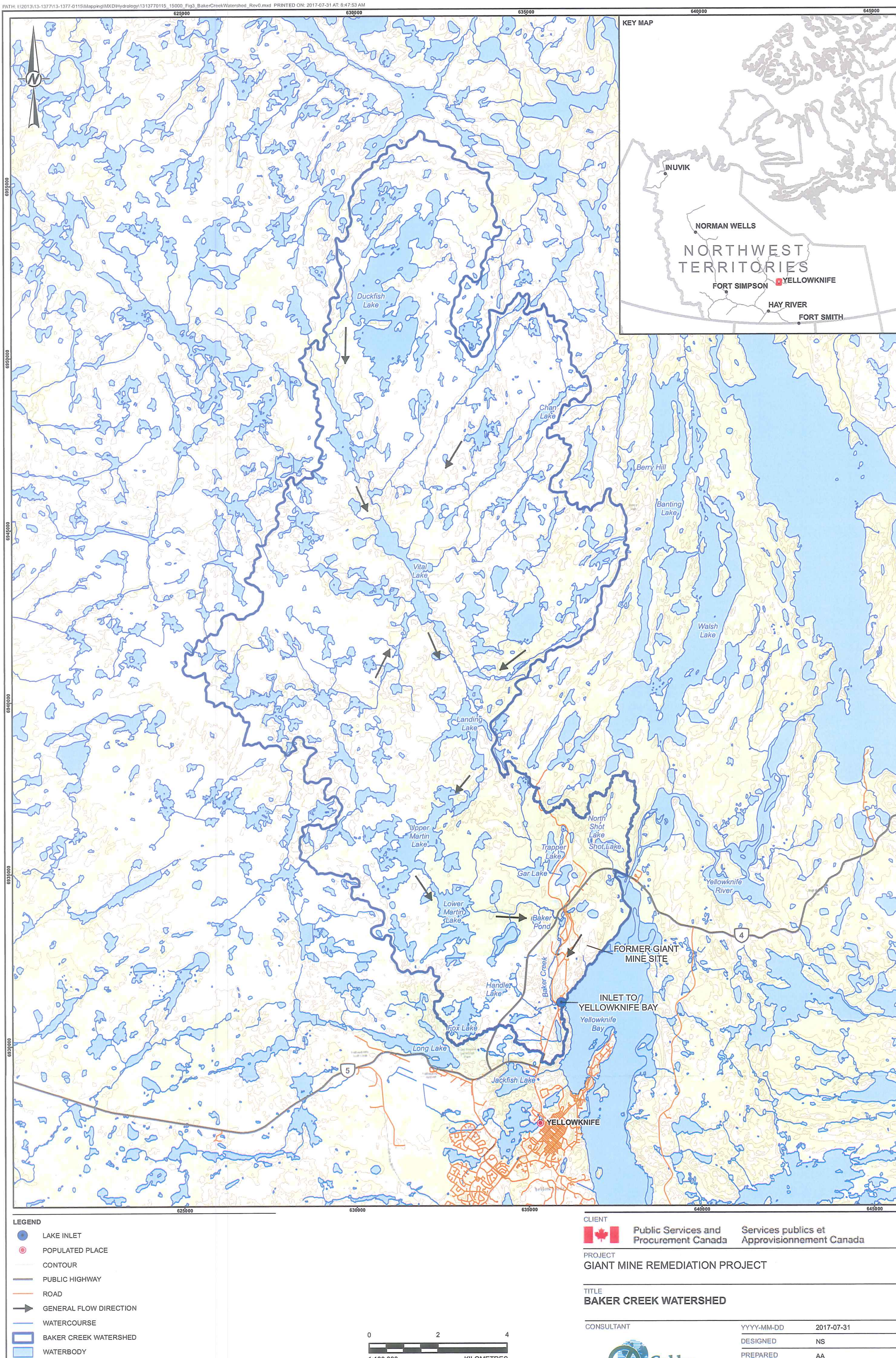

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PROJECT
GIANT MINE REMEDIATION PROJECT

TITLE
BAKER CREEK WATERSHED

CONSULTANT: Golder Associates

YYYY-MM-DD	2017-07-31
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PREPARED	AA
REVIEWED	JL
APPROVED	NS

PROJECT NO.	CONTROL	REV.	FIGURE
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The long-term mean annual flow at Baker Creek is estimated to be approximately 6,800,000 cubic metres (m^3) or 0.215 cubic metres per second (m^3/s) over the course of the year. This corresponds to a mean annual water yield of 56 mm, or approximately 17 percent (%) of the mean annual precipitation on the watershed. Typical peak discharge in spring has been approximately 2 m^3/s with an extreme high peak flow of approximately 8.5 m^3/s in 1991 and an extreme low peak flow of 0.012 m^3/s in 2016. A frequency analysis of annual floods measured by the WSC showed that the 1991 flood was approximately equal to the 50-year event.

Stream flow through the mine is dominated by the input of the upper watershed; the contribution of Giant Mine is relatively low (NHC 2005). At low flows, there is limited connectivity of the lower reaches of Baker Creek to the upper watershed. Since the 1990s, treated mine effluent has been discharged to the stream annually from July to September; this nearly doubles the baseline flows for summer but the volume of discharge is substantially lower than in the past.

In May 2011, anchor ice created a thick aufeis deposit in Baker Creek above Baker Pond, immediately upstream of the mine. Spring runoff was diverted by the ice accumulation and scoured out a road bed and historic tailings in the Jo Jo Lake / Baker Pond area, releasing contaminated sediment downstream to Baker Creek and Great Slave Lake. Tailings in this area were covered later in 2011, and monitoring of ice in the creek is part of regular water management on site.

Peak discharge historically occurred during spring freshet, with 76% of the Baker Creek annual stream flow in May and June compared to 8% between October and March. However, there has been a shift in regional streamflow regime related to an increasing trend in September rainfall and, from 1997, the proportion of annual stream flow has changed to 50% in spring and 20% in fall/winter (Kokelj et al. 2012; Spence et al. 2015).

Future climate change may include warmer temperatures, leading to greater precipitation, greater evaporation, changes to the balance between snowfall and rainfall, and changes to the timing of freeze-up and spring freshet. The nature of the Baker Creek watershed means that increased precipitation may be offset to some extent by increased evaporation. Peak flows may also be affected by changes to the seasonal distributions of rainfall, snowfall and snow melt. The range of available climate models is broad, and projections would vary greatly depending on the choice of model and climate change scenario. Furthermore, the models generally project much lower changes in the early time period (e.g., 2040-2070) than later periods (e.g., 2070-2100). The uncertainty associated with climate model projections, as well as the small changes generally projected in future decades compared to those in the longer term, mean that an historically-based flow regime characterization should be sufficient through mid-century.

2.2.3 Fishing

Historically, Baker Creek was a fish resource for Aboriginal communities. Although it is thought that Walleye were previously more abundant and highly sought after by local communities, there still exist several species of value to sport and Aboriginal fishers. The creek also offers important spawning and rearing opportunities for key prey species, such as shiners and sculpins, that are important to fish valued by Aboriginal and recreational users. On the basis of the limited studies occurring during later mining activities in the 1990s to 2012, twelve species of fish were documented in the creek: Northern Pike; Arctic Grayling; Lake Chub; Ninespine Stickleback; Emerald Shiner; Spottail Shiner; Trout Perch; White Sucker; Burbot; Longnose Sucker; Slimy Sculpin; and Lake Whitefish. Recreationally, Baker Creek is a convenient and popular angling destination, mainly for people residing in Yellowknife. Baker Creek also offers educational opportunities to local communities to visit the area and learn about local species and fish habitat (e.g., Fly Kid Foundation). As noted in Section 1.2.3, Fisheries and Oceans Canada implemented a managed fishery at the mouth of Baker Creek under the Northwest Territories Fishing Regulations in 2013. The creek is closed to Arctic Grayling fishing from April 1 to June 15 each year to reduce the potential effects of sportfishing on Arctic Grayling.

Overall, since the implementation of better mining practices in the late 1990s and with the mine beginning closure and reclamation, improvements in the Baker Creek aquatic ecosystem have been documented. Water quality has substantially improved in the creek due to improvements in the effluent treatment plant since mining operations ceased as well as stoppage of ammonia and other blast residues (Golder 2017). The discharge of treated effluent occurs in summer and fall only, after most spring spawning fish are out of the reaches of the creek on the mine site. Fish and benthos have recovered substantially. At this time, the creek may be characterized as containing highly contaminated sediment and altered habitat, but exhibiting substantial evidence of a system in recovery.

2.2.4 Water Quality in Baker Creek

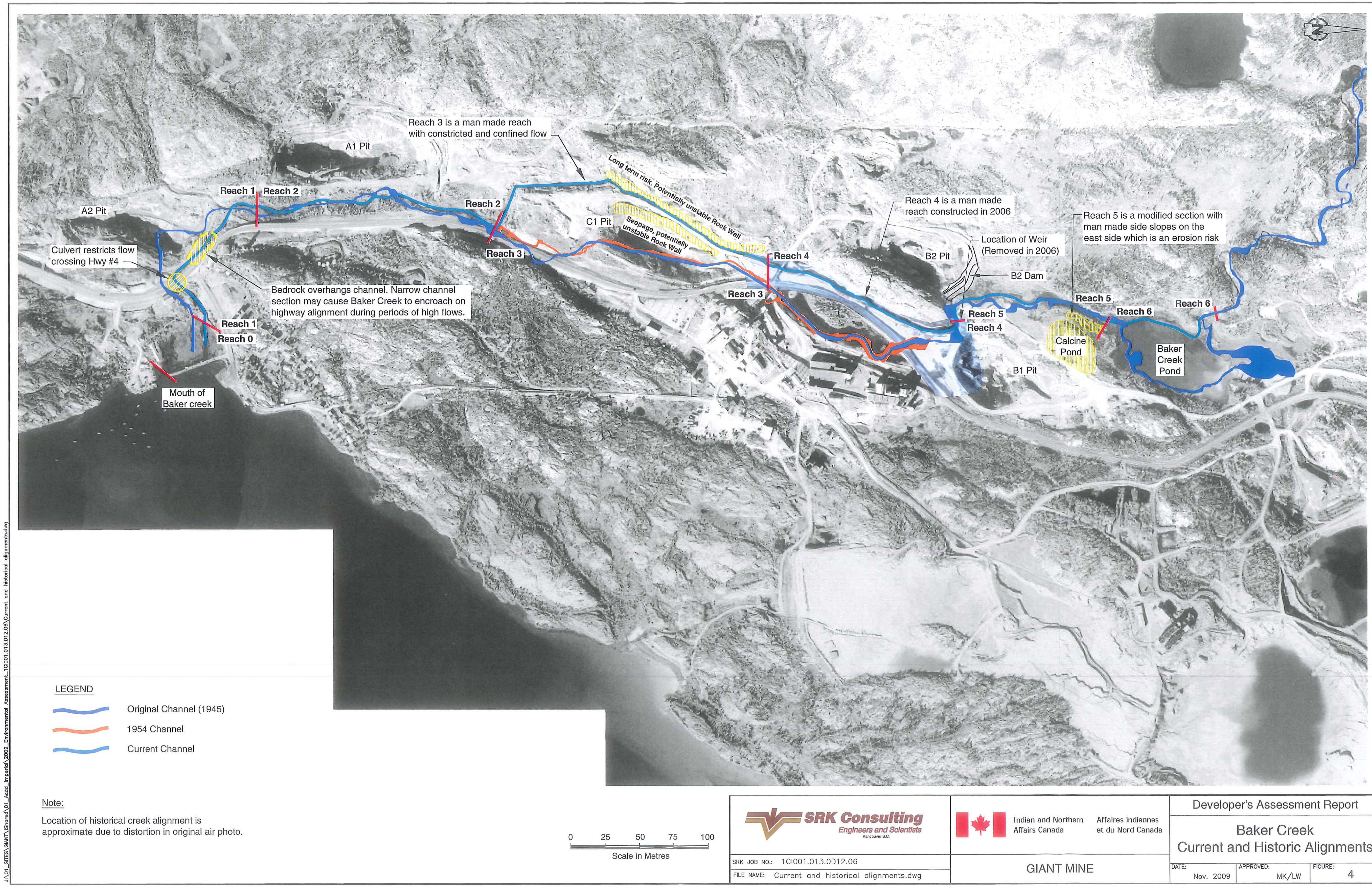
Every year, water quality in Baker Creek is monitored monthly during the open water season. When effluent is not present in Baker Creek (late winter and spring), the water quality in Baker Creek on the mine site is characterized as very clear, containing limited salts, nutrients and metals. Arsenic is one of the few metals that is consistently above aquatic life guidelines when effluent is absent; the median total arsenic concentration entering Baker Creek on-site is approximately 30 micrograms per litre (µg/L), above the aquatic life guideline of 5 µg/L.

When effluent is discharged to Baker Creek each summer, the creek contains concentrations of metals (e.g., arsenic and copper), and total dissolved solids (TDS) and its constituent anions (e.g., chloride and sulphate) that are elevated above reference areas and relevant aquatic life water quality guidelines (Golder 2017). Effluent quality is in compliance with applicable federal requirements. Contaminants in the water of Baker Creek historically have generally decreased with time as effluent treatment plant practices became more rigorous and lower volumes of effluent were released (Golder 2016a). For example, arsenic concentrations at the mouth of Baker Creek reported by Falk et al. (1973) of 12.6 milligrams per litre (mg/L), were substantially higher than arsenic concentrations observed between 2003 and 2016, which were below the average Metal Mining Effluent Regulation discharge limit of 0.5 mg/L (Golder 2017).

Despite the general decreasing temporal trend in metals concentrations in the treated effluent and mouth of Baker Creek, concentrations of aluminum, arsenic, copper, and iron in Yellowknife Bay, inside the breakwater and immediately downstream of Baker Creek, have remained consistent over time, suggesting that contaminants may have been remobilized into the water. TDS concentrations in the effluent and Baker Creek mouth (during discharge) have remained consistent with time and are currently around >2,500 mg/L (Golder 2017).

2.2.5 Human Impacts on Baker Creek

The current and historic alignments of Baker Creek at Giant Mine are shown on Figure 4. On the basis of aerial photographs from the 1940s, Baker Creek was originally a meandering, intermittent stream with riffle/run/pool habitat, vegetated shorelines, punctuated by inland lakes and wetlands (Dillon 1998). Two or more small inland lakes, named Jo-Jo Lake and Joe Lake, existed at the current Reach 6, now locally known as Baker Pond. On the basis of traditional knowledge of the Yellowknives Dene First Nation (YKDFN 1997; 2005) and information from local anglers, Baker Creek was a spring fishery for at least three species of fish, including Walleye, Arctic Grayling and Sucker spp. Northern Pike may have been seen in fall when berries were picked in the area. Wildlife was present in the creek area.


Reach 3 is a man made reach
with constricted and confined flow
A1 Pit
A2 Pit
Reach 1
Reach 2
Reach 2
Reach 3
Long term risk. Potentially unstable Rock Wall
C1 Pit
Seepage, potentially unstable Rock Wall
Culvert restricts flow
crossing Hwy #4
Bedrock overhangs channel. Narrow channel
section may cause Baker Creek to encroach on
highway alignment during periods of high flows.
Reach 1
Reach 0
Mouth of
Baker creek
Reach 4 is a man made
reach constructed in 2006
Reach 4
Reach 3
Location of Weir
(Removed in 2006)
B2 Pit
B2 Dam
Reach 5 is a modified section with
man made side slopes on the
east side which is an erosion risk
Reach 5
Reach 4
Reach 5
Reach 6
Reach 6
Calcine
Pond
Baker
Creek
Pond
B1 Pit
LEGEND
Original Channel (1945)
1954 Channel
Current Channel
Note:
Location of historical creek alignment is
approximate due to distortion in original air photo.
0 25 50 75 100
Scale in Metres
SRK Consulting
Engineers and Scientists
Vancouver B.C.
SRK JOB NO.: 1CI001.013.0D12.06
FILE NAME: Current and historical alignments.dwg
Indian and Northern
Affairs Canada
Affaires indiennes
et du Nord Canada
GIANT MINE
Developer's Assessment Report
Baker Creek
Current and Historic Alignments
DATE: Nov. 2009
APPROVED: MK/LW
FIGURE: 4
J:\01_SITES\GIANT\!Shared\01_Acad_Imperial\2009_Environmental Assessment_1CI001.013.012.06\Current and historical alignments.dwg

By the early 1950s, the lower reaches of Baker Creek were heavily altered by mining (Dillon 1998). The creek was altered by channelization, sedimentation and culvert installations at road crossings. When open pit mining was conducted on the property, the natural course of Baker Creek was diverted around the pits and mine infrastructure through artificial channels blasted out of bedrock.

In 2006, while mine closure planning was underway, two additional changes were made to the creek. In summer 2006, a portion of Baker Creek known as 'Reach 4' was diverted to the west side of Ingraham Trail. The primary objective of the Reach 4 diversion was to isolate the contaminated 'Mill Pond' from Baker Creek, thereby eliminating a source of ongoing contamination and preventing seepage loss from Baker Creek into areas of the mine itself (the C1 Pit and shallow underground features). Secondary objectives of the diversion were to provide a stable flood conveyance channel, maintain or improve fish passage, and provide spawning and rearing habitat for native fish species. During this time, Indian and Northern Affairs Canada (INAC) also initiated a small repair to a scour hole that was located below the Reach 1 Ingraham Trail culvert. A low rock riffle was constructed to create a backwater to flood the lower culvert and improve fish passage.

In addition to channel alteration, Baker Creek was heavily contaminated during the early years of mining. Tailings, treated effluent, spills of hydrocarbons and tailings material, uncontrolled runoff and sewage have been deposited to numerous reaches of the creek. A large portion of the fine sediments in the wetted portion of the creek are thought to be historical tailings (NHC 2007). Arsenic and sulphur dioxide were also deposited to the creek from decades of the operation of the roaster. Two detailed studies in the 1970s documented that mining activities had severely impacted the aquatic community in the creek (Falk et al. 1973; Moore et al. 1978). These studies found no fish, no crustaceans, no insects and no rotifers, and very few benthic invertebrates inhabiting the area of Baker Creek downstream of the mine. A 2011 study of the sediment in Baker Creek (Golder 2013a) measured elevated surface sediment total arsenic concentrations in one sample as 7,660 milligrams per kilogram dry weight (mg/kg dw), and subsurface arsenic concentrations as high as 21,300 mg/kg dw. Numerous other metals such as antimony, copper and zinc were also detected. This study is described further in Section 3.0.

3.0 INVESTIGATIONS INTO DIVERSION ALTERNATIVES

Since 2011, the GMRP has conducted a number of investigations focused on off-site and on-site diversion alternatives for Baker Creek, as well as factors influencing those alternatives.

3.1 Studies of Off Site Alternatives

3.1.1 North Diversion Assessment (2011)

During the Environmental Assessment period, a high-level assessment of Baker Creek north diversion alternatives was undertaken (Golder 2011). The objective of the assessment was to establish potential alignments for the north diversion of Baker Creek to Yellowknife Bay, and estimates of associated excavation quantities.

The assessment considered alignments following topographic lows (i.e., existing lakes and valleys) and specified maximum valley slopes of 2% for alignments intended to provide fish passage and flood conveyance, and 12% for alignments intended to provide flood conveyance only. Valley floodplain widths were specified as 32 m for the 2% slope alternatives, and 15 m for the 12% slope alternatives. Excavation volumes and flow velocities were calculated for each alternative.

This assessment examined four alignments that would provide fish passage and flood conveyance, and one alignment that would provide flood conveyance only. These diversion alternatives are included in those examined in Section 4.2.

3.1.2 Identification and Evaluation of Alternative Alignments for a Northern Diversion of Baker Creek (2014)

Stantec (2014a) further examined alternatives for a north diversion of Baker Creek to Yellowknife Bay, evaluating the Golder (2011) 6-2-8 alternative and introducing a second alternative that passed across upper and lower Shot Lake on a constructed fill.

This report also provided a discussion of fish habitat restoration concepts, including fish passage and habitat features, and applied a Habitat Suitability Index approach to quantify potential gains. It suggested designs for fish habitat features, including backwater channels, woody structures and vegetation.

The new diversion alternative proposed by Stantec (2014a) is included in those examined in Section 4.2.

3.1.3 North Diversion Bathymetry Surveys (2014)

Stantec (2014b) conducted bathymetric surveys of Gar, Trapper, Upper Shot and Lower Shot lakes, along the potential Baker Creek north diversion routes, in August 2014. The survey data were used to develop digital elevation models (DEM), volumetric calculations and descriptions of littoral habitat.

Trapper and Gar lakes were found to be shallow, each with a maximum depth of 1.0 m and soft, silty lake bottoms hosting water reeds and grasses. Both lakes were classified as 100% littoral habitat (water depth less than 2.0 m). Upper Shot Lake had a maximum depth of 2.5 m (97% littoral habitat), while Lower Shot Lake had a maximum depth of 5.0 m (37% littoral habitat).

3.1.4 North Diversion Aquatics and Fisheries Studies (2014)

Stantec (2014c) reported on fish and fish habitat, benthic invertebrate and water and sediment quality data collection conducted in September 2014. The survey data were used to characterize biological conditions in lakes along the potential Baker Creek north diversion routes.

Water chemistry sampling included physical parameters, anions and nutrients, total metals, dissolved metals and plant nutrients. Of note, total arsenic concentrations in Gar Lake ranged from 0.115 to 0.136 mg/L (dissolved arsenic concentrations 0.125 to 0.140 mg/L), total arsenic concentrations in Trapper Lake ranged from 0.182 to 0.235 mg/L (dissolved arsenic concentrations 0.206 to 0.227 mg/L), total arsenic concentrations in Upper Shot Lake ranged from 0.0111 to 0.0122 mg/L (dissolved arsenic concentrations 0.00932 to 0.0105 mg/L) and total arsenic concentrations in Lower Shot Lake ranged from 0.00796 to 0.00894 mg/L (dissolved arsenic concentrations 0.00739 to 0.00912 mg/L). These were compared to federal guidelines for the protection of aquatic life of 0.005 mg/L.

Arsenic exceeded sediment quality guidelines and concentrations in all samples, with concentrations ranging from 483 to 1,060 mg/kg in Gar Lake, 428 to 853 mg/kg in Trapper Lake, 138 to 288 mg/kg in Upper Shot Lake, and 148 to 589 mg/kg in Lower Shot Lake. These were compared to the CCME Interim Sediment Quality Guideline (ISQG) value of 5.9 mg/kg, the CCME Probable Effects Level (PEL) guideline of 17 mg/kg, the Yellowknife Natural Background Average of 150 mg/kg, and the Yellowknife Natural Background 90th percentile of 300 mg/kg.

Fisheries studies included net setting and incidental observations. No fish were observed or captured in any of Gar, Trapper, Upper Shot or Lower Shot lakes.

3.1.5 Baker Creek Water Quality Modeling (2015)

It was originally thought that diverting Baker Creek off-site would result in improved water quality in Baker Creek. Water quality modelling was initiated to evaluate if the assumption of improved water quality was valid and to address linked Measures 12 and 13. In 2014 and 2015 (Golder 2015), a north diversion scenario was modelled, to determine the influence on water quality in lakes along the potential northern flow path and in Yellowknife Bay near the Yellowknife River. The assessment predicted expected changes to water quality in the outlets of Baker Creek and Shot Creek, or in Yellowknife Bay as a result of the north diversion, and the magnitudes of exceedance at the creek outlets, and over what distance concentrations in Yellowknife Bay could be elevated (Appendix A).

A mass-balance model was used to predict water quality at the outlet of Baker Creek and Shot Creek (outlet of the north diversion route). The model used a daily time step, and each parameter was treated in a conservative manner (i.e., did not account for any potential settling, partitioning or decay), with predicted concentrations being developed at selected points in Baker Creek and Shot Creek watersheds. Plume dispersion in Yellowknife Bay was modelled for average conditions. Average flow conditions were selected to represent the typical plume behavior in Yellowknife Bay. By comparing the results for the scenarios under average conditions, the typical expected change in mixing zone length (i.e., affected area) was predicted for a possible diversion.

Results of the assessment indicated that there would be negative changes to water quality along the north diversion route and out into Yellowknife Bay. Specifically (Appendix A):

- Under the off-site scenario (i.e., diversion of upper Baker Creek), parameters concentrations were predicted to increase in Shot Creek and result in aquatic health/drinking water guideline exceedances at the outlet of Shot Creek. Arsenic concentrations would increase at the outlet of Shot Creek if the north diversion occurs with the existing water quality in upper Baker Creek and Gar and Trapper Lakes.
- The off-site scenario was also predicted to result in higher parameter concentrations in Baker Creek on the mine site ('the remnant channel'). However, predicted loading rates to Yellowknife Bay via Baker Creek were reduced, as loading was diverted north.
- Under the off-site scenario, the mixing zone in Yellowknife Bay near Shot Creek was predicted to increase from less than 10 m to more than 1,500 m into Yellowknife Bay.

3.1.6 Validation of Northern Route and Local Drainage Concepts (2016)

Golder (2016b) conducted a validation review of the Baker Creek north diversion alignment proposed by Stantec (2014a), as well as additional review of the hydrology of Baker Creek and hydraulic modeling of two north diversion alternatives (6-2-8 and 6-4-8) identified by Golder (2011). The hydraulic modeling examined variability in water surface elevation, mean flow velocity and channel bed shear stress over a range of flood return periods from 2 to 500 years.

The validation review of the north diversion alignment identified the perched nature of the Stantec (2014a) north diversion alternative as a flaw in the design, given that the proposed earthfill embankment would present a risk of channel realignment during extreme flood events, and would also need to provide conveyance of natural drainage under the embankment. Based on discussions with PSPC personnel, it was agreed that the concept would not be carried forward.

The previous (Golder 2011) north diversion alternatives were thought to be feasible from a hydraulic perspective, but based on recent water quality sampling, this report recommended a more rigorous water quality assessment[1] and consideration of stakeholder input.

This report also identified a number of south diversion alternatives, which are described in Section 4.4.

3.1.7 Baker Creek Geophysical Bedrock Survey (2016)

Golder (2016c) reported on geophysical surveys conducted in December 2014, to support future design of the Baker Creek north diversion. The work included approximately 8 km of ground penetrating radar and electrical resistivity imaging surveys along diversion alternative routes identified by Golder (2011). These depth-to-bedrock surveys were intended to provide input to future estimates of surficial soil and rock excavation quantities associated with construction of a selected alternative.

[1] Though this report was finalized in 2016, the recommendation was carried forwards prior to that and resulted in the water quality modeling assessment discussed in Section 3.1.5.

3.2 On-Site Investigations

3.2.1 Baker Creek Sediment – Human Health and Ecological Risk Study (2013)

An up-to-date assessment of the environmental conditions for aquatic life and human health was conducted in 2011. Current and possible future human health risks associated with recreational and worker exposure to water and sediments and fish consumption were determined. Existing data for water, sediment and tissue chemistry (benthic invertebrates and fish), aquatic toxicity (water column and sediment), benthic invertebrate and fish communities were compiled and reviewed and a 2011 field sampling program was undertaken to support the assessment of Baker Creek sediments and supplement historic data.

The study concluded the following:

- Water quality data from 2011 indicate that lower Baker Creek continues to receive inputs of water-borne arsenic independent of the seasonal discharge of treated effluent. Surface water in Upper Baker Creek (above Baker Creek Pond) and Trapper Creek are a continuing source of arsenic to Baker Creek but at lower concentrations than in the treated effluent.
- Sediment arsenic concentrations were elevated and, in both Baker and Trapper Creeks, were generally above sediment quality guidelines in surface and subsurface sediment.
- Benthic invertebrate recolonization of Baker Creek has progressed since mining operations ceased, despite the continued presence of elevated concentrations of metals in sediments.
- Metals concentrations in fish, periphyton and benthic invertebrate tissues were elevated in Baker Creek compared to the Yellowknife River reference area, particularly antimony and arsenic. This indicated that some metals are biologically available in Baker Creek.
- The creek is 'patchy' with some areas having the potential for negligible adverse effects and others with potential for significant adverse effects to benthic invertebrate based on elevated sediment metals concentrations and high sediment toxicity (in some cases 100% mortality in the laboratory tests).
- The human health risk assessment identified potential unacceptable risk for adults, toddlers and construction workers exposed to sediment, surface water and fish from Baker Creek related to arsenic and antimony. Based on the results of this assessment, swimming and barefoot wading by an adult or toddler recreational user was recommended to be limited in Baker Creek. Further, for construction or remediation activities appropriate personal protective equipment was recommended to be used to prevent dermal contact with sediment (e.g., gloves, long sleeves).

3.2.2 LiDAR Data Acquisition (2015)

A more detailed, current DEM was identified as a GMRP need, during work on the off-site and on-site diversion alternatives. PSPC commissioned Golder (2016d) to evaluate available LiDAR data sets and the potential need for additional data collection.

This report identified a data set collected for the City of Yellowknife in 2015 as the highest resolution (0.5 m) data set with coverage of the entire Giant Mine lease area and most of the surrounding lakes of interest. The report provided a budget estimate for collection of a higher resolution (0.1 m) data set, which could be collected at some point in the future to support design activities.

3.2.3 Baker Creek Alternative Routes Gap Analysis (2016)

Golder (2016e) reviewed the Baker Creek Preliminary Design Report (PDR; Golder 2012) including linkages to other GMRP activities, assumptions and uncertainties, and future study needs. It then outlined GMRP updates since the PDR that could potentially affect the design, on a component by component basis, and provided an updated hydraulic model summary based on the revised hydrological design basis presented by Golder (2016b).

A gap analysis was then presented, focusing on data gaps (i.e., unknown surface and subsurface conditions) and decision gaps associated with the design. The largest gap influencing the design was related to pit filling, which was identified as significantly reducing the consequences of an extreme flood, by limiting inflows to the underground mine.

The Report of Environmental Assessment was clear that the primary driver for moving Baker Creek off-site (Measure 11) was to eliminate the risk of underground flooding, which could release arsenic into the environment. SRK (2013) indicated that backfilling most of the pits would reduce mine inflows and reduce the long-term risk of mine flooding, by reducing the potential for inflow during flood event and reducing inflow rates to the extent that they could be managed by pumping.

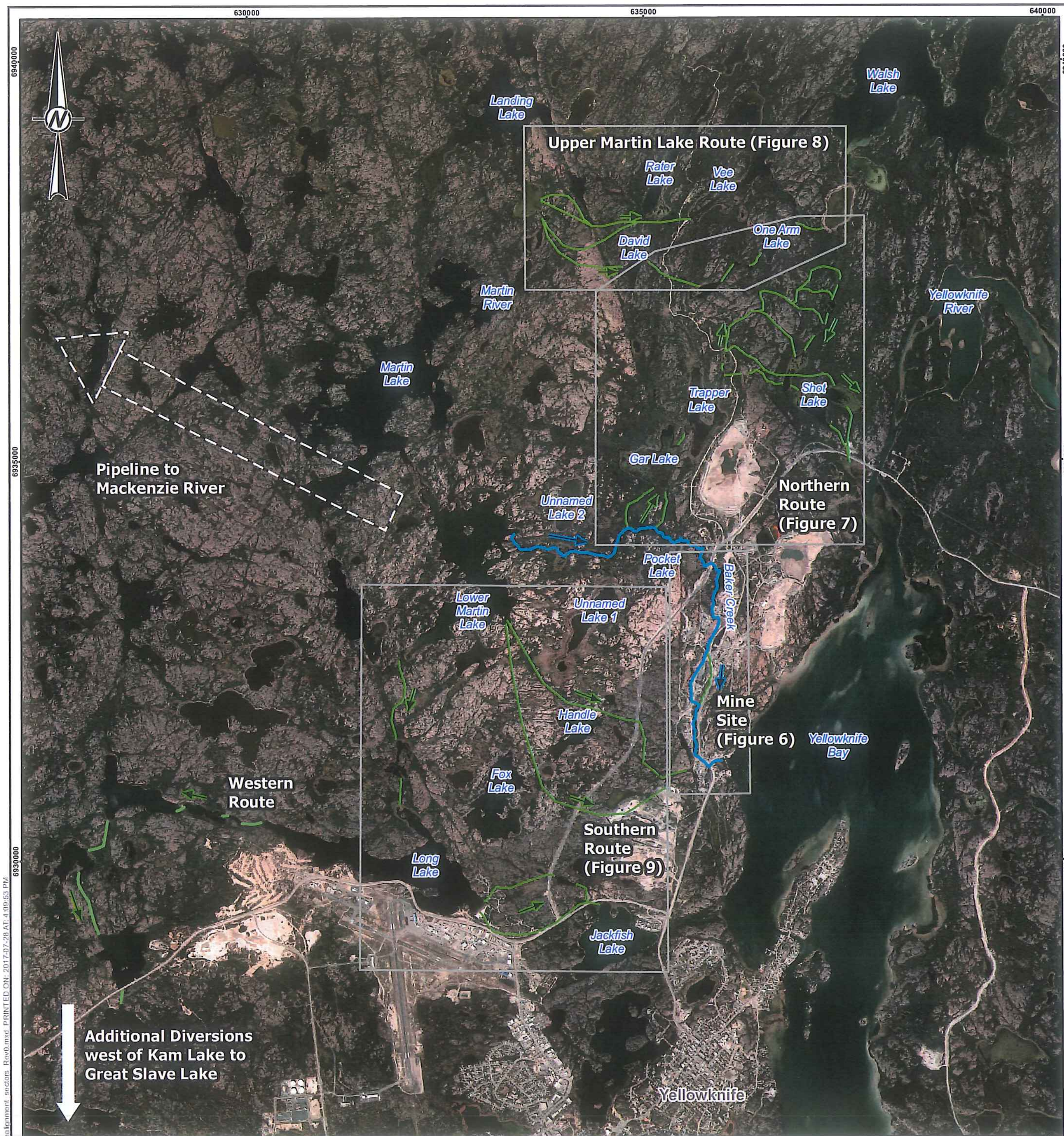
4.0 DIVERSION ALTERNATIVES

Diversion alternatives considered throughout the GMRP were compiled and defined based on a review of the following documents:

- GMRP Developer's Assessment Report (INAC and GNWT 2010);
- Baker Creek North Diversion Feasibility Evaluation (Golder 2011);
- Preliminary Design Report, Baker Creek – Giant Mine, Yellowknife, Northwest Territories (Golder 2012);
- Identification and Evaluation of Alternative Alignments for a Northern Diversion of Baker Creek, Northwest Territories (Stantec 2014a);
- Validation of Northern Route and Local Drainage Concepts (Golder 2016); and
- Giant Mine Surface Design Engagement – Baker Creek Diversion Options (SRK 2016a,b).

In addition to these documents, additional diversion alternatives were identified at the September 2016 Project Meeting. Alternatives were grouped in six geographic sectors and are identified and summarized here (Figure 5), as follows:

- **Mine Site**: the Mine Site sector consists of diversion alternatives between Baker Pond and the existing outlet at Baker Creek Reach 0 to Yellowknife Bay.
- **Northern Route**: the Northern Route sector consists of diversion alternatives from Upper Baker Creek, between Lower Martin Lake and the Giant Mine lease area, through Gar Lake and Trapper Lake. These were the first off-site diversion alternatives conceived as a potential solution for reducing the risk of underground flooding and incremental arsenic loading during conveyance of Baker Creek flows through the Giant Mine site. They would convey Baker Creek to Yellowknife Bay, downstream of the mouth of the Yellowknife River, or to the Yellowknife River. The Northern Route sector partially overlaps with the Upper Martin Lake Route (discussed below) where diversion alternatives convey Baker Creek to the Yellowknife River.
- **Upper Martin Lake Route**: the Upper Martin Lake sector consists of diversion alternatives upstream of Upper Martin Lake, through Landing Lake, located just north of Upper Martin Lake, and continuing east of Landing Lake. These alternatives were identified as diversions that could potentially avoid arsenic contaminated waterbodies (e.g., Trapper and Gar lakes) near the Giant Mine site, though the greater drainage area remaining below the diversions would result in greater runoff in the vestigial Baker Creek channel within the mine lease area. These diversion alternatives assumed that Baker Creek would no longer flow through the natural outlet of Lower Martin Lake, and convey Baker Creek to the Yellowknife River.
- **Southern Route**: the Southern Route sector consists of diversion alternatives flowing south from Lower Martin Lake, and continuing in the general east direction to convey Baker Creek into Yellowknife Bay. These off-site diversion alternatives were conceived to limit the drainage area below the diversion, while avoiding conveyance through known arsenic contaminated waterbodies (e.g., Trapper and Gar lakes). These diversion alternatives assumed that Baker Creek would no longer flow through the natural outlet of Lower Martin Lake.



LEGEND

- FLOW DIRECTION
- BAKER CREEK - EXISTING
- PROPOSED DIVERSION ALTERNATIVE
- CONCEPTUAL PIPELINE TO MACKENZIE RIVER

0 1,000 2,000

1:70,000 METRES

REFERENCE(S)

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DATUM: NAD 83 PROJECTION: UTM ZONE 11

CLIENT

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PROJECT

GIANT MINE REMEDIATION PROJECT

TITLE

PROPOSED DIVERSION ALTERNATIVE SECTORS

CONSULTANT

Golder Associates

YYYY-MM-DD	2017-07-28
DESIGNED	JL
PREPARED	SK
REVIEWED	NS
APPROVED	NS

PROJECT NO.	CONTROL	REV.	FIGURE
13-1377-0115	15000	0	5

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25mm

- **Western Route**: the Western Route sector consists of one diversion alternative, draining Baker Creek through the south of Lower Martin Lake, and continuing in a general westerly direction, away from Yellowknife Bay. This alternative was conceived to limit the drainage area below the diversion, avoiding conveyance through known arsenic contaminated waterbodies (e.g., Trapper and Gar lakes) and to further avoid conveyance through or runoff contributions from other waterbodies proximate to Giant Mine (e.g., Handle and Fox lakes). This alternative assumed that Baker Creek would no longer drain through the natural outlet of Lower Martin Lake.
- **Mackenzie River**: the Mackenzie River sector consists of one diversion alternative, diverting Baker Creek to the Mackenzie River, via pipeline. This alternative was conceived during brainstorming during a GMRP meeting, as a way to completely remove contaminated upstream runoff from the local area. This alternative assumed that Baker Creek would no longer flow through the natural outlet of Lower Martin Lake.

Diversion alternatives are discussed in greater detail in the sub-sections below.

4.1 Mine Site

The Mine Site sector includes six diversion alternatives, as defined below. The existing alignment and the diversion alternatives are shown in Figure 6.

- **Original**: the Original diversion is based on the historical alignment that conveyed Baker Creek through a 3.0 km reach from Baker Pond to the natural outlet to Yellowknife Bay. The Original diversion was originally presented in the DAR (INAC and GNWT 2010).
- **1954**: the 1954 diversion is based on the historical 1954 diversion that consisted of a 1.2 km diversion, away from the existing B2 Pit, with a minor diversion near the existing C1 Pit. The 1954 diversion was originally presented in the DAR (INAC and GNWT 2010).
- **DAR**: the DAR diversion consists of a 0.8 km diversion, away from the existing C1 Pit, along the existing highway. The DAR diversion alternative was originally presented in the DAR (INAC and GNWT 2010).
- **PDR Reach 3 - Option A**: the PDR Reach 3 - Option A diversion alternative consists of a 0.8 km diversion, to the east of the existing C1 Pit. The PDR Reach 3 - Option A diversion alternative was originally presented in the PDR (Golder 2012).
- **PDR Reach 3 - Option B**: the PDR Reach 3 - Option B diversion alternative consists of a 0.9 km diversion, to the west of the existing C1 Pit. The PDR Reach 3 - Option B diversion alternative was originally presented in the PDR (Golder 2012).
- **PDR Reach 3 - Option C:** the PDR Reach 3 - Option C diversion alternative consists of a 1.1 km diversion, to the west of the existing C1 Pit, and west of the PDR Reach 3 - Option B diversion alternative, in a deep cut. The PDR Reach 3 - Option C diversion alternative was originally presented in the PDR (Golder 2012).

4.2 Northern Route

The Northern Route sector includes eight diversion alternatives, as defined below. Diversions alternatives shown in yellow in Figure 7 were proposed by Golder (2011); those shown in orange were proposed by Stantec (2014a), and those shown in green were conceptually discussed without being explicitly presented (Golder 2011).

LEGEND

- BAKER CREEK - EXISTING
- FLOW DIRECTION

DIVERSION ALTERNATIVE

- DEVELOPER'S ASSESSMENT REPORT (DAR)
- PRELIMINARY DESIGN REPORT (PDR) REACH 3 - OPTIONS A, B AND C
- BAKER CREEK (ORIGINAL)
- BAKER CREEK (1954)
- BREAKWATER
- PIT BOUNDARY
- HIGHWAY
- ROAD
- GIANT MINE LEASE BOUNDARY

0 250 500
1:15,000 METRES

REFERENCE(S)

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PROJECT

GIANT MINE REMEDIATION PROJECT

TITLE

EXISTING BAKER CREEK ALIGNMENT AND DIVERSION ALTERNATIVES IN THE MINE SITE SECTOR

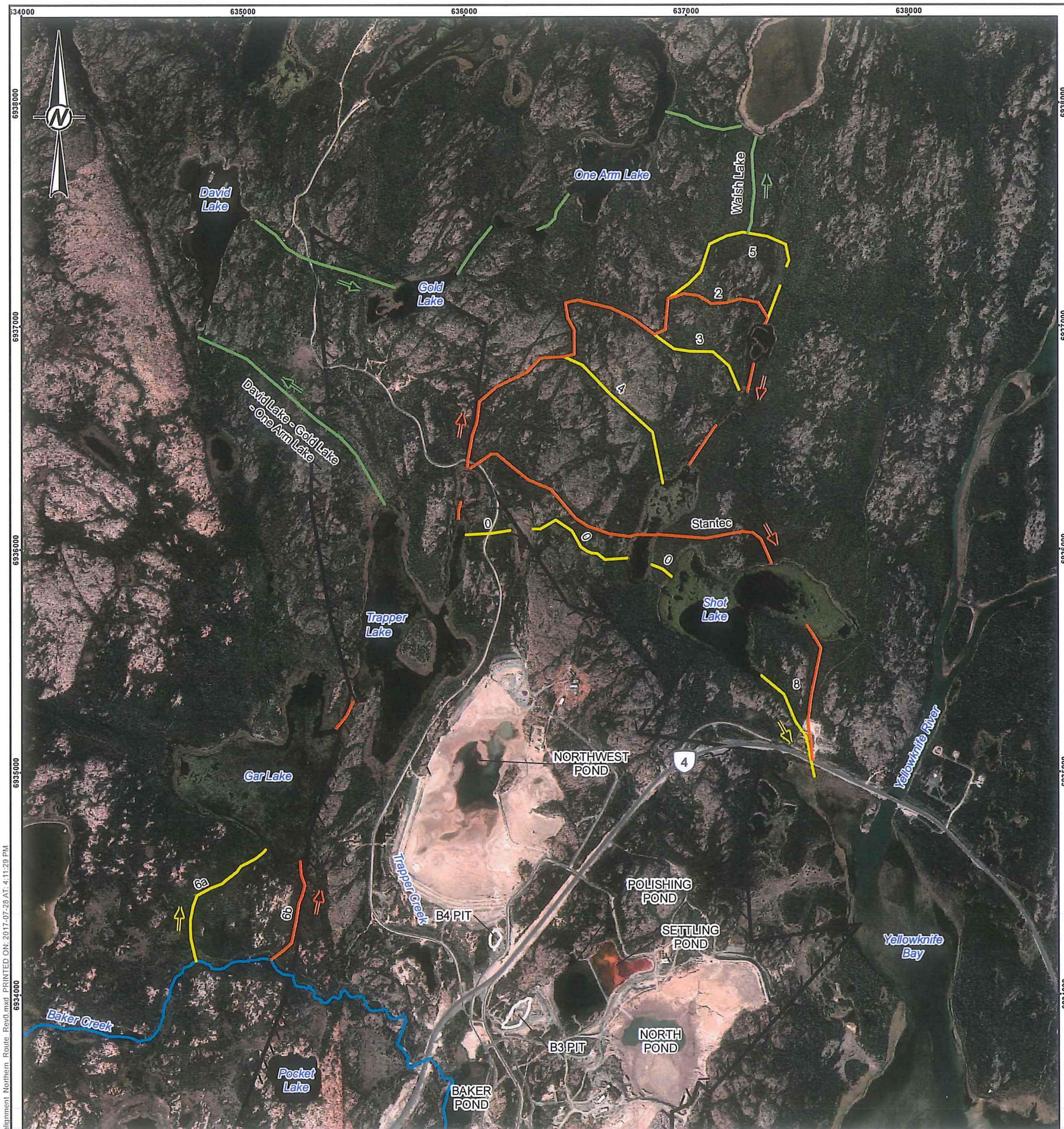
CONSULTANT

Golder Associates

YYYY-MM-DD	2017-07-28
DESIGNED	JL
PREPARED	SK
REVIEWED	NS
APPROVED	NS

PROJECT NO.	CONTROL	REV.	FIGURE
13-1377-0115	15000	0	6

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
25mm



LEGEND

- FLOW DIRECTION
- BAKER CREEK - EXISTING

DIVERSION ALTERNATIVE

- CONCEPTUAL DIVERSION
- NORTH DIVERSION - GOLDER
- NORTH DIVERSION - STANTEC
- PIT BOUNDARY
- HIGHWAY
- ROAD
- GIANT MINE LEASE BOUNDARY

0 500 1,000

1:25,000 METRES

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DATUM: NAD 83 PROJECTION: UTM ZONE 11

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PROJECT

GIANT MINE REMEDIATION PROJECT

TITLE

POTENTIAL BAKER CREEK DIVERSION ALTERNATIVES IN THE NORTHERN ROUTE SECTOR

CONSULTANT

Golder Associates

YYYY-MM-DD	2017-07-28
DESIGNED	JL
PREPARED	SK
REVIEWED	NS
APPROVED	NS

PROJECT NO.	CONTROL	REV.	FIGURE
13-1377-0115	15000	0	7

Alternative 6-2-8 was presented as the off-site diversion alternative at the SDE (SRK 2016b). Two diversion alternatives were previously proposed for Reach 6, noted as Reach 6a and Reach 6b on Figure 7. It is noted that the creek alignment downstream of Shot Lake to Yellowknife Bay may extend further south than shown on Figure 7, along the west shoreline of Yellowknife Bay, to avoid discharge into a sensitive area immediately south of the Yellowknife River mouth. This area has been identified as having cultural importance by the Yellowknives Dene First Nation and of importance to other stakeholders.

- Alternatives are distinguished between those providing flood conveyance only (Alternative 6-0-8) and all others, that would provide flood conveyance as well as conditions suitable for fish passage (i.e., channel slopes low enough to result in flow velocities low enough, and flow depths great enough, to facilitate upstream fish passage). At the time, it was thought that fish passage bypassing the mine could have been viewed favorably.
- **6-0-8**: the 6-0-8 (Flood Conveyance) diversion alternative consists of a 2.0 km diversion north through Gar Lake and Trapper Lake, east to Shot Lake, and flowing to Yellowknife Bay. The 6-0-8 (Flood Conveyance) diversion alternative was originally presented in the North Diversion Feasibility report (Golder 2011), and intended to convey flood discharges through a steep reach, between Trapper Lake and Shot Lake.
- **6-4-8**: the 6-4-8 (Fish Friendly) diversion alternative consists of a 3.3 km diversion north through Gar Lake, Trapper Lake, Shot Lake, and flowing to Yellowknife Bay. The 6-4-8 (Fish Friendly) diversion alternative was originally presented in the North Diversion Feasibility report (Golder 2011), and intended to provide fish passage through a longer reach than the 6-0-8 (Flood Conveyance) diversion alternative between Trapper Lake and Shot Lake, in consideration of rock cut volumes.
- **6-3-8**: the 6-3-8 (Fish Friendly) diversion alternative consists of a 3.8 km diversion north through Gar Lake, Trapper Lake, Shot Lake, and draining to Yellowknife Bay. The 6-3-8 (Fish Friendly) re- intended to provide fish passage through a longer reach than the 6-4-8 (Fish Friendly) diversion alternative between Trapper Lake and Shot Lake, in consideration of rock cut volumes.
- **6-2-8**: the 6-2-8 (Fish Friendly) diversion alternative consists of a 4.0 km diversion north through Gar Lake, Trapper Lake, Shot Lake, and flowing to Yellowknife Bay. The 6-2-8 (Fish Friendly) diversion alternative was originally presented in the North Diversion Feasibility report (Golder 2011), and intended to provide fish passage through a longer reach than the 6-3-8 (Fish Friendly) diversion alternative between Trapper Lake and Shot Lake, in consideration of rock cut volumes. This alignment was also investigated by Stantec (2014a), and was presented as the off-site diversion alternative at the SDE (SRK 2016b).
- **6-5-8**: the 6-5-8 (Fish Friendly) diversion alternative consists of a 4.3 km diversion north through Gar Lake, Trapper Lake, Shot Lake, and flowing to Yellowknife Bay. The 6-5-8 (Fish Friendly) diversion alternative was originally presented in the North Diversion Feasibility report (Golder 2011), and intended to provide fish passage through a longer reach than the 6-2-8 (Fish Friendly) diversion alternative between Trapper Lake and Shot Lake, in consideration of rock cut volumes.
- **David Lake - Gold Lake - One Arm Lake**: the David Lake - Gold Lake - One Arm Lake diversion alternative consists of a 3.3 km diversion north through Gar Lake, Trapper Lake, David Lake, Gold Lake, One Arm Lake, and flowing to the Yellowknife River through Walsh Lake. The David Lake - Gold Lake - One Arm Lake

diversion alternative was originally presented in the North Diversion Feasibility report (Golder 2011). This diversion alternative would require water to flow uphill without significant lake and channel alterations.

- **Walsh Lake**: the Walsh Lake diversion alternative consists of a 3.3 km diversion north following reaches 6 and 5 (partially) of the 6-5-8 (Fish Friendly) alignment through Gar Lake and Trapper Lake, and continuing to the Yellowknife River via Walsh Lake. The Walsh Lake diversion alternative was originally presented in the North Diversion Feasibility report (Golder 2011).
- **Stantec**: the Stantec (2014a) diversion alternative consists of a 2.8 km diversion north through Gar Lake, Trapper Lake, Shot Lake, and flowing to Yellowknife Bay. The Stantec diversion alternative was intended to provide fish passage through a longer reach than, and north of, the 6-0-8 (Flood Conveyance) diversion alternative between Trapper Lake and Shot Lake. The Stantec diversion alternative would result in a perched channel above Shot Lake.

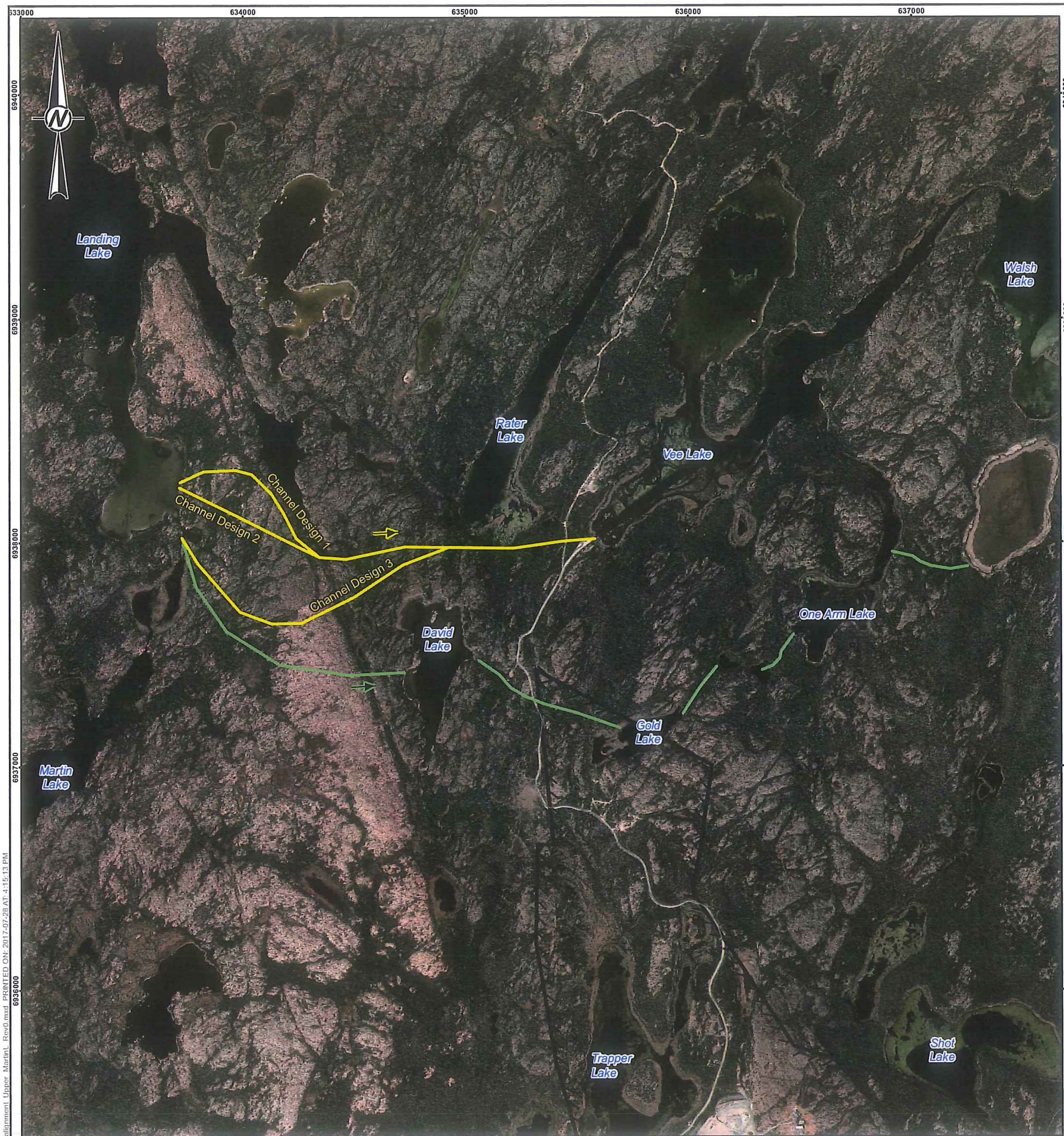
4.3 Upper Martin Lake Route

The Upper Martin Lake Route sector includes four diversion alternatives, as defined below. The diversion alternatives listed above are shown in Figure 8, in yellow (SRK 2016a), and in green (conceptually introduced during the September 2016 Project Meeting).

- **Channel Design 1**: the Channel Design 1 diversion alternative consists of a 2.1 km diversion, through Landing Lake, Vee Lake, and flowing to the Yellowknife River through Walsh Lake. The Channel Design 1 diversion alternative was originally presented in an SDE memorandum on Baker Creek Diversion Options (SRK 2016a).
- **Channel Design 2**: the Channel Design 2 diversion alternative consists of a 2.0 km diversion, through Landing Lake, Vee Lake, and flowing to the Yellowknife River through Walsh Lake. The Channel Design 2 diversion alternative was originally presented in an SDE memorandum on Baker Creek Diversion Options (SRK 2016a) and consists of a shorter reach between Landing Lake and Vee Lake than the Channel Design 1 diversion alternative.
- **Channel Design 3**: the Channel Design 3 diversion alternative consists of a 2.1 km diversion, through Landing Lake, Vee Lake, and flowing to the Yellowknife River through Walsh Lake. The Channel Design 3 diversion alternative was originally presented in an SDE memorandum on Baker Creek Diversion Options (SRK 2016a) and consists of a longer reach between Landing Lake and Vee Lake than the Channel Design 1 and Channel Design 2 diversion alternatives, and was routed to the north of both alternatives within the same reach.
- **Landing Lake to Walsh Lake**: the Landing Lake to Walsh Lake diversion alternative consists of a 2.9 km diversion, through Landing Lake, David Lake, Gold Lake, One Arm Lake, and flowing to the Yellowknife River through Walsh Lake. The Landing Lake to Walsh Lake diversion alternative was introduced during the September 2016 Project Meeting.

4.4 Southern Route

The Southern Route sector includes four diversion alternatives, as defined below. The diversion alternatives listed above are shown in Figure 9, in orange (Handle Lake alternatives), and in yellow (Long Lake alternatives).



LEGEND

FLOW DIRECTION

DIVERSION ALTERNATIVE

SRK DIVERSION

CONCEPTUAL DIVERSION

ROAD

GIANT MINE LEASE BOUNDARY

0 500 1,000

1:25,000 METRES

REFERENCE(S)

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DATUM: NAD 83 PROJECTION: UTM ZONE 11

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PROJECT

GIANT MINE REMEDIATION PROJECT

TITLE

POTENTIAL BAKER CREEK DIVERSION ALTERNATIVES IN THE UPPER MARTIN LAKE ROUTE SECTOR

CONSULTANT

Golder Associates

YYYY-MM-DD	2017-07-28
DESIGNED	JL
PREPARED	SK
REVIEWED	NS
APPROVED	NS

PROJECT NO.	CONTROL	REV.	FIGURE
13-1377-0115	15000	0	8

PATH: I:\2013\13-1377\13-1377-0115\Mapping\MXD\TA15_Report\1313770115_Fig8_Potential_realignment_Upper_MartinL_Rev0.mxd PRINTED ON: 2017-07-28 AT: 4:15:13 PM

25mm IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A

LEGEND

FLOW DIRECTION	BREAKWATER
BAKER CREEK - EXISTING	PIT BOUNDARY
DIVERSION ALTERNATIVE	HIGHWAY
HANDLE LAKE ROUTE	ROAD
LONG LAKE TO JACKFISH LAKE ROUTE	GIANT MINE LEASE BOUNDARY

0 500 1,000
1:30,000 METRES

REFERENCE(S)
HYDROLOGY AND TRANSPORTATION DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED. IMAGERY OBTAINED FROM CLIENT, 2015.
DATUM: NAD 83 PROJECTION: UTM ZONE 11

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PROJECT
GIANT MINE REMEDIATION PROJECT

TITLE
POTENTIAL BAKER CREEK DIVERSION ALTERNATIVES IN THE SOUTHERN ROUTE SECTOR

CONSULTANT
Golder Associates

YYYY-MM-DD	2017-07-28
DESIGNED	JL
PREPARED	SK
REVIEWED	NS
APPROVED	NS

PROJECT NO.	CONTROL	REV.	FIGURE
13-1377-0115	15000	0	9

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A
25mm

- **Long Lake to Jackfish Lake - North Route**: the Long Lake to Jackfish Lake - North Route diversion alternative consists of a 1.5 km diversion, through the south of Lower Martin Lake, Long Lake, flowing to Yellowknife Bay through Jackfish Lake. The Long Lake to Jackfish Lake - North Route diversion alternative was originally presented in the Validation of the Northern Route report (Golder 2016b).
- **Long Lake to Jackfish Lake - South Route**: the Long Lake to Jackfish Lake - South Route diversion alternative consists of a 1.7 km diversion, through the south of Lower Martin Lake, Long Lake, flowing to Yellowknife Bay through Jackfish Lake. The Long Lake to Jackfish Lake - South Route diversion alternative was originally presented in the Validation of the Northern Route report (Golder 2016b), with a reach between Long Lake and Jackfish Lake located south of the Long Lake to Jackfish Lake - North Route diversion alternative.
- **Handle Lake - North Route**: the Handle Lake - North Route diversion alternative consists of a 3.4 km diversion, through the south of Lower Martin Lake, flowing to Yellowknife Bay by bypassing Handle Lake, to the north. A bypass of Handle Lake was considered, to prevent mobilization of potentially contaminated sediments in the lake, because conveyance through lakes was not required to prevent deep valley excavation in the area, as is the case for the Northern Route alternatives. The Handle Lake - North Route diversion alternative was originally presented in the Validation of the Northern Route report (Golder 2016b).
- **Handle Lake - South Route**: the Handle Lake - South Route diversion alternative consists of a 3.9 km diversion, through the south of Lower Martin Lake, flowing to Yellowknife Bay by bypassing Handle Lake, to the south. Again, a bypass of Handle Lake was considered. The Handle Lake - South Route diversion alternative was originally presented in the Validation of the Northern Route report (Golder 2016b).

4.5 Western Route

The Western Route diversion alternative consists of a conceptual diversion to the west, flowing to Great Slave Lake, from Lower Martin Lake, and through the west outlet of Long Lake. This diversion alternative was introduced during the September 2016 Project Meeting, and its upper portion is shown conceptually in Figure 5. Its lower portion has not been developed, but would likely need to follow an alignment through existing lakes west of Kam Lake. One potential alignment would require approximately 9.0 km of channel construction.

4.6 Mackenzie River

The Pipeline to the Mackenzie River diversion alternative consists of a pipeline diversion to the Mackenzie River and was briefly introduced and discussed on a conceptual level during the SDE process, but without written documentation. The diversion alternative listed above is shown in Figure 5.

4.7 Summary and Consolidation of Diversion Alternatives

Diversion alternatives discussed in Sections 4.1 to 4.6 were compiled in Table 1, which presents the sector, diversion name, reference document, and approximate length of diversion (excluding existing waterbodies). An identification number (ID) was also provided to each alternative for further reference herein.

Given the similarities between diversion alternatives, several diversion alternatives were consolidated as follows, for future analysis:

- The DAR (ID 3), PDR Reach 3 - Option A (ID 4), and PDR Reach 3 - Option B (ID 5) diversion alternatives, were consolidated into the "PDR Reach 3 - Option A" diversion alternative, following the conceptual diversion of the PDR Reach 3 - Option A diversion alternative, and assigned an ID of 4.
- The four fish friendly Northern Route diversion alternatives (i.e., 6-4-8 [ID 8], 6-3-8 [ID 9], 6-2-8 [ID10], and 6-5-8 [ID 11]) were consolidated into the "6-4-8 (Fish Friendly)" diversion alternative, following the conceptual diversion of the 6-4-8 (Fish Friendly) diversion alternative, and assigned an ID of 8.
- The Channel Design 1 (ID 15), Channel Design 2 (ID 16), and Channel Design 3 (ID 17) diversion alternatives, were consolidated into the "Channel Design 1" diversion alternative, following the conceptual diversion of the Channel Design 1 diversion alternative, and assigned an ID of 15.
- The Long Lake to Jackfish Lake - North Route (ID 19) and Long Lake to Jackfish Lake - South Route (ID 20) diversion alternatives, were consolidated into the "Long Lake to Jackfish Lake" diversion alternative, following the conceptual diversion of the Long Lake to Jackfish Lake - North Route diversion alternative, and assigned an ID of 19.
- The Handle Lake - North Route (ID 21) and Handle Lake - South Route (ID 22) diversion alternatives, were consolidated into the "Handle Lake" diversion alternative, following the conceptual diversion of the Handle Lake - North Route diversion alternative, and assigned an ID of 21.

Table 1: Baker Creek Diversion Alternatives

Sector	ID	Diversion Name	Reference Document	Length (km)
Mine Site	1	Original	DAR	2.99
	2	1954	DAR	1.19
	3	DAR	DAR	0.77
	4	PDR Reach 3 - Option A	PDR	0.81
	5	PDR Reach 3 - Option B	PDR	0.86
	6	PDR Reach 3 - Option C	PDR	1.05
Northern Route	7	6-0-8 (Flood Conveyance)	North Diversion Feasibility	1.99
	8	6-4-8 (Fish Friendly)	North Diversion Feasibility	3.34
	9	6-3-8 (Fish Friendly)	North Diversion Feasibility	3.80
	10	6-2-8 (Fish Friendly)	North Diversion Feasibility	4.00
	11	6-5-8 (Fish Friendly)	North Diversion Feasibility	4.28
	12	David Lake - Gold Lake - One Arm Lake	North Diversion Feasibility	3.32
	13	Walsh Lake	North Diversion Feasibility	3.31
	14	Stantec	Stantec (2014a)	2.78
Upper Martin Lake Route	15	Channel Design 1	SDE (SRK 2016a)	2.07
	16	Channel Design 2	SDE (SRK 2016a)	1.95
	17	Channel Design 3	SDE (SRK 2016a)	2.11
	18	Landing Lake to Walsh Lake	September 2016 Project Meeting	2.85
Southern Route	19	Long Lake to Jackfish Lake - North Route	Validation of Northern Route	1.46
	20	Long Lake to Jackfish Lake - South Route	Validation of Northern Route	1.73
	21	Handle Lake - North Route	Validation of Northern Route	3.35
	22	Handle Lake - South Route	Validation of Northern Route	3.87
Western Route	23	Western Route	September 2016 Project Meeting	~9.0
Mackenzie River	24	Mackenzie River Pipeline	Not documented	> 300

Note: Grey font: Consolidated diversion alternatives.
Lengths do not consider conveyance through existing waterbodies.

5.0 DESCRIPTION OF THE MULTIPLE ACCOUNTS ANALYSIS PROCESS

The alternative routes for the diversion of Baker Creek were evaluated using an MAA process. An MAA is a standard transparent process for decision making which ranks alternatives relative to each other using a numerical method based on their performance in categories reflecting the expected environmental, social and economic impacts and technical feasibility of each alternative. The MAA process follows methods originally described by Robertson and Shaw (1998, 1999) and has been accepted practice for numerous industries in Canada including mine development (Government of Canada 2016), and transportation (Alberta Transportation 2015), among others.

The general MAA process involves the following steps further described in the sub-sections below:

- Alternative identification and definition;
- Screening process;
- Scoring system development;
- Evaluation criteria development; and
- Alternative evaluation using a matrix comprising evaluation criteria and the scoring system.

5.1 Alternative Identification and Definition

The purpose of this task is to introduce alternatives considered in the MAA process and provide sufficient information for the Screening Process described below. This information generally includes a brief description and illustration of each alternative.

5.2 Screening Process

Generally, prior to conducting a detailed MAA, a screening process is applied to all considered alternatives. The purpose of the screening process is to save the effort of evaluating alternatives that do not meet certain criteria considered essential to the project's success. If such a "must meet" criterion exists for a project, each alternative is evaluated based on its ability to satisfy said criterion. Any alternative not satisfying the "must meet" criterion is eliminated from further consideration in the MAA. Descriptions of the screening process developed for this MAA are provided in Section 6.1.

5.3 Scoring System Development

A scoring system is developed to compare the alternatives on a consistent scale, and include ratings and weightings. Ratings consist of numerical values assigned to each alternative based on its expected performance under each criterion. For instance, a higher rating is intended to correspond to a greater performance, and vice versa. Ratings can be applied to each criterion qualitatively or quantitatively.

Numerical weightings are assigned to each criterion to account for the relative importance of each criterion to the project's objectives, and increase or decrease its influence on the results of the MAA. Numerical weightings can also be assigned to each category considered.

5.4 Evaluation Criteria Development

For each MAA, evaluation criteria are developed to reflect the objectives of the project. Generally these criteria fit into the following categories:

- Environmental impact;
- Social impact;
- Economic impact; and
- Technical feasibility.

5.5 Alternative Evaluation

Screened alternatives are assembled into an evaluation matrix with evaluation categories and criteria, and are ranked relative to each other using the scoring system. This process typically requires input from stakeholders and technical experts to provide a balanced and defensible evaluation. The highest ranked alternative is deemed the preferred alternative. Descriptions of the categories, criteria and scoring system developed for this MAA are provided in Section 6.2 and Section 6.3.

6.0 MULTIPLE ACCOUNTS ANALYSIS MATRIX DEVELOPMENT

The MAA process for the Baker Creek diversion followed the general steps described in Section 5.0 and was completed by expert personnel with GMRP-specific understanding and expertise, informed by public and aboriginal consultation to meet requirements of Measure 11. Participants in meetings and workshops to develop diversion alternatives, MAA screening criteria, and MAA weights and ratings are presented in Table 2.

Table 2: Participants in Baker Creek Diversion Evaluation Meetings and Workshops

Meeting or Workshop Details	Participants
15 September 2016 **Baker Creek Diversion Project Meeting** *Conference Call*	Jane Amphlett, INAC Katherine Harris, INAC Doug Townson, PSPC Leslie Gray, PSPC Nathan Schmidt, Golder Julien Lacrampe, Golder
26 October 2016 **Baker Creek Expert Support Review Meeting** *Golder Edmonton Office*	Jane Amphlett, INAC Katherine Harris, INAC Doug Townson, PSPC Erika Nyssonen, GNWT Mark D'Aguiar, Fisheries and Oceans Canada Jody Small, Environment and Climate Change Canada Asish Mohapatra, Health Canada Tony Brown, Giant Mine Oversight Board Kathy Racher, Giant Mine Oversight Board Nathan Schmidt, Golder Hilary Machtans, Golder Tasha Hall, Golder
17 November 2016 **Baker Creek Diversion MAA Evaluation Workshop** Canada Place, Edmonton	Jane Amphlett, INAC Nathalie Plato, INAC Katherine Harris, INAC Tauhid-Brian Thomas, INAC Chris MacInnis, INAC Aaron Braumburger, INAC Doug Townson, PSPC Brad Thompson, PSPC Leslie Gray, PSPC Rudy Schmidtke, AECOM Nathan Schmidt, Golder Julien Lacrampe, Golder

Additional public and aboriginal information considered in this study was sourced from the following documents:

- Impact of the Yellowknife Giant Gold Mine on the Yellowknives Dene (YKDFN 2005); and
- Giant Mine Surface Design Engagement – Baker Creek Diversion Options (SRK 2016 a,b) as described in Section 1.3.2.

The alternative identification and definition was previously presented in Section 4.0. This section of the report describes the screening process (Section 6.1), scoring system development (Section 6.2) and evaluation criteria development (Section 6.3). Results of the evaluation matrix and rationales are presented in Section 7.0.

Conclusions, recommendations and next steps are presented in Section 7.3, in consideration of the MAA results, and of the scope of Measure 11.

6.1 Screening Assessment

6.1.1 Screening Considerations

Screening and evaluation criteria were initially developed by Golder and presented by conference call, along with compiled alignments, to PSPC and INAC during the September 2016 Project Meeting. These criteria were further reviewed and refined during a Giant Mine Expert Support review meeting, including representatives from external stakeholders, held on 26 October 2016 at Golder's Edmonton office. The resulting screening criteria were used to identify diversion alternatives that did not meet GMRP requirements, as presented in Section 6.1.3, and eliminate them prior to evaluation of remaining alternatives. Evaluation criteria and candidate diversion alternatives carried forward to the detailed evaluation process are presented in Section 6.2.

An initial version of the scoring system was developed by Golder, based on experience with MAA processes for other applications, and assembled into an evaluation matrix, along with screened diversion alternatives, evaluation categories and criteria. This was finalized with input from stakeholders provided during the MAA Evaluation Workshop (Section 6.2).

6.1.2 Screening Criteria

A screening assessment was completed on the diversion alternatives presented in Section 4.0 to prioritize requirements under Measure 11 and preferences/concerns identified during the surface design stakeholder engagement. Further consideration was given to Measure 12 and Measure 13 (Section 1.0), which emphasized the need for improved/managed water quality for a possible diversion and the remaining Baker Creek channel. The stakeholder input described in Section 1.3.2 was narrowed down to "must meet" criteria: not splitting the arsenic load reporting to Great Slave Lake into different areas (e.g., the mouth of Baker Creek and near the Yellowknife River); not contaminating areas of cultural/recreational value; and avoiding open pits. More explicitly:

- **Water Quality:**
  - *Outlet to Yellowknife Bay*: the diversion of Baker Creek must drain directly to Yellowknife Bay to limit the geographic extent of potential negative changes to water quality. This excluded alternatives draining to the Yellowknife River and to Great Slave Lake downstream of Yellowknife.
  - The diversion must not cause negative changes in water quality in:
    - a) waterbodies with high cultural/recreational value as identified by the local community (e.g., Yellowknife River including Yellowknife Bay at the mouth of Yellowknife River; Long Lake); or
    - b) areas presently unaffected by elevated arsenic concentrations.
- **Mine Pits:** the diversion of the Baker Creek channel must not be routed directly over mine pits, thereby minimizing the likelihood of conveyance to the arsenic chambers, stopes and underground workings. This criterion was not related to short duration flood discharges, but rather to long-duration, lower magnitude flows, with the potential to cause continuous seepage from the Baker Creek channel to the underground mine at a low rate. Seepage inflows during short duration extreme flood events that spill out of the Baker Creek channel

were assumed to be mitigated by open pit filling, limiting seepage rates to those able to be accommodated by the mine water management system.

Alternatives that did not meet these criteria were eliminated; those that met the above criteria were carried forward into the detailed evaluation process.

6.1.3 Eliminated Alternatives

Based on screening (i.e., "must meet") criteria defined in Section 6.1.2, diversion alternatives were eliminated as summarized in Table 3 and discussed in the following text.

Table 3: Baker Creek Diversion Alternatives Failing to Meet Screening Criteria

Sector	ID	Diversion Name	Screening ("Must Meet") Criteria		
			Outlet to Yellowknife Bay	Mine Pits	Water Quality
Mine Site	1	Original		×	
	2	1954		×	
	4	PDR Reach 3 - Option A			
	6	PDR Reach 3 - Option C			
Northern Route	7	6-0-8 (Flood Conveyance)			×
	8	6-4-8 (Fish Friendly)			×
	12	David Lake - Gold Lake - One Arm Lake	×		
	13	Walsh Lake	×		
	14	Stantec (2014a)			×
Upper Martin Lake Route	15	Channel Design 1	×		
	18	Landing Lake to Walsh Lake	×		
Southern Route	19	Long Lake to Jackfish Lake - North Route			×
	21	Handle Lake - North Route			
Western Route	23	Western Route	×		
Mackenzie River	24	Mackenzie River Pipeline	×		

Note: × = The diversion alternative does not meet the screening criterion and is screened out.

- Original and 1954: diversion ID 1 and diversion ID 2 flows would be routed on top of the mine pits.
- Northern Route 6-0-8 (Flood Conveyance) and 6-4-8 (Fish Friendly): diversion ID 7 and ID 8, parameter concentrations were predicted (Golder 2015) to increase in Shot Creek, and in the receiving environment, including the area at the mouth of the Yellowknife River and the north portion of Yellowknife Bay, which was of concern to stakeholders at SDE (SRK 2016b).
- David Lake - Gold Lake - One Arm Lake: diversion ID 12 would drain directly to the Yellowknife River.
- Walsh Lake: diversion ID 13 would drain directly to the Yellowknife River.
- Stantec: diversion ID 14, parameter concentrations were predicted (Golder 2015) to increase in Shot Creek, and in the receiving environment, including the area at the mouth of the Yellowknife River and the north portion of Yellowknife Bay, which was of concern to the Yellowknives Dene First Nation and other stakeholders.
- Upper Martin Lake Route diversion alternatives: diversion IDs 15, 16, 17 and 18 would drain directly to the Yellowknife River.

- Long Lake to Jackfish Lake - Northern Route: diversion ID 19, water quality in Long Lake could be negatively affected, a waterbody with cultural/recreational value.
- Western Route: diversion ID 23 would bypass the Yellowknife Bay watershed, thereby entering a new watershed.
- Mackenzie River Pipeline: diversion ID 24 would bypass the Yellowknife Bay watershed, thereby entering a new watershed.

6.1.4 Candidate Alternatives for Detailed Evaluation

Based on the results of this screening assessment, three diversion alternatives were carried forward into the detailed evaluation process, including Alternatives 4, 6, and 21, as shown in Table 4.

Table 4: Carried Forward Baker Creek Diversion Alternatives

Sector	ID	Diversion Name	Reference Document	Length (km)
Mine Site	4	PDR Reach 3 - Option A	PDR	0.81
	6	PDR Reach 3 - Option C	PDR	1.05
Southern Route	21	Handle Lake - North Route	Validation of Northern Route	3.35

Note: Lengths do not consider conveyance through existing waterbodies.

6.2 Scoring System

A general scoring system was initially developed and refined based on input from stakeholders provided during the MAA Evaluation Workshop discussed in Section 7.1. The refined system comprised three weightings and five ratings as shown in Table 5.

Table 5: MAA Scoring System

Description	Value	Rationale
Weighting		
Low Priority	0.5	Assigned to a criterion with a lower importance (or low priority) to the GMRP. This would typically include a “nice to have” criterion but not one that is necessarily required.
Required	1.0	Assigned to a criterion required for the GMRP
High Priority	2.0	Assigned to a criterion with a higher importance (or high priority) to the GMRP; not just required but absolutely essential.
Rating		
Very Bad Performance	0.0	Assigned to a diversion alternative with very bad performance under the considered criterion
Bad Performance	2.5	Assigned to a diversion alternative with bad performance under the considered criterion
Neutral Performance	5.0	Assigned to a diversion alternative with neutral performance under the considered criterion
Good Performance	7.5	Assigned to a diversion alternative with high performance under the considered criterion
Very Good Performance	10.0	Assigned to a diversion alternative with very high performance under the considered criterion

The weightings and ratings presented in Table 5 were used as guidance for participants in the MAA. During the MAA Evaluation Workshop (Section 7.1) these were used to ensure that criteria were evaluated relative to each other to provide internal consistency to the MAA. A sensitivity analysis (Section 7.3) was performed after the evaluation to determine whether these weightings influenced the MAA results.

6.3 Categories and Criteria

6.3.1 Categories

Three categories (i.e., accounts), were identified, based on broad level considerations of the GMRP:

- Environmental (50%): this category was intended to document environmental impacts of each diversion alternative relative to existing conditions.
- Feasibility (20%): this category was intended to document the feasibility of each diversion alternative from construction, economic, and land acquisition perspectives.
- Society (30%): this category was intended to document impacts on community relative to existing conditions.

Weightings of these categories were determined by consensus of participants in the MAA Evaluation Workshop, A sensitivity analysis (Section 7.3) was performed after the evaluation to determine whether these weightings influenced the MAA results.

6.3.2 Criteria

Criteria (i.e., sub-accounts), were developed for each category defined in Section 6.3.1, and compiled into Table 6, with a rationale and/or definition for each criterion. The following assumptions were considered:

- The risk of flooding the underground mine including arsenic chambers, associated with an on-site diversion alternative, was assumed to be mitigated to address Measure 11. Filling of open pits is presently being investigated as a mitigation alternative.
- Contaminated sediments, including any tailings, in Baker Creek were assumed to be capped or removed from Reach 0 to Reach 6.
- Fish passage and presence were assumed to be addressed at a later phase of the GMRP, in consultation with Fisheries and Oceans Canada.

Table 6: Definition and/or Rationale of Criteria

Category	Weight[(a)]	Criterion	Sub-Criterion	Weight[a]	Definition and/or Rationale
Environmental	50%	Incremental Disturbance	Footprint Area of Diversion Within Undisturbed Land	Required (1.0)	This criterion considered the length and location of the diversion alternative, channel design, and topography, which may impact undisturbed land. Potential environmental effects were defined as proportional to the footprint area of the diversion alternative within the undisturbed land.
		Risk of Underground Flooding	Risk of Underground Flooding	High Priority (2.0)	This criterion considered the location of the diversion alternative relative to the location of the pits, underground chambers, and stopes. While it was assumed **that flood risk on site would be fully mitigated, (e.g., the pits would be filled), the potential for underground flooding is proportional to the proximity of the diversion alternative to the pits, underground chambers, and stopes. Potential environmental effects were defined as proportional to the risk of underground flooding.
		Water Quality	Changes to Water Quality to/from Nearby Waterbodies	High Priority (2.0)	This criterion considered the routing of the diversion alternative, where the creek could receive inflow from nearby waterbodies with elevated parameter concentrations, resulting in potential negative changes to water quality in the creek and downstream waterbodies, increasing potential exposure to arsenic. Potential environmental effects were defined to be proportional to adverse changes on water quality.
			Changes to Water Quality from Other Sources	Required (1.0)	This criterion considered the routing of the diversion alternative, where the creek could receive inflow from sources other than waterbodies, resulting in potential negative changes to water quality in the creek and downstream waterbodies, increasing potential exposure to arsenic. Potential environmental effects were defined to be proportional to adverse changes on water quality.
Feasibility	20%	Construction Complexity	Construction Complexity	Low Priority (0.5)	This criterion considered the routing, length, channel design, and topography along a diversion alternative, and access requirements. Feasibility was defined as inversely proportional to construction complexity.
		Land Ownership	Land Ownership and/or Land Rights	Required (1.0)	This criterion considered the location of the diversion alternative, whether on or off site. Off-site diversion alternatives require land acquisition. Feasibility was defined as inversely proportional to land acquisition requirements.[b]
		Cost	Implementation Cost	Required (1.0)	The criterion considered the cost of engineering, construction, and management, to implement a diversion alternative. Feasibility was defined as inversely proportional to implementation costs.
Society	30%	Public Acceptance	Traditional Land Use	High Priority (2.0)	The criterion considered potential effects to, or implications on, areas with traditional land use values (e.g., existence of the natural habitat and ecosystem). Potential effects on society were defined as proportional to impacts and implications on traditional land use.
			Other Land Use	Required (1.0)	The criterion considered potential effects to, or implications on, areas with direct land use values (e.g., recreation, tourism, non-traditional hunting and fishing) and archaeological and/or heritage sites. Potential effects on society were defined as proportional to impacts and implications on recreational land use.
			Perception	High Priority (2.0)	This criterion considered public feedback on the alignment alternative. Potential effects on society were defined as proportional to negative perception.
			Risk of human contact	High Priority (2.0)	This criterion considered the potential for human access to contaminated water, contaminated sediment, and contaminated fish. Potential effects on society were defined as proportional to risk of human contact.

(a) Weights were assigned during the MAA Evaluation Workshop as discussed in Section 7.1.
(b) Some off-lease land areas may be subject to the Akaitcho Interim Land Withdrawal (see City of Yellowknife Bylaw No. 4656) which includes areas near the mouth of the Yellowknife River, west of Yellowknife Airport and the City of Yellowknife, and north of Yellowknife in the vicinity of Jackfish Lake and Fault Lake. This may affect the availability of those lands for a Baker Creek diversion.

7.0 MULTIPLE ACCOUNT ANALYSIS MATRIX

7.1 MAA Evaluation Workshop

The MAA matrix was developed based on information presented in Section 6.0. The MAA Evaluation Workshop was hosted by Golder on 17 November 2016 at Canada Place in Edmonton, Alberta, and was attended by representatives of INAC, PSPC, and AECOM (Table 2). The evaluation considered previously produced technical documents, and public and aboriginal consultation documents as identified in previous sections of this report. When insufficient information was available to support the evaluation under certain criteria, the evaluation proceeded using assumptions to be confirmed following the workshop. The workshop resulted in the refinement of the scoring system into a more intuitive system, and a preliminary evaluation.

Workshop participants reviewed the alignment compilation (Section 4.0) and screening process (Section 6.0), prior to participating in the detail evaluation process, which included:

- Reviewing the scoring system (Section 6.2);
- Reviewing and finalizing the evaluation categories, criteria, sub-criteria and rationales (Section 6.3);
- Assigning weights to each category, criterion and sub-criterion using the scoring system (Section 7.2);
- Rating each alternative according to each criterion and sub-criterion (Section 7.2); and
- Using the weighted ratings to identify a preference of alternatives (Section 7.2).

Additional investigations were required to support assumptions and corresponding conclusions from the workshops, and are documented in Appendix B. Evaluation results were subsequently confirmed or refined by technical experts, including members of Golder's fish and fish habitat, water quality, construction, and traditional studies facilitator team, who did not attend the meetings or workshops.

7.2 Results

The MAA evaluation matrix, with the screened diversion alternatives, evaluation categories and criteria and corresponding weightings and ratings based on feedback from the MAA Evaluation Workshop and additional expert reviews, is presented in Figure 11.

Results of the evaluation process are summarized in numerical format in Figure 12, graphical format by criterion in Figure 13, and graphical format by category in Figure 14. Figure 11 through Figure 14 are provided at the end of Section 7.0. Conclusions, recommendations and next steps are provided in Section 7.3.

7.2.1 Environment

The environment category was assigned a weight of 50%.

7.2.1.1 Incremental Disturbance

The importance of the "incremental disturbance" criterion to the GMRP was evaluated as Required and was assigned a weighting of 1.0.

The performance of each diversion alternative was evaluated under the "incremental disturbance" criterion, based on consideration of the size of the expected footprint area of each diversion alternative within the undisturbed land, as follows:

- The footprint of the PDR Reach 3 - Option A diversion alternative was expected to be approximately 2.52 hectares (ha), within existing the existing disturbed area. Given that this alternative is not expected to disturb additional land, but would affect previously disturbed areas that have had time to stabilize and revegetate in some areas, a rating of Neutral was assigned, with a corresponding numerical value of 5.0.
- The footprint of the PDR Reach 3 - Option C diversion alternative was expected to be approximately 5.01 ha primarily within existing disturbances, with a minor portion (i.e., 0.4 ha) outside of the current mine lease boundary. Incremental disturbances, although minor, are therefore expected, and this diversion alternative was ranked lower than the PDR Reach 3 – Option A diversion alternative. A rating of Bad Performance was assigned, with a corresponding numerical value of 2.5. Note that this effect on off-lease lands could possibly be eliminated during detailed design.
- The footprint of the Handle Lake - North Route diversion alternative was expected to be approximately 15.1 ha, completely outside of existing disturbances. This diversion alternative was therefore ranked as the worst diversion alternative, and assigned a rating of Very Bad Performance, with a corresponding numerical value of 0.0.

Quantitative information and the fully developed Handle Lake - North Route diversion alternative are presented in Section B1.0.

7.2.1.2 Risk of Underground Flooding

The importance of the "risk of underground flooding" criterion to the GMRP was evaluated as High Priority and was assigned a weighting of 2.0, in consideration of the high priority placed on mitigating the risk of underground flooding by Measure 11.

The performance of each diversion alternative was evaluated qualitatively under this criterion based on consideration of the expected proximity of each diversion alternative to the pits, underground chambers, and stopes, and assumptions provided in Section 6.3.2.

Given that mine pits were assumed to be filled, all diversion alternatives were expected to fully mitigate the risk of uncontrolled spills to the underground mine; however, the Handle Lake - North Route diversion alternative was considered to be more effective at decreasing the risk of flooding, because flood flows would be conveyed far away from the historical mining area, and was rated as Very Good Performance with a corresponding numerical value of 10.0. The two on-site diversion alternatives were rated as Good Performance, with a corresponding value of 7.5, in recognition of the mitigation provided by filling the pits.

It is important to note that the risk of underground flooding was also expected to be substantially mitigated when the arsenic chamber freeze program is fully implemented during the mine closure. Prior to that time, underground flooding would have the potential to mobilize arsenic trioxide stored in the underground chambers. After the freeze program is implemented, large-scale uncontrolled underground flooding would potentially only cause the release of contaminated mine water.

7.2.1.3 Changes to Water Quality to/from Nearby Waterbodies

The importance of "water quality changes to/from nearby waterbodies" criterion to the GMRP was evaluated as High Priority and was assigned a weighting of 2.0, in consideration of the high priority placed on mitigating adverse effects on water quality by Measure 11.

For the water quality evaluation, ratings were assigned based on expected changes to overall water quality in Baker Creek and Yellowknife Bay once diversion has occurred. Arsenic concentrations from the upper reaches of Baker Creek (Reaches 7 to 11), waterbodies upstream of Baker Creek (Lower Martin, Unnamed 1 and 2, and Pocket lakes) or draining to Baker Creek (Gar, Trapper), and nearby waterbodies (Long, Fox, and Handle lakes) between 2011 and 2016 are presented in Figure 10 and Appendix B, Table B-2, with lake locations shown on Figure 5. These data represent existing conditions in the area, before diversion, and were used to identify the main sources of arsenic to Baker Creek and Yellowknife Bay, such that changes to water quality in various alignments could be reviewed. These estimates exclude the influence of treated effluent, which in the future would no longer be discharged to Baker Creek, but directly to Yellowknife Bay from a new effluent treatment plant.

Arsenic concentrations in Baker Creek were expected to be influenced by loadings originating in upstream areas. Baker Creek was understood to flow from Lower Martin Lake through reaches above the mine, join with combined outflow from Gar and Trapper lakes via Trapper Creek, and then travel through Baker Creek to Yellowknife Bay. At the outlet of Lower Martin Lake, the average total arsenic concentration was 52 µg/L between 2011 and 2015, and was 41 µg/L at the outlet of Baker Creek Reaches 7 to 11 between 2011 and 2016 (Figure 10; Appendix B, Table B-2). Average arsenic concentrations in two tributaries to Reaches 7 to 11 were high, at 1,560 µg/L in Pocket Lake and 172 µg/L in Unnamed Lakes 1 and 2 (Figure 10); however, low outflow volumes from these lakes mean that they may not substantially influencing the arsenic concentrations in the upper reaches of Baker Creek.

For PDR Reach 3 - Option A and Option C diversion alternatives, minor changes to water quality in Baker Creek were anticipated as the overall conveyance of loadings is unchanged (i.e., water from upstream would still be conveyed through the Giant Mine lease area to Yellowknife Bay via Baker Creek. These diversion alternatives would not change water quality loadings overall and as such, PDR Reach 3 - Option A and Option C diversion alternatives were assigned ratings of Neutral Performance, with corresponding values of 5.0.

For the Handle Lake - North Route diversion alternative, flows from Lower Martin Lake to Baker Creek would be diverted south through a constructed channel to bypass, but be in close proximity to, Handle Lake and the City of Yellowknife landfill before entering Yellowknife Bay. Arsenic concentrations in Handle Lake (mean total arsenic of 187 µg/L from 2014 to 2016) and Fox Lake (detectable total arsenic of 202 µg/L in 2015); are elevated (Figure 10; Appendix B, Table B-2); a low volume of outflow from Fox and Handle Lakes already enters Baker Creek at Reach 0. After diversion, upstream loadings to Baker Creek from overland flow to Reaches 7 to 11 and from Gar and Trapper lakes would remain. However, overall loadings to Baker Creek from upstream areas would be reduced as outflow from Lower Martin Lake would be diverted through the Handle Lake channel. Therefore, in this off-site diversion alternative, the loadings to Yellowknife Bay would be split between the vestigial Baker Creek and the constructed channel near Handle Lake.

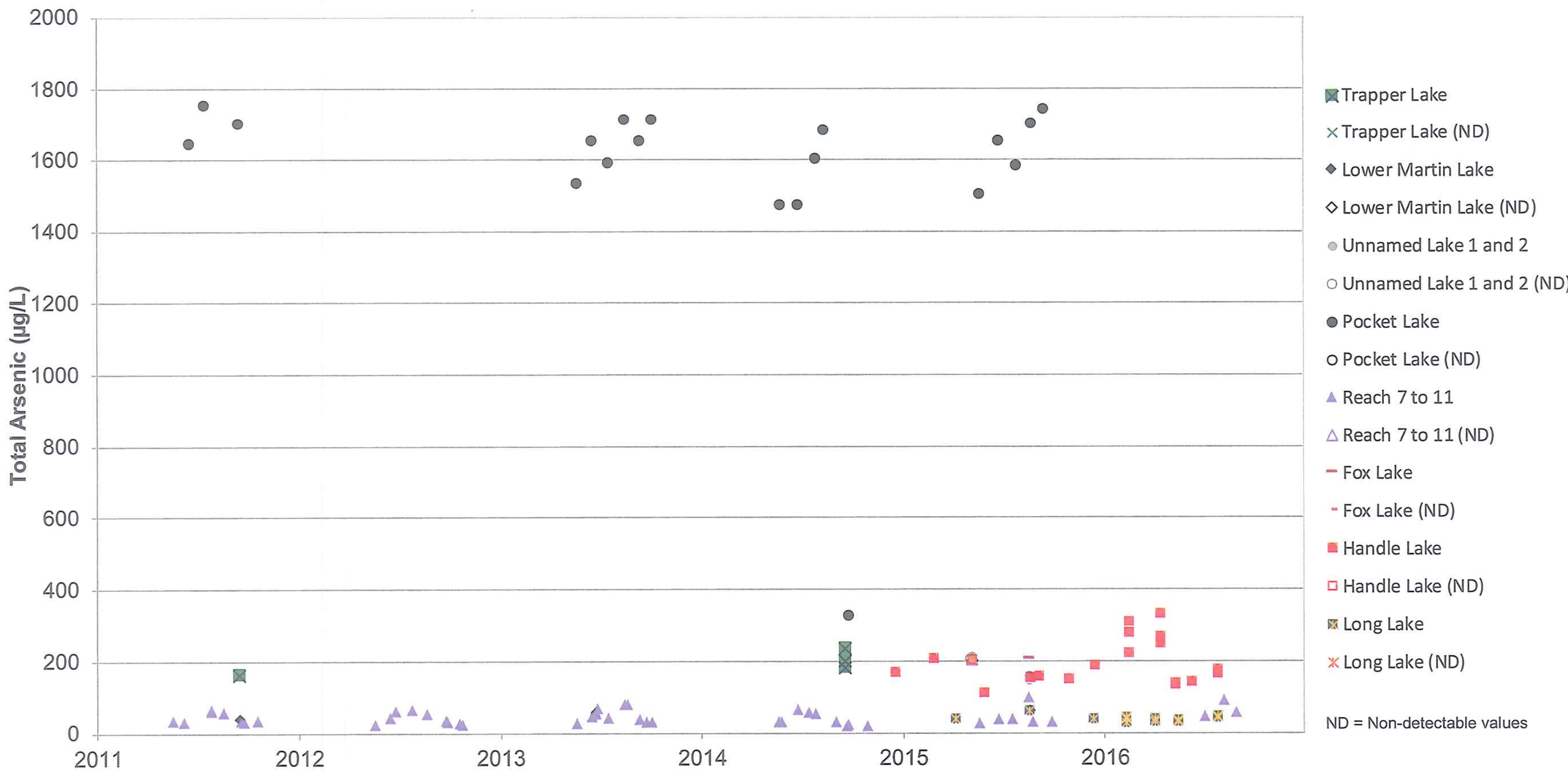

Figure 10: Measured Total Arsenic Concentrations in Waterbodies Upstream and Nearby Baker Creek, and in the Upper Reaches of Baker Creek

At best, the total loading to Yellowknife Bay through the off-site Baker Creek diversion and on-site vestigial Baker Creek would be approximately equivalent to the on-site alternative (i.e., no substantive change to existing water quality), with an uncertainty that loading from overland runoff loading to the constructed channel has not been quantified. However, given that the total load from the two was estimated to be approximately similar to an on-site alternative, and enter Yellowknife Bay at a similar location, the Handle Lake - North Route diversion was given a Neutral rating of 5.0. It should be noted that a rating of Bad Performance was assigned during the MAA Evaluation Workshop, and was subsequently increased to Neutral based on this discussion and additional input from GMRP water quality experts.

The fully developed Handle Lake - North Route diversion alternative is presented in Appendix B, based on input from stakeholders during the MAA Evaluation Workshop.

These ratings did not consider potential changes to runoff water quality from the remediated mine site, which were anticipated to have an equivalent effect on total loadings to receiving waterbodies.

7.2.1.4 Changes to Water Quality from Other Sources

The importance of the “adverse effects from other sources” criterion to the GMRP was evaluated as Required and was assigned a weighting of 1.0.

The performance of each diversion alternative was evaluated qualitatively under this criterion based on consideration of the routing of each diversion alternative, where the creek may receive inflow from sources other than waterbodies, increasing potential exposure to arsenic.

This criterion was considered primarily due to the proximity of the conceptual Handle Lake - North Route diversion alternative to the City of Yellowknife landfill and the landfill lease line, which are potential sources of contaminants. Potential contamination can be fully mitigated by refinement of the alignment away from the landfill during future design stages assuming a final off-site alignment. Thus, potential changes on water quality from sources other than waterbodies were not expected for any of the diversion alternatives, and a rating of Neutral, with a corresponding value of 5.0, was assigned to all three diversion alternatives.

The fully developed Handle Lake - North Route diversion alternative is presented in Appendix B, based on input from stakeholders during the MAA Evaluation Workshop.

7.2.2 Feasibility

The feasibility category was assigned a weight of 20%.

7.2.2.1 Construction Complexity

The importance of the “construction complexity” criterion to the GMRP was evaluated as Low Priority and was assigned a weighting of 0.5.

The performance of each diversion alternative was evaluated qualitatively under this criterion based on consideration of access through undisturbed land, and excavation volume requirements[2].

[2] Note that minimizing excavation volumes was assessed as favorable in the MAA; overall GMRP material balance requirements may govern the ultimate preference between Reach 3 – Option A and Reach 3 – Option C. These alternatives are also being examined in current Flood Hazard Assessment work.

As provided in Appendix B, the PDR Reach 3 - Option A diversion alternative was expected to require the least amount of excavation given the existing topography, and would be accessed through currently disturbed land. The PDR Reach 3 - Option C diversion alternative would require substantial excavation through bedrock, and would be accessed through existing disturbed land where possible. The Handle Lake - North Route diversion alternative would require new access roads to be pioneered through undisturbed land, and would also include a crossing of the re-aligned Ingraham Trail (Highway 4), requiring a bridge or bridge-sized culvert. Excavation quantities of the Handle Lake - North Route diversion alternative are expected to be less than those for the PDR Reach 3 - Option C diversion alternative.

Thus, the PDR Reach 3 - Option A diversion alternative was rated as Neutral, with a corresponding value of 5.0. The PDR Reach 3 - Option C and Handle Lake - North Route diversion alternative was rated as Bad Performance, with a corresponding value of 2.5, given the substantial volume of excavation through bedrock required. The Handle Lake - North Route was rated as Bad Performance, with a corresponding value of 2.5, based on its access requirements through undisturbed land, and the need for a watercourse crossing.

It should be noted that the PDR Reach 3 - Option C diversion alternative was rated as Neutral following the MAA Evaluation Workshop, based on consideration of access only, and the rating was subsequently decreased in consideration of excavation requirements, as discussed above. The rating could be increased should the GMRP material balance require additional material, in particular quarried rock, to provide for closure.

7.2.2.2 Land Ownership

The importance of the "land ownership" criterion to the GMRP was evaluated as Required and was assigned a weighting of 1.0.

The performance of each diversion alternative was evaluated qualitatively under this criterion based on the need for land acquisition.

Concern was noted during the MAA Evaluation Workshop regarding potential inability to obtain land rights and permits required for the off-site alignment; this would depend to a large extent on the City of Yellowknife. See also the note attached to Table 6 regarding the Akaitcho Interim Land Withdrawal. Both of the on-site diversion alternatives were rated as Very Good, with a corresponding value of 10.0, on the basis of not requiring any additional lands, and the Handle Lake - North Route diversion alternative was rated as Bad Performance, with a corresponding value of 2.5, based on uncertainty in being able to obtain land rights and permits.

7.2.2.3 Implementation Cost

The importance of the "implementation cost" criterion to the GMRP was evaluated as Required and was assigned a weighting of 1.0.

The performance of each diversion alternative was evaluated quantitatively under this criterion based on consideration of potential costs of engineering, construction, and management.

Cost estimates were developed for each diversion alternatives as presented in Appendix B. Based on this exercise, the PDR Reach 3 - Option A diversion alternative was expected to be substantially less expensive than the other two diversion alternatives, driven by its lower excavation volume requirements. Comparable costs were expected for the PDR Reach 3 - Option C and Handle Lake - North Route diversion alternatives without consideration of access requirements. The Handle Lake - North Route diversion alternative was therefore expected to be more expensive than the PDR Reach 3 - Option C diversion alternative from additional costs related to the construction of access roads through undisturbed land.

Thus, the PDR Reach 3 - Option A diversion alternatives was rated as Very Good, with a corresponding value of 10.0. The PDR Reach 3 - Option C diversion alternative was rated as Bad, with a corresponding value of 2.5. The Handle Lake - North Route diversion alternative was rated as Very Bad, with a corresponding value of 0.0.

7.2.3 Society

The society category was assigned a weight of 30%.

As outlined in Section 1.3.2, the evaluation of criteria for Society was informed by the results of a SDE Options Evaluation Workshop held in February 2016, with interested Indigenous groups and other stakeholders, as part of a larger engagement process initiated in early 2015 related to plans for remediating the surface of Giant Mine (SRK 2016b). Participants of this workshop are referred hereinafter as "SDE Workshop Participants". The objectives of the engagement process were to provide the opportunity for stakeholder input to the surface remediation plan, and to ensure that the GMRP understands the perspectives and preferences of various parties.

7.2.3.1 Traditional Land Use

The importance of the "traditional land use" criterion to the GMRP was evaluated as High Priority and was assigned a weighting of 2.0. The performance of each diversion alternative was evaluated qualitatively under this criterion based on potential impacts to, or implications on, areas with traditional land use values (e.g., hunting, fishing, berry picking).

As outlined in Section 1, SDE Workshop Participants were largely opposed to diverting Baker Creek off site, based on concerns related to potential adverse effects on water, land, wildlife and fish, which could also affect traditional use of the land and resources. Concerns were mostly related to the potential contamination of other surface waterbodies along the diversion route and subsequent effects to fish that could be introduced to those new areas. Having two contaminated streams entering Yellowknife Bay was viewed as negative, because it was perceived as increasing the risk of exposure to fish. Continued public access to disturbed areas could potentially affect traditional use by exposing harvesters to contaminated water and fish that are relied on as an important component of their traditional diet.

SDE Workshop Participants agreed that an off-site alignment increased risk to wildlife, through potential contamination to land and wildlife habitat adjacent to the diversion route, and the accumulation of contaminants in the wildlife food chain leading to potential increased risk of exposure to traditional harvesters. Participants strongly disagreed with the premise that this option would contribute to the objective of "repairing the land and water", due to the increased footprint of disturbance from the new channel construction, and the increased risk of contaminants into new areas. Participants agreed that an off-site alignment would result in limited opportunities for future use of the land, including traditional land use, in part from increased perceptions of harm to the land and resources. Based on the potential adverse effects of diverting Baker Creek off-site to traditional land use, the Handle Lake - North Route diversion alternative was rated overall as Very Bad, with a corresponding value of 0.0.

Overall, feedback provided by stakeholder groups indicated a strong preference towards keeping the Baker Creek alignment on site rather than off site, although both benefits and risks of an on-site diversion alternative were acknowledged. Concerns were expressed related to the potential for continued risk of contaminant exposure to fish in Baker Creek even with remediation, and to human health from fish consumption. In contrast, some SDE

Workshop Participants noted that the removal of contaminated sediments in Baker Creek mitigated this potential risk. Similarly, there were mixed opinions related to continued risk of exposure to wildlife, such as muskrats and waterfowl, following remediation, because not all contaminated soils would be removed (i.e., some physically undisturbed but contaminated areas would remain). There was general agreement that an on-site alignment was a preferred alternative for "repairing the land and water" because of the beneficial effect of remediation activities, containment of blasting activities and quarried materials on site, and the limited amount of land disturbance outside of the Giant Mine lease area. Most participants agreed that an on-site alternative allowed for a greater range of potential future land uses, including traditional land use, because of remediation efforts and access to the area outside the mine site would remain the same for both wildlife and people.

Based on the perceived benefits and risks of the Baker Creek on-site diversion alternatives, the PDR Reach 3 - Option C diversion alternative was rated as Bad Performance, with a corresponding value of 2.5, primarily because a small portion (i.e., 0.4 ha) of undisturbed land would be disturbed outside the current Giant Mine lease boundary as stated in Section 7.2.1.1, resulting in potential adverse effects to traditional land use and resources. Note that this effect on off-lease lands could possibly be eliminated during detailed design. The PDR Reach 3 - Option A diversion alternative was rated as Neutral, with a corresponding value of 5.0, because it was not expected to disturb additional land outside the Giant Mine lease boundary, and therefore has the least potential for adverse effects on traditional land use (Section 7.2.1).

7.2.3.2 Other Land Use

The importance of the "other land use" criterion to the GMRP was evaluated as Required and was assigned a weighting of 1.0. The performance of each diversion alternative was evaluated qualitatively under this criterion based on potential impacts to, or implications on, areas with direct land use values (e.g., recreation, tourism, non-aboriginal hunting and fishing) and archaeological and/or heritage sites.

As previously described in Section 7.2.3.1, SDE Workshop Participants were largely opposed to diverting Baker Creek off site and expressed several concerns, primarily related to two contaminated streams entering Yellowknife Bay, the contamination of other surface waterbodies along the diversion route, and fish that could be introduced to those new areas. The existence of two contaminated streams entering Yellowknife Bay was viewed as negative since it was perceived as increasing the risk of exposure to fish, and therefore to recreational users and fishers who continue to access these disturbed areas. Concerns were expressed regarding the potential contamination to land and wildlife habitat along the diversion route, which would lead to adverse effects to hunters using the wider area. Participants strongly disagreed with the premise that an off-site alignment would contribute to "repairing the land and water", due to the increased footprint of disturbance from new channel construction, and the increased risk of contaminants into new areas. The diversion of Baker Creek off site would lead to limited opportunities for future use of the land, because the incremental off-site disturbance was considered most likely to interfere with public use and recreation and more likely to require historical resources work to support the planning and design. Given these potential adverse effects to other land use, the Handle Lake - North Route diversion alternative was rated as Very Bad Performance, with a corresponding value of 0.0.

There was a strong preference by stakeholder groups towards keeping the Baker Creek alignment on site rather than off site. Despite the mixed results pertaining to the potential adverse effects of contaminant exposure to wildlife and fish following remediation, the majority of participants agreed that there would be fewer adverse effects to the land and water in general with an on-site alignment compared to an off-site alignment. This was in part due to the removal of a large portion of contaminated soils and sediment in Baker Creek, the relocation of tailings leading to a smaller footprint, and maintaining existing levels of public access, which would ultimately facilitate more opportunities for future land use in the wider area, including recreational activities and hunting.

Although Baker Creek would remain on site with the PDR Reach 3 - Option C diversion alternative, a limited amount (i.e., 0.4 ha) of undisturbed land would be disturbed outside the current Giant Mine lease boundary, therefore having some impact to non-traditional land use such as fishing and recreational activities. As a result, the PDR Reach 3 - Option C diversion alternative was rated as Bad Performance, with a corresponding value of 2.5. Note that this effect on off-lease lands could possibly be eliminated during detailed design. Given that PDR Reach 3 - Option A would result in the least disturbance of presently undisturbed land, thus having the least effect on non-traditional land use out of all diversion alternatives, the route was rated as Neutral, with a corresponding value of 5.0.

7.2.3.3 Perception

The importance of the "perception" criterion to the GMRP was evaluated as High Priority and was assigned a weighting of 2.0. The performance of each diversion alternative was evaluated qualitatively under this criterion based on public feedback on the diversion alternatives from the SDE (SRK 2016b) process.

SDE Workshop Participants held greater perceptions of harm for the off-site diversion alternative compared to the on-site alignment. These negative perceptions were largely related to the increased risk of exposure pathways to fish and wildlife due to having two contaminated streams entering Yellowknife Bay, the potential contamination of other surface waterbodies along the diversion route, and to land adjacent to the diversion route. An off-site alignment could potentially lead to increased human contact with contaminated water, fish, and wildlife. SDE Workshop Participants strongly agreed that the diversion of Baker Creek off site would lead to limited opportunities for future use of the land due to the increased footprint of disturbance from the new channel construction and contamination, and from increased perceptions of harm to the land and general lack of confidence by the public in use of the area. Conversely, the isolated location of the diverted channel in the forest may attract people to the Creek for fishing or other recreational activities, and give the public a false sense of safety, when the risk of contamination may still exist.

In addition, the majority of SDE Workshop Participants indicated that they believed that diverting Baker Creek off site would only have a minor reduction in flooding risk but no gain in environmental performance, therefore not justifying the cost of the diversion. Given the strong resistance and overall negative perception by all stakeholder groups on diverting Baker Creek off site, the Handle Lake - North Route diversion alternative was rated Very Bad Performance, with a corresponding value of 0.0.

The majority of SDE Workshop Participants held more positive perceptions for keeping Baker Creek on site and believed it would be more cost-effective than diverting off site (SRK 2016b). There were mixed results among participants concerning potential adverse effects to fish and wildlife, based on the perceived benefits and risks of site remediation. Although some participants perceived that remediation efforts would mitigate potential adverse effects, thereby restoring public confidence in use of the area, uncertainty still existed regarding the exposure risk to fish and whether wildlife would be attracted to re-vegetated areas where contaminants persisted. It was acknowledged that an on-site alignment was the preferred alternative in terms of meeting the objective of "repairing the land and water", even though some level of uncertainty remained. In addition, an on-site alternative was preferred because it allowed for a range of potential future land uses, since it limited the amount of disturbance to undisturbed areas, thereby decreasing perceptions of harm.

Given the public feedback on keeping Baker Creek on site, the PDR Reach 3 - Option A and PDR Reach 3 - Option C diversion alternatives were rated Neutral, with a corresponding value of 5.0. These route alternatives were not given a higher rating than Neutral, as the SDE Workshop Participants did not reach consensus on issues described above, including future land use, fish access to Baker Creek, tailings ponds and backfilled pits, and site remediation (SRK 2016b).

7.2.3.4 Risk of Human Contact

The importance of the "risk of human contact" criterion to the GMRP was evaluated as High Priority and was assigned a weighting of 2.0. The performance of each diversion alternative was evaluated qualitatively under this criterion based on the likelihood of human access to contaminated water, contaminated sediment, and potentially contaminated fish.

The PDR Reach 3 - Option A and PDR Reach 3 - Option C diversion alternatives would allow for continued access to Baker Creek at the Ingraham Trail crossing in Reach 7 and at the mouth prior to flowing into Yellowknife Bay, potentially affecting recreational users and those engaging in non-traditional fishing, as it could expose them to contaminated water, sediment, and potentially contaminated fish. Because an on-site alignment will provide continued public access to the area, the PDR Reach 3 - Option A and PDR Reach 3 - Option C diversion alternatives were rated as Bad Performance, with a corresponding value of 2.5.

The Handle Lake - North Route diversion alternative will still include a vestigial Baker Creek channel, that will be accessible at the Ingraham Trail in Reach 7 and at the mouth prior to flowing into Yellowknife Bay (as shown in Figure 9, with an additional access point to the diverted Creek at a new Ingraham Trail crossing and possibly near the mouth prior to flowing into Yellowknife Bay. SDE Workshop Participants expressed concern that the off-site diversion alternative could contaminate new areas and potentially introduce fish into these areas (SRK 2016b). Participants generally disagreed with the premise that this alternative would meet the objective of "keeping fish healthy for eating", because of concerns about the exposure to arsenic from fish coming from Baker Creek and the subsequent effect on human health from fish consumption. SDE Workshop Participants also expressed concerns about increased risk to wildlife, including potential contamination to land and wildlife habitat adjacent to the diversion route, and the accumulation of contaminants in the wildlife food chain leading to increased risk to human health. Given that the multiple access points increases the risk for human interaction with contaminated water, sediment, potentially contaminated fish, land and wildlife, the Handle Lake - North Route diversion alternative was rated Very Bad Performance, with a corresponding value of 0.0.

EVALUATION MATRIX

PDR REACH 3 - OPTION A DESCRIPTION:	East alternative of Reach 3
PDR REACH 3 - OPTION C DESCRIPTION:	West alternative of Reach 3
HANDLE LAKE - NORTH ROUTE DESCRIPTION:	Lower Martin Lake to Reach 0

ENVIRONMENT (Weight = 50%)		WEIGHT	PDR REACH 3 - OPTION A	PDR REACH 3 - OPTION C	HANDLE LAKE - NORTH ROUTE
Incremental Disturbance	Footprint Area of Diversion Within Undisturbed Land	Required (1.0)	Neutral Performance (5.0)	Bad Performance (2.5)	Very Bad Performance (0.0)
Risk of Underground Flooding	Risk of Underground Flooding	High Priority (2.0)	Good Performance (7.5)	Good Performance (7.5)	Very Good Performance (10.0)
Water Quality	Changes to Water Quality from Nearby Waterbodies and/or Runoff	High Priority (2.0)	Neutral Performance (5.0)	Neutral Performance (5.0)	Neutral Performance (5.0)*
	Changes to Water Quality from Other Sources	Required (1.0)	Neutral Performance (5.0)	Neutral Performance (5.0)	Neutral Performance (5.0)

*: This rating was increased from Bad Performance (2.5) adopted during the MAA Evaluation Workshop, following additional investigations, as described in Section 7.2.1.3.

FEASIBILITY (Weight = 20%)		WEIGHT	PDR REACH 3 - OPTION A	PDR REACH 3 - OPTION C	HANDLE LAKE - NORTH ROUTE
Construction Complexity	Construction Complexity	Low Priority (0.5)	Neutral Performance (5.0)	Bad Performance (2.5)*	Bad Performance (2.5)
Land Ownership	Land Ownership and/or Land Rights	Required (1.0)	Very Good Performance (10.0)	Very Good Performance (10.0)	Bad Performance (2.5)
Cost	Implementation Cost	Required (1.0)	Good Performance (7.5)	Bad Performance (2.5)	Very Bad Performance (0.0)

*: This rating was reduced from Neutral Performance (5.0) adopted during the MAA Evaluation Workshop, following additional investigations, as described in Section 7.2.2.1.

SOCIETY (Weight = 30%)		WEIGHT	PDR REACH 3 - OPTION A	PDR REACH 3 - OPTION C	HANDLE LAKE - NORTH ROUTE
Public Acceptance	Traditional Land Use	High Priority (2.0)	Neutral Performance (5.0)	Bad Performance (2.5)	Very Bad Performance (0.0)
	Other Land Use	Required (1.0)	Neutral Performance (5.0)	Bad Performance (2.5)	Very Bad Performance (0.0)
	Perception	High Priority (2.0)	Neutral Performance (5.0)	Neutral Performance (5.0)	Very Bad Performance (0.0)
	Risk of Human Contact	High Priority (2.0)	Bad Performance (2.5)	Bad Performance (2.5)	Very Bad Performance (0.0)

Figure 11: Evaluation Matrix

RESULTS:

WEIGHT	CATEGORY	PDR REACH 3 - OPTION A	PDR REACH 3 - OPTION C	HANDLE LAKE - NORTH ROUTE
50%	ENVIRONMENT	5.83	5.42	5.83
20%	FEASIBILITY	8.00	5.50	1.50
30%	SOCIETY	4.29	3.21	0.00
100%	Total	5.80	4.77	3.22

WEIGHT	CRITERIA / INDICATOR	PDR REACH 3 - OPTION A	PDR REACH 3 - OPTION C	HANDLE LAKE - NORTH ROUTE
1.0	Footprint Area of Diversion Within Undisturbed Land	5.00	2.50	0.00
2.0	Risk of Underground Flooding	7.50	7.50	10.00
2.0	Changes to Water Quality from Nearby Waterbodies	5.00	5.00	5.00
1.0	Changes to Water Quality from Other Sources	5.00	5.00	5.00
6.0	**Total**	**5.83**	**5.42**	**5.83**
0.5	Construction Complexity	5.00	2.50	2.50
1.0	Land Ownership and/or Land Rights	10.00	10.00	2.50
1.0	Implementation Cost	7.50	2.50	0.00
2.5	**Total**	**8.00**	**5.50**	**1.50**
2.0	Traditional Land Use	5.00	2.50	0.00
1.0	Other Land Use	5.00	2.50	0.00
2.0	Perception	5.00	5.00	0.00
2.0	Risk of Human Contact	2.50	2.50	0.00
7.0	**Total**	**4.29**	**3.21**	**0.00**
	Total	5.80	4.77	3.22

Figure 12: Results in Numerical Format

Figure 13: Results By Criterion

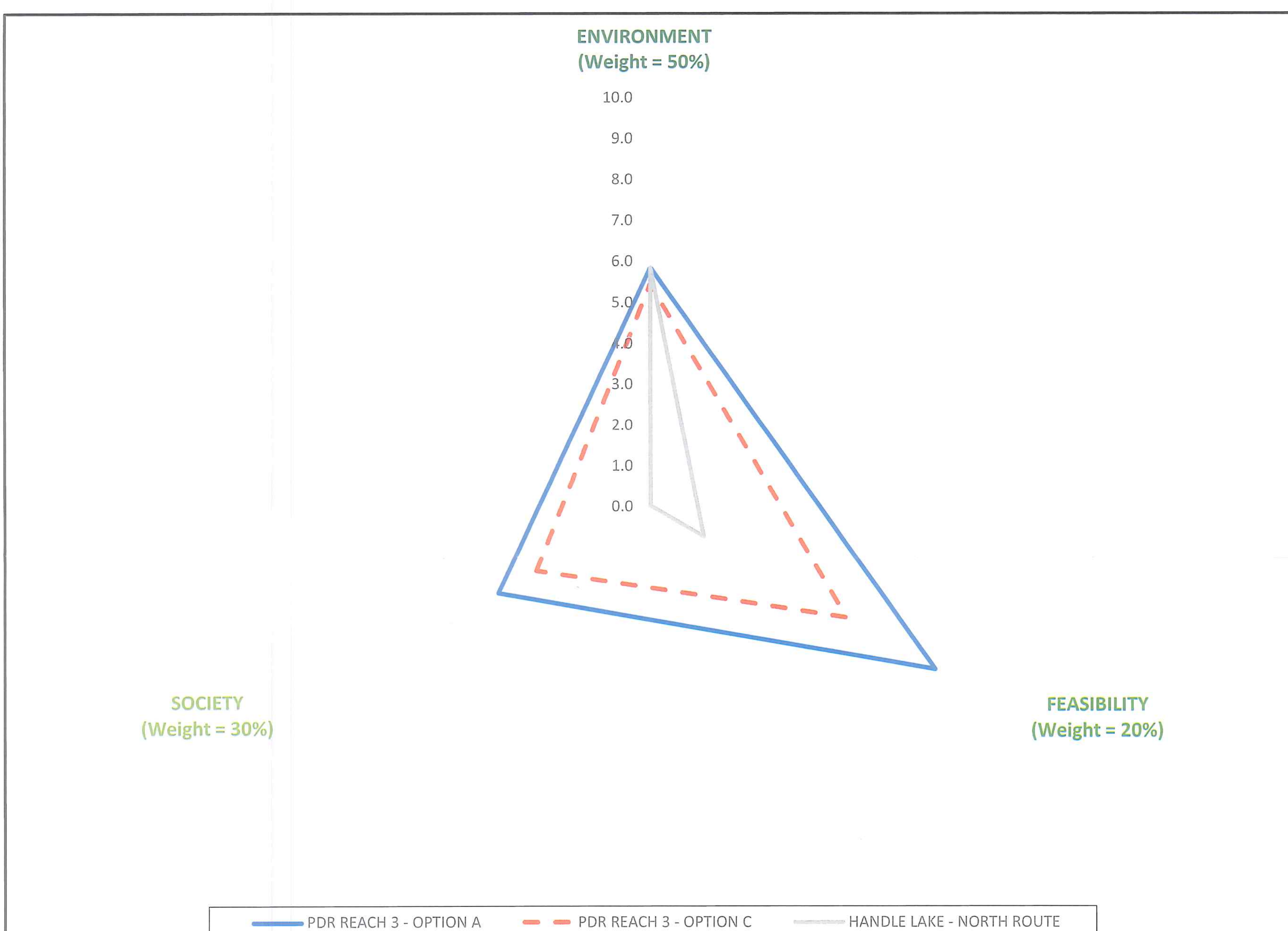

Figure 14: Results by Category

7.3 Sensitivity Analysis

Conclusions of the MAA Evaluation Workshop presented in Section 7.2 were assessed using a sensitivity analysis on weightings of categories and criteria, based on three scenarios described below:

- Scenario 1: Weightings of categories were kept neutral (i.e., assigned the same relative importance to the GMRP), and the weightings of criteria were based on input from stakeholders provided during the MAA Evaluation Workshop;
- Scenario 2: Weightings of categories and criteria were both kept neutral; and
- Scenario 3: Weightings of categories were based on input from stakeholders provided during the MAA Evaluation Workshop, and the weightings of criteria were kept neutral (i.e., assigned the same relative importance to the GMRP).

Table 7 presents a summary of the MAA sensitivity analysis results, with the detailed sensitivity analysis presented in Appendix C.

Table 7: MAA Sensitivity Analysis Result Summary

Scenario	Alternative		
	PDR – Reach 3 Option A	**PDR – Reach 3 Option C**	**Handle Lake – North Route**
Evaluation Workshop	5.80	4.77	3.22
Sensitivity 1	6.03	4.71	2.44
Sensitivity 2	5.83	4.37	2.22
Sensitivity 3	5.63	4.44	2.83

8.0 CONCLUSIONS, RECOMMENDATIONS AND NEXT STEPS

8.1 Conclusions and Recommendations

A comprehensive evaluation of off-site and on-site diversion alternatives for Baker Creek was completed to identify a preferred final alignment and comply with the requirements of Measure 11. This evaluation was completed by expert personnel with GMRP-specific understanding and expertise, informed by public and First Nations and Métis consultation, Giant Mine Oversight Board and Working Group input, using a standard MAA process.

Twenty-four diversion alternatives were identified and compiled through a review of technical reports, and communications, and reduced to three diversion alternatives, including two on-site diversion alternatives (i.e., PDR Reach 3 - Option A, and PDR Reach 3 - Option C) and an off-site diversion alternative (i.e., Handle Lake - North Route) following a screening process, based on GMRP objectives. An evaluation matrix, comprising the three diversion alternatives and evaluation criteria and a scoring system, was developed to evaluate the screened alternatives in detailed categories based on input from the Giant Mine Expert Support review meeting, including representatives from external stakeholders. The detailed evaluation was completed during the MAA Evaluation Workshop attended by representatives of INAC, PSPC, AECOM, and Golder, in consideration of existing GMRP-specific information. Results of this evaluation process were further reviewed by members of Golder's fish and fish habitat, water quality, construction, and traditional studies facilitator team and refined as applicable and as noted in the preceding text.

Based on this MAA process, the Handle Lake – North Route diversion alternative was evaluated as the lowest ranked alternative, below both on-site alternatives, primarily from its footprint within undisturbed areas requiring additional land, temporary infrastructure during construction, and permanently increasing the potential for human and wildlife interaction with the diversion. The PDR Reach 3 - Option A diversion alternative was evaluated slightly higher than the PDR Reach 3 - Option C diversion alternative, primarily influenced by its lower footprint and excavation requirements, and GMRP assumptions.

The objective of this MAA process, in consideration of requirements of Measure 11, was to determine the final alignment corridor of the Baker Creek, whether on site or off site. This evaluation showed that off-site diversion should clearly be discarded from future consideration, and the final alignment of Baker Creek is therefore recommended to remain on site. The location of the final on-site alignment, whether following the PDR Reach 3 - Option A, PDR Reach 3 - Option C, or other proposed on-site alignment based on refinements of the two, is beyond the scope of Measure 11, and should be subject to further evaluation once the GMRP design is better defined, and assumptions from this study, pertaining to pit and sediment remediation, and fish passage, can be confirmed or revisited. Neither the closure material balance, which could affect the ratings of the two on-site alternatives, nor management alternatives of Baker Creek Reach 6, were considered in this study.

8.2 Next Steps

This document will be reviewed by independent technical reviewers and then provided to the Giant Mine Oversight Board and the Giant Mine Working Group for review. Public engagement on various diversion options was completed during the SDE Process. The results of this MAA, namely the selection of an on-site Baker Creek diversion alternative, will be discussed in upcoming public meetings.

Once the review and engagement is complete, further engineering of the on-site alignment alternatives (Option A versus Option C) will be initiated; this will include consideration of the GMRP closure material balance and Baker Creek flood hazard assessment. A final diversion decision will be made once the engagement and review process is complete and other design considerations are reviewed (e.g., fish passage, pit and sediment remediation, closure material balance and management alternatives of Baker Creek Reach 6.

Report Signature Page

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APPENDIX A

North Diversion Water Quality Modelling

TECHNICAL MEMORANDUM

DATE December 11, 2015 **PROJECT No.** 1313770115-014-TM-Rev0-4000

TO Brad Thompson, P.Eng.
Senior Project Manager
Giant Mine Remediation Team
Senior Project Manager Public Works and Government of Services Canada

CC Steven Fiddler, Kerrie Serben, Hilary Machtans

FROM Gerard Van Arkel, Adwoa Cobbina, JP Bechtold **EMAIL** Gerard_VanArkel@golder.com

WATER QUALITY MODELLING RESULTS FOR BAKER AND SHOT CREEKS, AND YELLOWKNIFE BAY

PWGSC Project No.: R.014204.317
Contract No.: EW702-140228/001/GMP-TA03

Dear Mr. Thompson,

Client Name	Project Name and Site	Golder Project No.
Public Works and Government Services Canada	Giant Mine – Civil Design	13-1377-0115

1.0 SCOPE OF SERVICES

Golder Associates Ltd. (Golder) is pleased to submit this technical memorandum to Public Works and Government Services Canada (PWGSC) in support of the Baker Creek Post-Environmental Assessment (EA) investigations for Giant Mine (hereafter referred to as "the Site"). This technical memorandum provides a summary of the water quality modelling conducted as per Phase 1 of the two-phase scope of work to derive site-specific water quality objectives (SSWQO), as described in the January 30, 2015 work plan (Work Plan No. 008).

Golder submitted a draft technical memorandum to PWGSC on June 4, 2015 (Golder 2015a), which underwent a technical review by Stantec Consulting Ltd. (Stantec) (Stantec 2015). A summary table of Stantec's comments and Golder's responses is provided in Appendix A. Components of each response have been incorporated into this technical memorandum, where appropriate.

The purpose of the Phase 1 work was to:

1) characterize existing water quality in Baker Creek and associated waterbodies; and
2) predict future water quality of Baker Creek at its outlet and in Yellowknife Bay for both on-site and off-site channel alignments, accounting for the fact that, under future conditions, treated effluent from the effluent treatment plant (ETP) would no longer be discharged into Baker Creek.

This work was completed to answer the following study questions:

- What is the existing water quality in Baker Creek, waterbodies along the northern diversion route, and Yellowknife Bay?

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- What changes to water quality are expected in the outlets of Baker Creek and Shot Creek, or in Yellowknife Bay as a result of the diversion?
- Are predicted concentrations of parameters of potential concern (POPC) expected to exceed applicable water quality guidelines (WQGs) for protection of aquatic life and human health?
- If so, what are the magnitudes of exceedance at the creek outlets, and over what distance could concentrations in Yellowknife Bay be elevated?

It is anticipated that this information will be used by PWGSC in assessing the benefits and constraints of an off-site diversion. The information outlined herein will also support refinement of the POPCs and the SSWQO development that is required by the Report of Environmental Assessment (REA) Measures. The SSWQO development will be part of the second phase of work (Phase 2), which will be included as part of another contract with PWSGC.

2.0 APPROACH

The scope of work was divided into three main tasks to address the study purpose and associated questions; they are described below. An additional fourth task was completed to characterize mixing lengths in Baker Creek to provide an indication of the distance over which incomplete lateral mixing may be expected to occur. The approach and methods used to complete this task, along with a summary of results, are outlined in Appendix B. They are not discussed in the main body of this memorandum, because they have little influence on the overall key findings of this study; the results simply indicate that a mass balance approach assuming completely mixed conditions at set points in the system is valid.

2.1.1 Compile Existing Water Quality Data

The first task involved compiling existing water quality data for waterbodies in the study area, including Baker Creek, waterbodies along the northern diversion route, and Yellowknife Bay. The data compilation focussed on recent data (2010 to 2014), because of the potential issues with variation in analytical methods and detection limits in older data. The data were compiled in a database to facilitate modelling and any future work that requires an understanding of the existing water quality in the study area.

2.1.2 Predict Future Water Quality at the Outlets of Baker Creek and Shot Creek

The second task involved creating a mass-balance model to predict water quality at the outlet of Baker Creek and Shot Creek (outlet of the northern diversion route). The following scenarios were examined to represent existing and future conditions in Baker Creek and Shot Creek:

1) existing conditions in Baker Creek and Shot Creek with effluent being discharged from the ETP to Baker Creek and no diversion;
2) future conditions in Baker Creek and Shot Creek with no effluent discharge from the ETP to Baker Creek and no diversion (i.e., the “on-site” option); and
3) future conditions in Baker Creek and Shot Creek with no effluent discharge from the ETP to Baker Creek and the diversion of the upper portion of the Baker Creek watershed to the Shot Creek watershed (i.e., the “off-site” option with a remnant Baker Creek channel that continues to discharge to Yellowknife Bay).

The first scenario, which represents existing conditions, is included for verification of the modelling approach (i.e., verification that the model can replicate existing observed conditions) and to provide a point of comparison for the predictions of future conditions. Concentrations of POPCs (mean and 95th percentile) were predicted at two key locations (nodes):

- Reach 0 (Baker Creek at the breakwater); and
- Shot Creek at the discharge into Yellowknife Bay.

Concentrations were compared to water quality guidelines for the protection of aquatic life and human health (drinking water quality).

2.1.3 Estimate the Dispersion of Creek Discharges in Yellowknife Bay

The third task involved linking the results of the mass balance model to estimate the dispersion of the creek discharges into Yellowknife Bay. A Cornell Mixing Zone Expert System (CORMIX) model was used to estimate the required dilution to meet WQGs. For this exercise, the lower of either the water quality guideline for the protection of aquatic life or the drinking water quality guideline was used. The modelling output was the extent of the mixing zone (distance from the outlet of the creek into Yellowknife Bay) where the WQGs are achieved at the edge of the mixing zone.

3.0 METHODS

3.1 Compilation of Current Water Quality

3.1.1 Data Sources

Current water quality data (2010 to 2014) were compiled to characterise existing conditions in the study area. The dataset included information from the following sources:

- Surveillance Network Program (SNP) stations (Deton Cho Nuna Joint Venture 2013, 2014);
- Environmental Effects Monitoring (EEM) stations (Golder 2013a, 2014a);
- Golder (2014b) for site runoff to Baker Creek;
- Stantec (2014a) for Yellowknife Bay;
- Stantec (2014b) for Shot, Gar, and Trapper Lakes; and
- Golder (2013b) for Trapper Lake.

The dataset included concentrations for dissolved organic carbon, major ions, nutrients, metals (including arsenic speciation), total dissolved solids (or specific conductivity), and suspended solids. Data were also compiled for pH, alkalinity, hardness, and water temperature.

The data were uploaded into Golder's EQuIS database, then exported to calculate mean and 95th percentile concentrations for the following waterbodies and water inputs to Baker Creek:

- Baker Creek, downstream of mine inputs (at monitoring station SNP 43-5);
- Upper Baker Creek, upstream of mine inputs (at monitoring station SNP 43-11);
- Yellowknife Bay;

- Site effluent;
- Site runoff;
- Gar Lake;
- Trapper Lake;
- Upper Shot Lake; and
- Lower Shot Lake.

Data were also compared to water quality guidelines for the protection of human and aquatic health:

- Aquatic life guidelines were defined using Canadian water quality guidelines for the protection of aquatic life (WQG PAL; CCME 1999). A Canadian WQG-PAL does not exist for antimony or manganese; therefore, the British Columbia Ministry of Environment (BC MOE) water quality guidelines for the protection of aquatic life (antimony, BC MOE 2015a; manganese, BC MOE 2015b) were used for these parameters. For hardness-dependent guidelines, a hardness of 100 milligrams per litre (mg/L) as $CaCO_3$ was assumed for the screening.
- Human health guidelines were defined using Canadian drinking water quality guidelines (CDWQG; Health Canada 2014). A CDWQG was not available for nickel; therefore, the United States Environmental Protection Agency (US EPA) Regional Screening Levels (RSLs) for tap water (US EPA 2014) was used. The US EPA tap water RSLs were derived based on an acceptable hazard quotient (HQ) of 1 for non-carcinogens and an acceptable incremental lifetime cancer risk (ILCR) of 10-6 for carcinogens, whereas Health Canada has adopted an acceptable HQ of 0.2 and ILCR of 10-5. Therefore, the nickel RSL was adjusted to match Health Canada's guidelines (nickel is not a carcinogen, therefore, the RSL was multiplied by 0.2) (Golder 2013b).

An export of the compiled data was provided to Wildrose Consulting for uploading into Lodestar.

3.1.2 Identification of Parameters of Potential Concern for Water Quality Modelling

A preliminary list of POPCs was identified in the Gap Analysis (Golder 2015b) (i.e., aluminium, antimony, arsenic, cadmium, chromium, cobalt, copper, cyanide, fluoride, iron, lead, lithium, manganese, mercury, nickel, selenium, silver, thallium, vanadium, and zinc). This list was refined by reviewing the detection frequency of each POPC in the compiled water quality dataset. Chromium, cobalt, cyanide, fluoride, lithium, mercury, selenium, silver, thallium and vanadium were not retained for modelling, because the detection frequency of these parameters was less than 20 percent (%). For example, there were no detectable fluoride or cyanide measurements in the runoff to Baker Creek or in Yellowknife Bay, and the detection frequencies for these parameters in the effluent (SNP 43-1) were less than 2% for fluoride and less than 12% for cyanide. Therefore, the following list of parameters was carried forward into the water quality modelling component:

- Aluminum
- Antimony
- Arsenic
- Cadmium
- Copper
- Iron
- Lead
- Manganese
- Nickel
- Zinc

In addition to the above parameters, total dissolved solids (TDS) was also retained, because it was required as input into the density calculations for the plume dispersion modelling.

Although the available dataset included information for individual arsenic species, they were not modelled as separate species. In other words, the concentrations were combined, and treated as a single total arsenic concentration that was not subject to decay, partitioning or other loss processes.

3.1.3 Data Processing to Support Water Quality Modelling

For modelling purposes, current concentrations of the POPCs in site waters were defined using the information outlined in Table 1.

Table 1: Information Used to Define Parameter Concentrations in Site Waters

Group	Water Type	Monitoring Locations	Equivalent Catchment in Water Quality Mass Balance Model[(a)]
1	Upper Baker Creek, upstream of Proposed Diversion	SNP 43-11	R1, R2, R9
2	Baker Creek, Downstream of Trapper Lake and above Baker Pond	SNP 43-16	R6, R12
3	Site Runoff	GM-B2, GM-B3, GM-SNP43-15, GM-W11, GM-W24, GM-W42, GM-W43, GM-W48, GM-W48A, GM-W48B, GM-W49, GM-W5, GM-W50, GM-W50B, GM-W51, GM-W53N, GM-W53S, GM-W54, GM-W58, GM-W58A,	R5, R7
4	Site Effluent (from the ETP) [(b)]	SNP 43-1	P1
5	Gar, Trapper and Shot Lakes	GL-01, GL-02, GL-03, LS-01, LS-02, LS-03, LS-04, TL-01, TL-02, TL-03, US-01, US-02	R3, R4, R10, R11
6	Lower Baker Creek, Downstream of Mine Inputs	SNP 43-5, SNP 43-12	J3, L4
7	Yellowknife Bay	S1, S2, S3, S4, S6, S7, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24	P2

Notes:

ETP = Effluent Treatment Plant

[(a)] See Section 3.2 below.

[(b)] Effluent only enters the system under existing conditions; there is no effluent discharge to Baker Creek under future conditions.

The compiled data were analysed to identify outliers or seasonal patterns. A seasonal trend was detected in the TDS values across groups and in antimony levels in the effluent (Group 4 - P1). Therefore, mean monthly values were established for those groups. Group 5 (Gar, Trapper, and Shot lakes) only had one to two days of readings for each lake; therefore, a mean value was used to define TDS levels in runoff to those lakes. For the other parameters included in the water quality modelling, single mean and 95th percentile values were derived for each group shown in Table 1.

3.2 Mass Balance: Evaluation of Mixing for In-Stream Portion of Watersheds

3.2.1 Model Configuration and Flow Conditions

An Excel-based, completely-mixed mass balance model was developed to predict water quality in Baker Creek and Shot Creek watersheds. The model used a daily time step, and each parameter was treated in a conservative manner (i.e., did not account for any potential settling, partitioning or decay), with predicted concentrations being developed at selected points in Baker Creek and Shot Creek watersheds (identified as junction points in Figure 1).

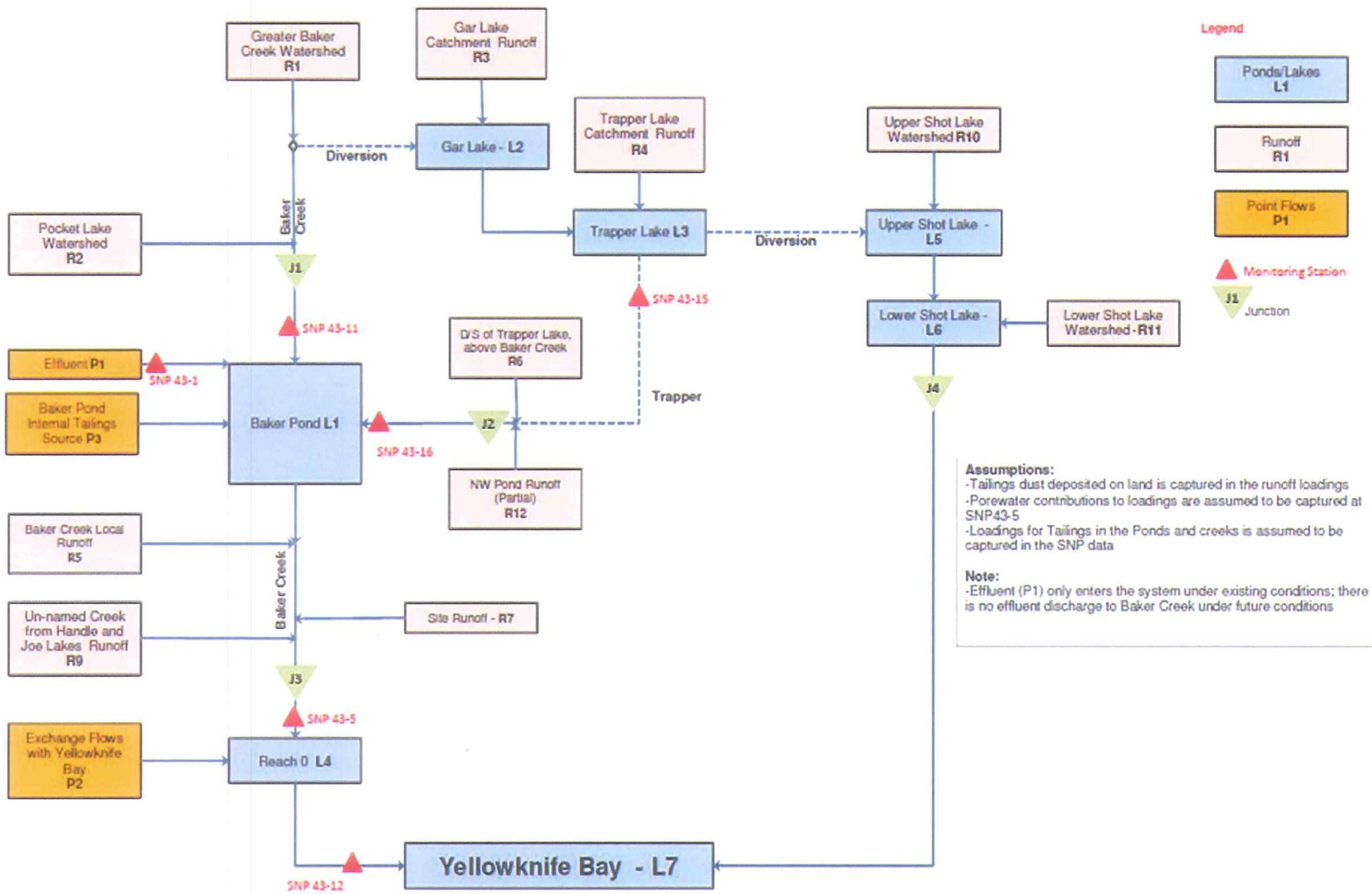
The model considered loadings from:

- upstream flows;
- flow diversions;
- surface runoff;
- tributaries;
- effluent from the ETP; and
- water level driven exchange flows between Reach 0 and Yellowknife Bay.

The model configuration shown in Figure 1 was selected, because it provides a means of evaluating how water quality may vary with the elimination of the treated effluent and the potential diversion of upper Baker Creek. It also reflects the level of information availalble to characterize the existing system. Assumptions inherent in the model include the following:

- Lakes in each watershed have a small volume and do not significantly affect hydrology or water quality.
- Water quality parameters being considered are conservative and do not react with, or in, the watersheds (e.g., no deposition, adsorption, decay, etc.).

Figure 1: Mass Balance Flow Schematic



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3.2.2 Water Balance

The water balance was based on the following assumptions:

- **Junctions**: The flows into junctions equal the flow out of the junctions. There are three junctions (J1, J2, and J3) in the model set upstream of SNP stations to aid with model verification.
- **Lakes**: The flows into a lake equal the flow out of the lake. Storage, evaporation, sublimation and seepage were assumed to be negligible. There were six lakes included in the model; the assumed lake volumes are shown in Table 3.

The water balance was set up with two (2) options:

- **Diversion**: This option determines whether or not the upper portion of the Baker Creek watershed is diverted through Gar and Trapper lakes to Shot Lake (dotted flow paths in Figure 1).
- **Effluent to Baker Creek or Yellowknife Bay**: This option determines if the effluent flows (P1) to Baker Pond or to a dedicated outfall that discharges directly into Yellowknife Bay. When the effluent flows to Yellowknife Bay, the effluent is removed from the Baker and Shot Creek mass and water balances.

The mass balance model used four years (2010 to 2013) of continuous flow data to provide predictions of water quality during non-frozen periods and to characterize hydrologic variability. Runoff rates, as shown in Figure 2, were generated for average, wet and dry year scenarios using a surface water balance model developed using a GoldSim-based modelling platform (see Appendix C). The scenarios were primarily based on total annual precipitation supplemented by Environment Canada hydrometric data where available. Consequently, the modelled flows took into account rainfall, snowmelt and evaporation.

Point flows were not provided by the GoldSim model, and were generated as follows:

- **Effluent (P1)**: The effluent flows for 2010 to 2014 were provided with the water quality data for location SNP 43-1. These flows were estimated for the average, wet and dry year scenarios, noting that treated effluent is usually only produced during the open-water seaon.
- **Exchange Flows (P2):** Exchange flows are the flows from Yellowknife Bay that enter Reach 0 when the water levels in Yellowknife Bay are slightly higher or lower (e.g., typically less than 4 cm) than the levels at the mouth of Baker Creek due to wind seiche effects on Yellowknife Bay and Great Slake Lake. Monthly estimates of the exchange flows were estimated based on hourly 2013 Yellowknife Bay water level data. The daily exchange flow (P2) was only used when the creek flow (J3) was less than twice the exchange flow (e.g., exchange flows did not occur during high flow events in the creek). It was assumed that the exchange flows were the same for the average, wet or dry year scenarios.
- **Baker Pond Internal Loadings from Tailings (P3):** The tailings that have historically accumulated in Baker Pond contribute to the downstream water quality in Baker Creek. The contribution of the seepage from these tailings was represented by a small discharge (assumed to be 4 cubic metre per day [m^3/d] during the unfrozen period) in order to contribute the reported annual arsenic load to Baker Pond. During the winter, the discharge was set to zero. This flow was assumed to remain the same under the average, wet and dry year scenarios.

Table 2: Estimated Exchange Flows Between Reach 0 and Yellowknife Bay

Month	Exchange Flow (m^3/d)
January	2,124
February	1,812
March	1,471
April	1,242
May	1,132
June	1,284
July	1,643
August	1,468
September	1,808
October	2,072
November	1,947
December	1,833

Notes:
m^3/d = cubic metres per day.

3.2.3 Input Water Quality

The summary of current water quality in Baker Creek, site effluent, site runoff, waterbodies along the northern diversion route (Gar, Trapper, and Shot lakes), and Yellowknife Bay compiled in Section 3.1 includes most of the elements of the mass balance with the following exceptions:

- **Baker Creek Internal Loadings from Tailings (P3)**: SRK (2005) estimated that approximately 30 kilograms per year (kg/yr) of arsenic are released from Baker Pond area. An arsenic concentration of 20 mg/L (e.g., 20 times the concentration of the overlying water) was used with the assumed flow rate of 4 m^3/d to maintain the reported annual arsenic loading to Baker Pond. A similar assumption was applied to the other parameters (i.e., concentrations were assumed to be 20 times the Baker Pond [R5] concentrations). These assumptions may be overestimating the loading due to the capping of Jo Jo Lake at the northern end of Baker Pond that was completed after the SRK study.
- **Unnamed Creek (R9)**: Since this catchment has no monitoring locations, the background concentrations used to represent the Greater Baker Creek (R1) and Pocket Lake (R2) watersheds were assumed.

3.2.4 Mass Balance

The mass balance for each parameter was performed on separate worksheets that use the same water balance. The mass balance at each junction is shown in Equation 1.

$$\sum Q_n C_n = Q_o C_o \qquad \text{Equation 1}$$

Where Q_n are the n inflows to the junction in m^3/d;

C_n are the concentrations of the inflows to the junction in mg/L;

Q_o is the junction outflow in m^3/d; and

C_o is the concentration of the outflow in mg/L.

The mass balance in the lakes was calculated in two ways, depending on the retention time (defined as the lake volume divided by the lake outflow) in the given time step:

- If the retention time was less than the model time step (i.e., one day) then Equation 1 was used. This condition would occur during high flow events when the lake in question was effectively flushed.
- If the retention time was greater than the model time step, then the lake was represented as a mixed basin that can retain mass from one time step to the next. The lake-wide concentration of the lake was estimated based on the mass entering and exiting the lake well as the mass retained in the lake from the previous step. The exit concentration was assumed to be the same as the lake wide concentration. If needed, the model was configured to complete up to 10 intermediate sub-step estimates of lake-wide concentration to maintain numerical stability.

Table 3: Mass Balance Lake Volumes

Lake	Volume (m^3)
L1 – Baker Pond	28,115[(a)]
L2 – Gar Lake	148,000[(b)]
L3 – Trapper lake	108,000[(b)]
L4 – Reach 0	5,300[(c)]
L5 – Upper Shot Lake	17,800[(b)]
L6 – Lower Shot Lake	339,000[(b)]

Notes:

m^3 = cubic metres.

(a) Volume based on the pond surface area and an assumed average depth of 1 m.

(b) Stantec (2014c).

(c) Stantec (2014d).

3.2.5 Model Check

The accuracy of the model was checked against existing conditions with no diversion under average climatic conditions. The flows were checked by comparing the flows in the spreadsheet-based water balance with the values generated as per the methods outlined in Appendix C. Parameter concentrations generated in the mass balance were compared with the data from downstream monitoring stations.

Flow Check

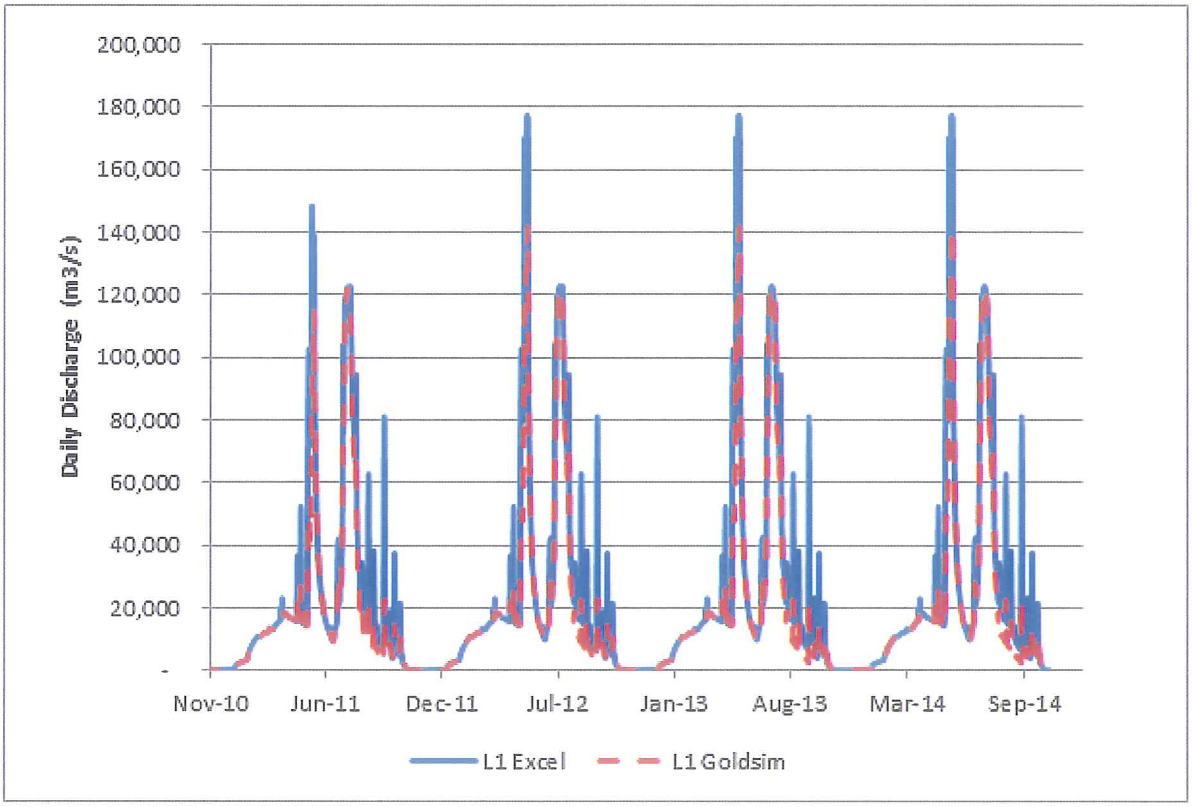
Inputs for the spreadsheet-based water balance were generated using the GoldSim water balance. The outflows were then compared with the GoldSim generated outflows. A comparison of the outflow from L1 (Baker Pond) is shown in Figure 2 as an example. The mass balance model generally recreated the flow patterns; however, mass balance model tended to over-predict lake outflows and flushing rates during runoff events, because the spreadsheet model did not account for the effects of evaporation or lake storage. As a result, the spreadsheet model may under-predict some parameter concentrations in downstream segments during high flow conditions.

In addition, the over-estimation of lake outflows during runoff events resulted in a positive bias in the total annual runoff predicted by the mass balance model, in the order of 15 to 20%. For example, at the outflow of L1, the annual discharge was ~18% higher than predicted using the GoldSim water balance. This over-estimation in outflow likely results in a higher mass loading to downstream environments, because the water and associated mass is not being retained. However, the net effect of this model bias on the study conclusions is expected to be small, because:

- the highest predicted concentrations tend to occur during low flow periods when model accuracy is higher; and

- a positive bias in the outflow rate in the order of 20% is not expected to substantially alter predicted effects in Yellowknife Bay, given the size of the bay relative to the flow inputs from Baker and Shot creeks.

Figure 2: GoldSim and Spreadsheet Generated Outflows from Baker Pond (L1) under Average Climatic Conditions



Concentration Check

The modelled concentrations at Trapper Creek (J2 and SNP 43-16) and Baker Creek at Reach 0 (J3 and SNP 43-5) were compared to the measured concentrations for the typical monitoring period (May to October). The comparisons for TDS and arsenic are shown in Table 4.

At Trapper Creek (SNP 43-16), the model over-predicts arsenic by 17% and TDS by 9%. These errors are likely attributed to the averaging of many sampling locations that are attributed to site runoff (e.g., Group 2 on Table 1). At this location, there were no identifiable season trends in either TDS or arsenic.

At the outlet of Baker Creek into Reach 0 (SNP 43-5), the average concentrations predicted by the model were approximately 42% lower for arsenic and 31% lower for TDS. Because the effluent is the primary source of arsenic and TDS to Baker Creek under the existing conditions, predicted concentrations in Baker Creek would be directly related to effluent flow and concentration. While the effluent quality is routinely measured and consistent, the effluent flow rate is only reported once or twice a month. Consequently, the errors in predicted arsenic and TDS concentrations in Baker Creek are likely primarily related to inaccurate estimates of effluent flow. They may also reflect inaccuracies in the downstream flow balance and/or in the inputs from other loading sources that occur year-round (as opposed to the seasonal operation of the water treatment plant).

Although the model under-estimates concentrations at the outlet of Baker Creek under existing conditions, it is expected to produce reasonable estimates of future conditions for the following reasons:

- The treated effluent will be discharged directly to Yellowknife Bay, so inaccuracies in effluent flow rates will not influence predicted future concentrations in Baker Creek.
- Results of the comparison to observed concentrations in Trapper Creek (as discussed above) indicate that the model tends to more accurately simulate parameter concentrations in the upper watersheds or local catchments (e.g., average difference in arsenic levels of +17% versus -42% - Table 4), which will be the source of most of the water reporting to Baker Creek in the future.

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Table 4: Comparison of the Predicted and Recorded Mean Concentrations of Arsenic and Total Dissolved Solids in the Baker Creek Discharge to Yellowknife Bay

Monitoring Location	Arsenic			Total Dissolved Solids		
	Predicted (mg/L)	Recorded (mg/L)	Difference	Predicted (mg/L)	Recorded (mg/L)	Difference
SNP 43-5	0.14	0.24	-42%	417	609	-31%
SNP 43-16	0.10	0.088	+17%	234	214	+9%

Notes:
mg/L = milligrams per litre; % = percent.
Measured data from 2010 to 2014.
Averages are for the May to October monitoring period.

3.3 Plume Dispersion Modelling in Yellowknife Bay

The following sections outline the methods of the dispersion modelling of the discharges to Yellowknife Bay from Baker Creek and the Shot Creek watersheds using the CORMIX model (Doneker and Jirka 2007).

Plume dispersion in Yellowknife Bay was modelled for average conditions that were representative of September. Average flow conditions were selected to represent the typical plume behavior in Yellowknife Bay. By comparing the results for the scenarios under average conditions, the typical expected change in mixing zone length can be determined as a result of the diversion.

Given that the previous plume delineation studies (Golder 2009) were typically based on data collected in September, and the average flow conditions were similar to flows used in the previous studies, the results of this study could be compared directly to the results of the previous studies.

3.3.1 Representation of Baker Creek Outlet

The following assumptions and rationales were used to develop the representation of the Baker Creek outlet (Reach 0) into Yellowknife Bay in CORMIX. These assumptions were defined based on a review of available bathymetry information, flow data, current modelling and temperature data:

- The outlet of Baker Creek is formed between the breakwater to the north and the Yellowknife Sailing Club to the south.
- Based on flow predictions for average hydrologic conditions (Table 1), the flows are expected to range from 0.083 to 0.176 cubic metres per second (m^3/s) and the exit velocity is expected to range from 0.003 to 0.061 metres per second (m/s) depending on the scenario. As a result, minimal turbulent mixing is expected at the outlet.

- Water temperature profiles measured in Yellowknife Bay indicate that the thermocline typically forms at a depth of 4 metres (m). Because the assumed temperature of the discharge is greater than the water temperature below the thermocline, the plume is not expected to mix below the thermocline. As such, the water depth in Yellowknife Bay was assumed to be 4 m.

- To the north of the outlet, the bottom slope is fairly consistent to a depth of 7 m. However, to the south there is a submerged sill with a minimum depth of approximately 2 m. This sill likely reduces the ambient currents at the outlet during the open water periods. The effect is likely more evident during the ice-covered period when the water above the sill is frozen.

- Based on hydrodynamic modelling (Stantec 2014a), the ambient currents were assumed to be 0.02 m/s during the ice-free periods and 0.001 m/s during the ice-covered period. While the hydrodynamic modelling suggests that the currents are predominantly to the north, the assessment also considers the potential for other directions.

The assumed ambient conditions at the Baker Creek outfall are summarized in Table 5.

Table 5: Assumed Ambient Conditions at Baker Creek and Shot Creek Outlets

	Baker Creek	Shot Creek
Temperature (°C)	9.4[(a)]	11.1[(b)]
Total Dissolved Solids[(a)] (mg/L)	66	66
Density (kg/m³)	999.818	999.663
Current Speed (m/s)	0.020	0.075[(c)]
Depth to Thermocline (m)	4	no thermocline
Wind Speed[(d)] (m/s)	3	3

Notes:
°C = degrees Celsius; mg/L = milligrams per litre; kg/m³ = kilograms per cubic metre; m/s = metres per second; m = metre.
(a) Based on average values at Stations S2, S10, S12, and S13 above 4 m depth.
(b) Based on measured water temperatures at Water Survey of Canada (WSC) Gauge (07SB003).
(c) Based on Yellowknife River flow of 31.7 m³/s, channel width of 300 m, and average depth of 1.4 m.
(d) Average wind speed measured at Yellowknife Airport in September.

3.3.2 Representation of Shot Creek Outlet

The following assumptions and rationales were used to develop the representation of the Shot Creek outlet (referred to as Shot Creek) into Yellowknife Bay in CORMIX. These assumptions were defined based on a review of available bathymetry information, flow data, Yellowknife River flow and temperature data.

- Shot Creek discharges to Yellowknife Bay just west of the mouth of the Yellowknife River. The outlet of Shot Creek discharges into a shallow (less than 1 m depth) embayment that is separated from the Yellowknife River by a rocky outcrop (see Figure 3). The aerial photography suggests that the Shot Creek flow follows the western edge of the embayment.

- The opening of the embayment is approximately 100 m wide and has an average depth less than 1 m. However, given the limitation of CORMIX regarding depth to width ratio of an outfall (1:20), the opening was assumed to be 1 m deep and 20 m wide. As a result, CORMIX may overestimate the initial mixing at the outlet. However, since the expected exit velocities for the actual and assumed configuration are small in comparison to the ambient velocities caused by the Yellowknife River, the differences in in the predicted initial mixing is expected to be minimal.

- At its mouth, the Yellowknife River is approximately 70 m wide with a maximum depth of 10 m (at end of rocky outcrop). The bay widens quickly beyond the mouth (up to 500 m) and becomes shallow (average depth less than 2 m). The bathymetry suggests the flow from the Yellowknife River follows the southwest shore as shown on Figure 3.
- Approximately 1.5 kilometre (km) downstream of the bridge, the bay narrows to about 200 m before opening into the main body of Yellowknife Bay. The flow is expected to follow a deeper channel on the east side of the narrows.
- The currents in the area are directly related to the flow in the Yellowknife River.

The assumed ambient conditions at the Shot Creek outfall are summarized in Table 5.

S:\Clients\Canadian_Federal_Government\Giant_Mine\99_PROJ\1313770115_PublicWorksCanada\40_PROD\0002_WaterQualityModelling_TechMemo\1313770115-0002-CS-0003.mxd

LEGEND

- Yellowknife River Flow
- Shot Creek Flow
- Predicted shape of the Shot Lake discharge plume

REFERENCE(S)
1. IMAGERY - ESRI, DIGITALGLOBE, GEOEYE, I-CUBED, USDA, USGS, AEX, GETMAPPING, AEROGRID, IGN, IGP, SWISSTOPO, AND THE GIS USER COMMUNITY
PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83 COORDINATE SYSTEM: UTM ZONE 11N

0 200 400
1:9,000 METRES

CLIENT
PUBLIC WORKS CANADA

PROJECT
BAKER CREEK POST EA \ SSWQO GAP ANALYSIS

TITLE
PREDICTED SHAPE OF DISCHARGE PLUME FROM SHOT LAKE WITH DIVERSION OF UPPER BAKER CREEK

CONSULTANT
Golder Associates

YYYY-MM-DD	2015-11-20
DESIGNED	JMC
PREPARED	JMC
REVIEWED	GV
APPROVED	GV

PROJECT NO.	CONTROL	REV.	FIGURE
13-1377-0115	4000	-	3

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: 25mm

3.3.3 Selected Discharge Scenarios

The mixing in Yellowknife Bay was completed for each of the three scenarios described in Section 2.0 under average flow conditions. The following points outline the methods used to develop the physical characteristics for the discharges for each of the scenarios:

- The average monthly flows and total dissolved solids were estimated from the output from the mass balance model for each of the scenarios.
- Monthly creek water temperatures were based on field measurements at SNP 43-12. The water temperatures in Shot Creek were assumed to be the same as those in Baker Creek.
- Discharge density was estimated based on temperature and total dissolved solids using the formulation from Cole and Wells (2008).
- Exit velocity was estimated using the widths and depths described in Section 3.3.1 and Section 3.3.2.

The resulting discharge conditions for Baker Creek and Shot Creek are summarized in Table 6.

Table 6: Estimated September Discharges into Yellowknife Bay from Baker Creek and Shot Creek under Average Flow Conditions

Location	Scenario Name	Water Temperature (°C)	Total Dissolved Solids (mg/L)	Density (kg/m³)	Flow (m³/s)	Exit Velocity (m/s)
Baker Creek	Existing Conditions	10.8	945	1000.238	0.176	0.006
	Future without Diversion	10.8	272	999.821	0.138	0.005
	Future with Diversion	10.8	344	999.866	0.083	0.003
Shot Creek	Existing Conditions	10.8	177	999.762	0.029	0.001
	Future with Diversion	10.8	142	999.740	0.918	0.046

Notes:

°C = degrees Celsius; mg/L = milligrams per litre; kg/m^3 = kilograms per cubic metre; m^3/s = cubic metres per second; m/s = metres per second.

3.3.4 Mixing Zone Length

CORMIX was used to predict the dispersion and behaviour of the creek discharges for the identified scenarios. The distance required for the water quality to reach the specified water quality guidelines (e.g., required mixing zone to achieve the lowest of either the water quality guidelines for the protection of aquatic life or the drinking water quality guidelines) was estimated for each scenario. This calculation was done for all the parameters with the exception of:

- aluminum, which has background concentrations in Yellowknife Bay above water quality guidelines (e.g., cannot calculate distance).
- manganese and zinc, which have predicted concentrations that are consistently below the water quality guidelines at the discharge to Yellowknife Bay (e.g., no mixing zone required).

The required mixing length for each parameter to reach their respective criteria was based on the 95th percentile measured and predicted concentrations for Yellowknife Bay, Baker Creek, and Shot Creek. The CORMIX predictions were also used to estimate the width of the plume at the end of the required mixing zone and the extent of the 1% plume (e.g., distance required for the dilution in the plume to reach 100:1).

4.0 RESULTS

4.1 Summary of Existing Water Quality

Mean and 95th percentile concentrations calculated at particular locations in the study area are presented in Table 7, Table 8 and Table 9. A comparison of the existing water quality to the water quality guidelines showed that:

- When effluent is included in the dataset, several parameters in Baker Creek currently have average and 95th percentile concentrations that are above water quality guidelines for the protection of aquatic life and drinking water guidelines (Table 7). Similarly, several parameters in site effluent and site runoff exceed both guidelines (Table 8).
- Background concentrations in Upper Baker Creek exceed water quality guidelines for arsenic on average, and copper, iron, and manganese when upper limit (95th percentile) concentrations are considered (Table 7). Mean and 95th percentile concentrations of arsenic and the 95th percentile of iron exceed both aquatic life and drinking water guidelines. The 95th percentile concentration for copper exceeds the aquatic life guideline and the 95th percentile concentration for manganese exceeds the drinking water guideline.
- The 95th percentile aluminum concentration in Yellowknife Bay slightly exceeds aquatic life and drinking water guidelines (Table 7).
- Mean and 95th percentile arsenic concentrations exceed aquatic life and drinking water guidelines in Gar, Trapper, and Upper Shot lakes; only the aquatic life guideline is exceeded in Lower Shot Lake (Table 9).
- The 95th percentile antimony concentrations in Gar, Trapper, and Shot lakes are higher than the drinking water guideline but lower than the aquatic life guideline (Table 9).

Table 7: Observed Mean and 95th Percentile Concentrations of Selected Parameters in in Baker Creek and Yellowknife Bay Under Existing Conditions

Parameter	Aquatic Life Guidelines[a]	Drinking Water Guidelines[b]	Baker Creek, Downstream of Mine Inputs Including Effluent (SNP 43-5)		Upper Baker Creek (SNP 43-11)		Yellowknife Bay	
			Mean	95th Percentile	Mean	95th Percentile	Mean	95th Percentile
Total Dissolved Solids	-	-	870	nc	110	nc	63	nc
Aluminum	0.100	0.1	**0.34**	**0.66**	0.012	0.024	0.063	**0.12**
Antimony	0.009	0.006	**0.15**	**0.19**	0.0014	0.0024	0.00043	0.00067
Arsenic	0.005	0.010	**0.18**	**0.24**	**0.043**	**0.076**	0.0016	0.0035
Cadmium	0.00016	0.005	0.000055	0.000055	-	-	0.000012	0.000017
Copper	0.00236	1.0	**0.010**	**0.010**	0.0022	**0.0084**	0.001	0.0014
Iron	0.3	0.3	0.26	0.26	0.16	**0.36**	0.043	0.082
Lead	0.00318	0.010	0.0011	0.0011	0.00025	0.00090	0.00012	0.00015
Manganese	1.0	0.05	0.058	0.058	0.032	0.056	0.0040	0.0050
Nickel	0.09558	0.08	0.017	0.018	0.014	0.038	0.0019	0.0020
Zinc	0.030	5.0	0.010	0.010	0.0061	0.0071	0.0056	0.012

Notes:

Concentrations are in milligrams per litre (mg/L).

"-" = no guideline available or no data available to calculate statistics; nc = not calculated.

(a) Bold values exceed aquatic life water quality guidelines. Aquatic life water quality guidelines were selected from the following sources (in order of preference): Canadian water quality guidelines for the protection of aquatic life (CCME 1999) and British Columbia water quality guideline (antimony, BC MOE 2015a; manganese; BC MOE 2015b). A hardness of 100 mg/L was assumed for hardness-dependent parameters (i.e., cadmium, copper, lead, nickel). A pH of ≥6.5 was assumed for aluminum.

(b) Underlined values exceed drinking water guidelines. Either Canadian drinking water guidelines (CDWQG; Health Canada 2014) or United States Environmental Protection Agency (US EPA) regional screening levels (RSL) for tap water were used (nickel only; US EPA 2014).

Table 8: Observed Mean and 95th Percentile Concentrations of Selected Parameters in Site Effluent and Site Runoff Under Existing Conditions

Parameter	Aquatic Life Guidelines[(a)]	Drinking Water Guidelines[(b)]	Site Effluent		Site Runoff	
			Mean	95th Percentile	Mean	95th Percentile
Total Dissolved Solids	-	-	643	nc	2,356	nc
Aluminum	0.100	0.1	0.010	0.019	0.22	0.75
Antimony	0.009	0.006	**0.40**	**0.46**	**0.067**	**0.24**
Arsenic	0.005	0.010	**0.41**	**0.47**	**0.43**	**0.85**
Cadmium	0.00016	0.005	0.00013	0.00013	0.00012	**0.00051**
Copper	0.00236	1.0	**0.014**	**0.017**	**0.010**	**0.037**
Iron	0.3	0.3	0.044	0.013	**0.59**	**2.86**
Lead	0.00318	0.010	**0.036**	**0.83**	0.0010	**0.0038**
Manganese	1.0	0.05	0.017	0.090	0.15	0.60
Nickel	0.09558	0.08	0.040	0.086	0.0088	0.027
Zinc	0.030	5.0	0.0069	**0.051**	**0.054**	**0.28**

Notes:

Concentrations are in milligrams per litre (mg/L).

"-" = no guideline available or no data available to calculate statistics; nc = not calculated.

(a) Bold values exceed aquatic life water quality guidelines. Aquatic life water quality guidelines were selected from the following sources (in order of preference): Canadian water quality guidelines for the protection of aquatic life (CCME 1999) and British Columbia water quality guideline (antimony, BC MOE 2015a; manganese; BC MOE 2015b). A hardness of 100 mg/L was assumed for hardness-dependent parameters (i.e., cadmium, copper, lead, nickel). A pH of ≥6.5 was assumed for aluminum.

(b) Underlined values exceed drinking water guidelines. Either Canadian drinking water guidelines (CDWQG; Health Canada 2014) or United States Environmental Protection Agency (US EPA) regional screening levels (RSL) for tap water were used (nickel only; US EPA 2014).

Table 9: Observed Mean and 95th Percentile Concentrations of Selected Parameters in Gar, Trapper, Upper Shot and Lower Shot Lakes Under Existing Conditions

Parameter	Aquatic Life Guidelines[a]	Drinking Water Guidelines[b]	Gar Lake		Trapper Lake		Upper Shot Lake		Lower Shot Lake	
			Mean	95th Percentile	Mean	95th Percentile	Mean	95th Percentile	Mean	95th Percentile
Total Dissolved Solids	-	-	177	nc	213	nc	189	nc	159	nc
Aluminum	0.100	0.1	0.012	0.013	0.034	0.037	0.018	0.020	0.024	0.026
Antimony	0.009	0.006	0.0024	0.0078	0.0073	0.0078	0.00056	0.0078	0.00043	0.0078
Arsenic	0.005	0.010	**0.12**	**0.13**	**0.21**	**0.23**	**0.012**	**0.012**	**0.0085**	**0.0089**
Cadmium	0.00016	0.005	0.000010	0.000010	0.000010	0.000010	0.000010	0.000010	0.000010	0.000010
Copper	0.00236	1.0	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
Iron	0.3	0.3	0.033	0.036	0.050	0.056	0.068	0.072	0.10	0.11
Lead	0.00318	0.010	0.00016	0.00012	0.00011	0.00010	0.00010	0.00010	0.0001	0.00027
Manganese	1.0	0.05	0.011	0.014	0.011	0.011	0.0070	0.0082	0.0070	0.0082
Nickel	0.09558	0.08	0.0020	0.0020	0.0020	0.0020	0.00200	0.0020	0.0020	0.0020
Zinc	0.030	5.0	0.0040	0.0040	0.0040	0.0040	0.00400	0.0040	0.0040	0.0040

Notes:

Concentrations are in milligrams per litre (mg/L).

"-" = no guideline available; nc = not calculated.

(a) Bold values exceed aquatic life water quality guidelines. Aquatic life water quality guidelines were selected from the following sources (in order of preference): Canadian water quality guidelines for the protection of aquatic life (CCME 1999) and British Columbia water quality guideline (antimony, BC MOE 2015a; manganese; BC MOE 2015b). A hardness of 100 mg/L was assumed for hardness-dependent parameters (i.e., cadmium, copper, lead, nickel). A pH of ≥6.5 was assumed for aluminum.

(b) Underlined values exceed drinking water guidelines. Either Canadian drinking water guidelines (CDWQG; Health Canada 2014) or United States Environmental Protection Agency (US EPA) regional screening levels (RSL) for tap water were used (nickel only; US EPA 2014).

4.2 Predicted Water Quality in Baker Creek, Reach 0 and Shot Creek

Table 10 and Table 11 summarize the predicted concentrations in Baker Creek and Shot Creek at their outlets to Yellowknife Bay. The following general conclusions can be made:

- For the on-site scenario, removal of the treated effluent discharge is predicted to result in improved water quality in Baker Creek, although arsenic levels at the creek outlet (i.e., SNP 43-12, where Baker Creek enters Yellowknife Bay) are predicted to remain above aquatic life and drinking water quality guidelines. Peak concentrations of aluminum, antimony, copper, iron, and manganese are also predicted to exceed aquatic life and/or drinking water guidelines.
- Under the off-site scenario (i.e., diversion of upper Baker Creek), parameters concentrations are generally predicted to increase in Shot Creek and result in aquatic health/drinking water guideline exceedances at the outlet of Shot Creek. Arsenic concentrations will increase at the outlet of Shot Creek if the north diversion occurs with the existing water quality in upper Baker Creek and Gar and Trapper Lakes.
- The off-site scenario is also predicted to result in higher parameter concentrations in Baker Creek on the mine site ('the remnant channel'). However, predicted loading rates to Yellowknife Bay via Baker Creek are reduced.
- Predicted arsenic levels in either scenario, at the outlet of either Baker Creek or Shot Creek, are sufficiently high that use of the drinking water guideline as a site-specific water quality objective (SSWQO) is not likely to be achievable, unless compliance with the SSWQO is only required in the main basin of Yellowknife Bay some distance from the outlets.

Table 10: Predicted Concentrations of Selected Parameters in Baker Creek Discharge to Yellowknife Bay, based on a Four Year Simulation Period considering Average, Wet and Dry Climatic Conditions

Parameter	Aquatic Life Guidelines[(a)]	Drinking Water Guidelines[(b)]	Existing Condition		Future Condition Without Diversion (On-site Scenario)		Future Condition With Diversion (Off-site Scenario)	
			Mean	95th Percentile	Mean	95th Percentile	Mean	95th Percentile
Aluminum	0.100	0.1	0.084	**0.12**	0.086	**0.13**	**0.19**	**0.26**
Antimony	0.009	0.006	**0.028**	**0.056**	0.0027	0.0081	0.0036	0.016
Arsenic	0.005	0.010	**0.086**	**0.13**	**0.066**	**0.097**	**0.075**	**0.12**
Cadmium	0.00016	0.005	0.000017	0.000017	0.000015	0.000030	0.000025	0.00003
Copper	0.00236	1.0	0.0023	**0.0069**	0.0015	**0.0065**	0.0016	**0.0040**
Iron	0.3	0.3	0.24	**0.44**	0.26	**0.45**	**0.31**	**0.66**
Lead	0.00318	0.010	**0.0033**	**0.0096**	0.0002	0.0008	0.0002	0.0006
Manganese	1.0	0.05	0.041	0.0902	0.043	0.092	0.044	0.16
Nickel	0.09558	0.08	0.014	0.0260	0.014	0.025	0.0038	0.0064
Zinc	0.030	5.0	0.0061	0.015	0.0060	0.015	0.0060	0.026

Notes:

Concentrations are in milligrams per litre (mg/L).

[(a)] Bold values exceed aquatic life water quality guidelines. Aquatic life water quality guidelines were selected from the following sources (in order of preference): Canadian water quality guidelines for the protection of aquatic life (CCME 1999) and British Columbia water quality guideline (antimony, BC MOE 2015a; manganese; BC MOE 2015b). A hardness of 100 mg/L was assumed for hardness-dependent parameters (i.e., cadmium, copper, lead, nickel). A pH of ≥6.5 was assumed for aluminum.

[(b)] Underlined values exceed drinking water guidelines. Either Canadian drinking water guidelines (CDWQG; Health Canada 2014) or United States Environmental Protection Agency (US EPA) regional screening levels (RSL) for tap water were used (nickel only; US EPA 2014).

Table 11: Predicted Concentrations of Selected Parameters in Lower Shot Creek Discharge to Yellowknife Bay, based on a Four Year Simulation Period considering Average, Wet and Dry Climatic Conditions

Parameter	Aquatic Life Guidelines[(a)]	Drinking Water Guidelines[(b)]	Existing Condition and Future Condition without Diversion (On-site Scenario)		Future Condition With Diversion (Off-site Scenario)	
			Mean	95th Percentile	Mean	95th Percentile
Aluminum	0.100	0.1	0.020	0.021	0.014	0.022
Antimony	0.009	0.006	0.0005	0.0005	0.0015	0.0021
Arsenic	0.005	0.010	**0.010**	**0.011**	**0.060**	**0.074**
Cadmium	0.00016	0.005	0.000006	0.000010	0.000003	0.000006
Copper	0.00236	1.0	0.0010	0.0010	0.0012	**0.0061**
Iron	0.3	0.3	0.086	0.088	0.16	0.27
Lead	0.00318	0.010	0.0001	0.0001	0.0002	0.0007
Manganese	1.0	0.05	0.0078	0.0081	0.030	0.042
Nickel	0.09558	0.08	0.0020	0.0020	0.014	0.027
Zinc	0.030	5.0	0.0040	0.0040	0.0057	0.0061

Notes:

Concentrations are in milligrams per litre (mg/L).

(a) Bold values exceed aquatic life water quality guidelines. Aquatic life water quality guidelines were selected from the following sources (in order of preference): Canadian water quality guidelines for the protection of aquatic life (CCME 1999) and British Columbia water quality guideline (antimony, BC MOE 2015a; manganese; BC MOE 2015b). A hardness of 100 mg/L was assumed for hardness-dependent parameters (i.e., cadmium, copper, lead, nickel). A pH of ≥6.5 was assumed for aluminum.

(b) Underlined values exceed drinking water guidelines. Either Canadian drinking water guidelines (CDWQG; Health Canada 2014) or United States Environmental Protection Agency (US EPA) regional screening levels (RSL) for tap water were used (nickel only; US EPA 2014).

4.3 Plume Dispersion Modelling

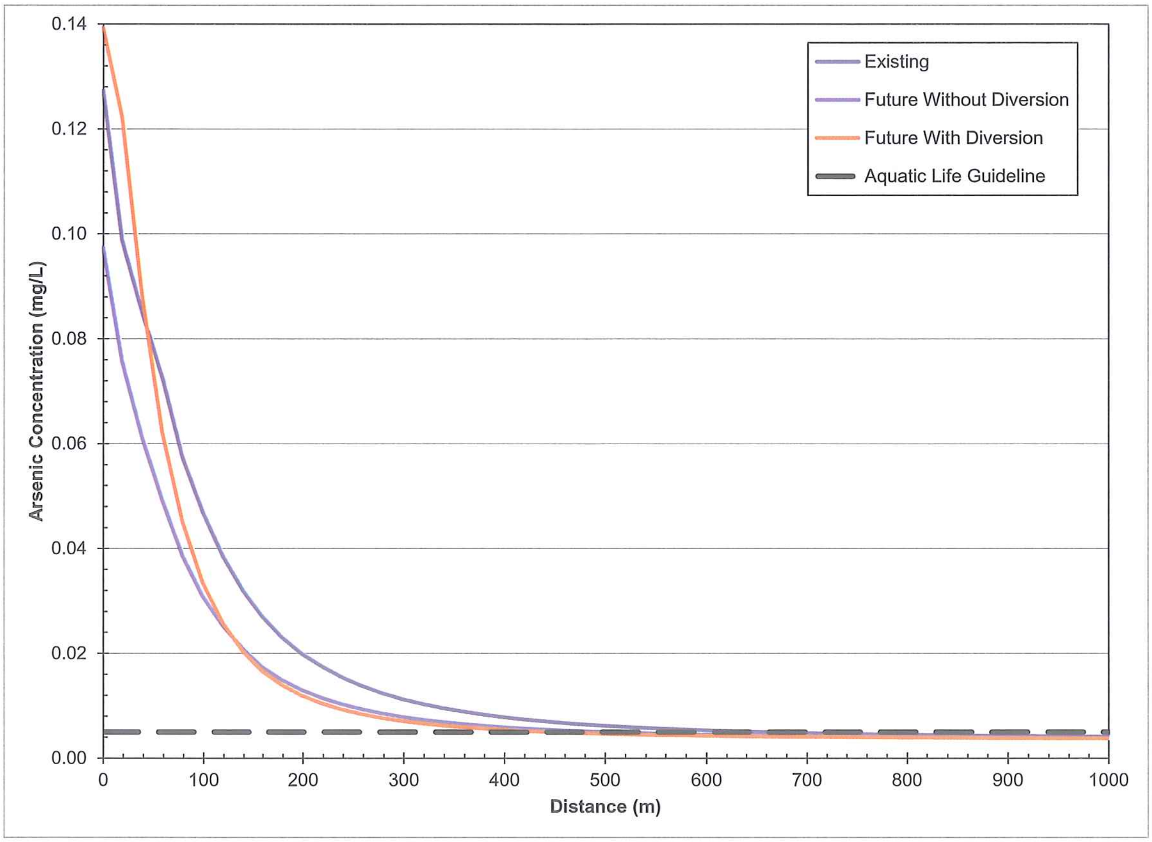
4.3.1 Plume Description for Baker Creek

The results of the mixing zone assessment for Baker Creek are summarized in Table 12. The following points provide a description of the expected plume behavior from the discharge of Baker Creek.

- The low energy at the mouth results in a large recirculation area with relatively low dilutions (e.g., less than 2:1) for all the scenarios modelled. This area can extend up to 100 m from the mouth of the creek.
- The plumes are vertically mixed to the extent of the CORMIX model and are not expected to form a sinking plume.
- The plume width increases rapidly with distance and is typically as wide as it is long (e.g., at a distance 500 m, the plume is approximately 500 m wide).
- In all the scenarios, the largest mixing zone is required for arsenic, with the water released from Baker Creek needing a dilution of up to 92:1 to reach guideline levels.

- The predicted arsenic profiles (Figure 4) show that all the plumes follow a pattern of dispersion that gradually reduces with distance.
- Under the existing conditions, the mixing zone for arsenic is approximately 650 m. In the future conditions, the length of the mixing zone reduces to approximately 500 m (23% decrease) without the diversion and to approximately 450 m (31% decrease) with the diversion.
- These results suggest that, under future conditions, the diversion results in a small decrease in the length of the arsenic mixing zone.

Figure 4: Predicted Plume Centerline Arsenic Concentrations for Baker Creek Discharge



4.3.2 Plume Description for Shot Creek

The results of the mixing zone assessment for Shot Creek are summarized in Table 13. The following points provide a description of the expected plume behavior from the discharge of Shot Creek.

- The diversion is expected to increase the flow in Shot Creek by approximately 30 times (Table 6).
- Given the low energy associated with the Shot Creek discharge and the relatively high velocities caused by the Yellowknife River, the plume is expected to form a narrow plume (e.g., less than 20 m wide) that is attached to the shoreline as shown in Figure 3.
- Beyond the initial mixing zone, mixing and dilution of the plume is expected to occur slowly.

- Due to the sudden and drastic changes to bathymetry and width at the narrows, the output from CORMIX could only be used to maximum downstream distance of 1,500 m. Modelling beyond the narrows would require a more complex approach.
- In both cases, CORMIX predicts a certain amount of initial mixing that is inversely proportional to the ratio of Shot Creek flow to the Yellowknife River flow. In other words, as flow in Shot Creek increases, the amount on initial dilution decreases, which produces higher predictions of parameter concentrations in Yellowknife Bay near the Shot Creek outlet with the diversion than without..
- Without the diversion, arsenic was the only parameter that required a mixing zone. The resulting mixing zone was predicted to be very small (e.g., 4 m long).
- With the diversion, mixing zones were required for arsenic, copper and nickel. In case for arsenic, the mixing zone was always in excess of 1,500 m as shown on Figure 5. The arsenic concentrations at a location 1,500 m downstream are expected to be approximately 0.036 mg/L.

Figure 5: Predicted Plume Centerline Arsenic Concentrations for Shot Creek Discharge

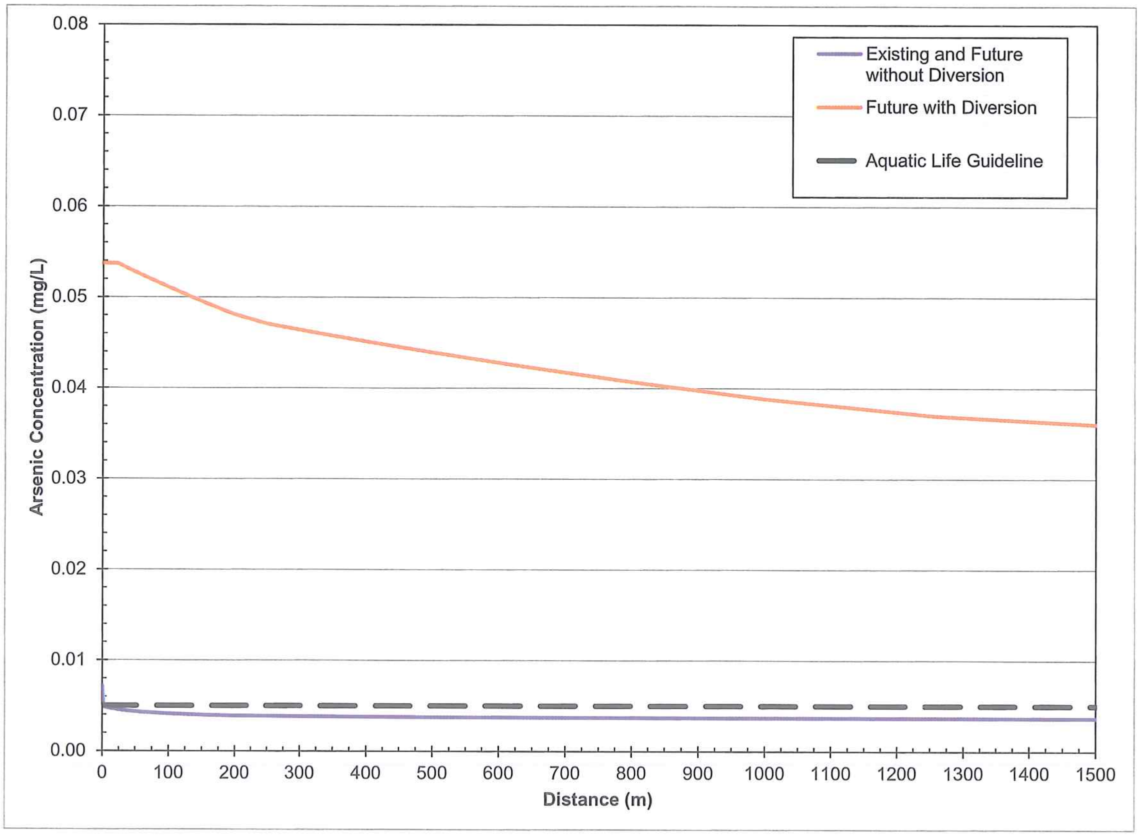


Table 12: Required Mixing Zone Lengths from the Outlet of Baker Creek, as Predicted for Average September Flow Conditions under Existing Conditions and under Future Conditions With and Without the Diversion

		Conservative Tracer[a]	Antimony	Arsenic	Cadmium	Copper	Iron	Lead	Nickel
	Aquatic Life Guideline[b] (mg/L)	--	0.009	0.005	0.00016	0.00236	0.3	0.00318	0.09558
	Drinking Water Guideline[c] (mg/L)	--	0.006	0.010	0.005	1.0	0.3	0.010	0.08
	Minimum Guideline (mg/L)	0.01	0.006	0.005	0.00016	0.00236	0.3	0.00318	0.08
	Background Concentration (mg/L)	0.00	0.00067	0.0035	0.000017	0.0014	0.082	0.00015	0.0020
Existing	Discharge Concentration (mg/L)	1.00	0.056	0.13	0.000017	0.0069	0.44	0.0096	0.0260
	Required Dilution	100	10.4	83.7	B[d]	5.7	1.7	3.1	B
	Distance to Guideline (m)	710	240	655	--	169	50	108	--
	Plume Width (m)	494	247	469	--	201	107	156	--
Future without Diversion (On-site Scenario)	Discharge Concentration (mg/L)	1.00	0.0081	0.097	0.000030	0.0065	0.45	0.00080	0.0249
	Required Dilution	100	1.4	63.5	B	5.3	1.7	B	B
	Distance to Guideline (m)	614	29	499	--	138	45	--	--
	Plume Width (m)	415	79	363	--	165	94	--	--
Future with Diversion (Off-site Scenario)	Discharge Concentration (mg/L)	1.00	0.016	0.14	0.000030	0.0040	0.66	0.00060	0.0064
	Required Dilution	100	2.8	91.8	B	2.7	2.7	B	B
	Distance to Guideline (m)	464	72	447	--	70	69	--	--
	Plume Width (m)	290	90	283	--	89	88	--	--

Notes:

"—" = not applicable; mg/L = milligrams per litre; m = metre.

(a) Conservative tracer included to provide distance to 1% for consistency with previous studies (i.e., Golder 2009).

(b) Aquatic life water quality guidelines were selected from the following sources (in order of preference): Canadian water quality guidelines for the protection of aquatic life (CCME 1999) and British Columbia water quality guideline (antimony, BC MOE 2015a; manganese; BC MOE 2015b). A hardness of 100 mg/L was assumed for hardness-dependent parameters (i.e., cadmium, copper, lead, nickel). A pH of ≥6.5 was assumed for aluminum.

(c) Either Canadian drinking water guidelines (CDWQG; Health Canada 2014) or United States Environmental Protection Agency (US EPA) regional screening levels (RSL) for tap water were used (nickel only; US EPA 2014).

(d) "B" denotes discharge concentrations below water quality criteria and a mixing zone is not required.

Table 13: Required Mixing Zone Lengths from the Outlet of Shot Creek, as Predicted for Average September Flow Conditions under Existing Conditions and under Future Conditions With and Without the Diversion

		Conservative Tracer[a]	Antimony	Arsenic	Cadmium	Copper	Iron	Lead	Nickel
	Aquatic Life Guideline[b] (mg/L)	--	0.009	0.005	0.00016	0.00236	0.3	0.00318	0.09558
	Drinking Water Guideline[c] (mg/L)	--	0.006	0.010	0.005	1.0	0.3	0.010	0.08
	Minimum Criteria (mg/L)	0.01	0.006	0.005	0.00016	0.00236	0.3	0.00318	0.08
	Background Concentration (mg/L)	0.00	0.00067	0.0035	0.000017	0.00140	0.0820	0.00015	0.0020
Existing or Future Without Diversion (On-site Scenario)	Discharge Concentration (mg/L)	1.00	0.00050	0.011	0.000010	0.0010	0.088	0.00010	0.0020
	Required Dilution	100	B[d]	4.8	B	B	B	B	B
	Distance to Criteria (m)	1,500	--	4	--	--	--	--	--
	Plume Width (m)	14	--	0.6	--	--	--	--	--
Future with Diversion (Off-site Scenario)	Discharge Concentration (mg/L)	1.00	0.0021	0.074	0.000010	0.0061	0.27	0.00070	0.027
	Required Dilution	100	B	47.5	B	4.9	B	B	B
	Distance to Criteria (m)	1,500[e]	--	1,500[e]	--	1,500[e]	--	--	--
	Plume Width (m)	18	--	18	--	18	--	--	--

Notes:

"—" = not applicable; mg/L = milligrams per litre; m = metre.

(a) Conservative tracer included to provide distance to 1% for consistency with previous studies (i.e., Golder 2009).

(b) Aquatic life water quality guidelines were selected from the following sources (in order of preference): Canadian water quality guidelines for the protection of aquatic life (CCME 1999) and British Columbia water quality guideline (antimony, BC MOE 2015a; manganese; BC MOE 2015b). A hardness of 100 mg/L was assumed for hardness-dependent parameters (i.e., cadmium, copper, lead, nickel). A pH of ≥6.5 was assumed for aluminum.

(c) Either Canadian drinking water guidelines (CDWQG; Health Canada 2014) or United States Environmental Protection Agency (US EPA) regional screening levels (RSL) for tap water were used (nickel only; US EPA 2014).

(d) "B" denotes discharge concentrations below water quality criteria and a mixing zone is not required.

(e) Required distance exceeds limit of CORMIX calculation (1,500 m).

5.0 UNCERTAINTY AND LIMITATIONS

The assessment documented in this memorandum is considered a screening level assessment and is intended to provide a preliminary assessment of the expected effects on water quality associated the two modelling scenarios. As such, the approach incorporated several assumptions and simplifications that should be considered when reviewing the results.

Major uncertainties and limitations of the assessment include

- To be conservative, the plume dispersion assessment considered water quality concentrations that were representative of worst case conditions (e.g., 95th percentile). The actual and expected average concentrations would be lower than those presented in this assessment.
- The water quality guidelines for the protection of aquatic life used in this assessment assumed a water hardness of 100 mg/L. Simplifications in the modelling approach did not allow for the representation of hardness. Actual hardness may vary higher or lower in the receiving environment, which would alter the calculation of hardness-dependent guidelines for cadmium, copper, lead, and nickel.
- Water quality of surface runoff was based on a small sample size (e.g., Shot Lake was sampled on two dates in the same year).
- Internal contaminant loads in Baker Pond may be overestimated. The load was based on a 2005 estimate and does not account for the capping of Jo Jo Lake at the northern end of Baker Pond in 2011 and 2012.
- The assessment assumes that the existing background conditions in Yellowknife Bay are representative of future conditions. Once the effluent is diverted to a dedicated outfall in Yellowknife Bay, the concentrations in Yellowknife Bay can be expected to gradually increase over time as the effluent mixes with the entire volume of Yellowknife Bay. An increase in background concentrations could potentially increase the length of mixing zones.
- The off-site scenario assumed that the channel at the outlet of Shot Creek would not change. However, because the flow from the north diversion can increase by 50 times, some channel alterations are likely to occur to accommodate the increased flows. If those channel alterations extend through the shallow area behind the rocky outcrop (e.g., dredge a channel), then there may be an opportunity to enhance the mixing at point where the Shot Creek flow meets the Yellowknife flow and reduce the length of the shoreline plume.

6.0 CONCLUSIONS

As stated in Section 2.0, the study questions were addressed using three tasks:

- Compile existing water quality data in the study area (Baker Creek, waterbodies along the northern diversion route, and Yellowknife Bay) for use in the modelling tasks.
- Create a mass-balance model to predict water quality at the outlet of Baker Creek and Shot Creek under both on-site and off-site scenarios, which both assume that no treated effluent from the ETP will be discharged to Baker Creek.
- Evaluate the dispersion of the creek discharges under future conditions into Yellowknife Bay.

6.1 Existing Water Quality

Under existing conditions in Baker Creek and Shot Creek, which consists of seasonal discharge of treated effluent to Baker Creek, and no diversion of Baker Creek flow, several conclusions can be made:

- When effluent is discharged to Baker Creek, the water quality in Baker Creek downstream of the mine inputs (i.e., SNP 43-5) is characterized as having concentrations of several parameters that exceed guidelines; for example, mean and 95th percentile concentrations of aluminum, antimony, and arsenic exceed both aquatic life and drinking water guidelines and copper exceeds the aquatic life guideline. The 95th percentile manganese concentration exceeds the drinking water guideline. Site effluent and site runoff have concentrations of several parameters that contribute to the observed water quality in Baker Creek.
- Water quality in Baker Creek prior to entering Baker Pond (i.e., upper Baker Creek at SNP 43-11) is characterized as having fewer parameters with concentrations that exceed guidelines compared to water downstream of the mine inputs. However, mean and 95th percentile arsenic concentrations also exceed aquatic life and drinking water guidelines, although the magnitude of the exceedences are lower. The 95th percentile concentration of iron exceeds the aquatic life and drinking water guidelines, of copper exceeds the aquatic life guideline, and of manganese exceeds the drinking water guideline.
- Arsenic concentrations exceed aquatic life and drinking water guidelines and manganese concentrations exceed drinking water guidelines in Gar, Trapper, and Shot lakes.
- In Yellowknife Bay, only aluminum (at the 95th percentile) exceeds aquatic life and drinking water guidelines.

6.2 Effects on Water Quality in Baker Creek and Shot Creek

The key findings of the mass-balance model are as follows:

- For the on-site scenario, removal of the treated effluent discharge is predicted to result in improved water quality in Baker Creek, although arsenic levels at the creek outlet (i.e., SNP 43-12, where Baker Creek enters Yellowknife Bay) are predicted to remain above aquatic life and drinking water quality guidelines. Peak concentrations of aluminum, antimony, copper, iron, and manganese are also predicted to exceed aquatic life and/or drinking water guidelines.
- Under the off-site scenario (i.e., diversion of upper Baker Creek), parameters concentrations are generally predicted to increase in Shot Creek and result in aquatic health/drinking water guideline exceedances at the outlet of Shot Creek. Arsenic concentrations are predicted to increase at the outlet of Shot Creek if the north diversion occurs with the existing water quality in upper Baker Creek and Gar and Trapper lakes.
- The off-site scenario is also predicted to result in higher parameter concentrations in Baker Creek on the mine site ('the remnant channel'). However, predicted loading rates to Yellowknife Bay via Baker Creek are reduced.
- Predicted arsenic levels in either scenario, at the outlet of either Baker Creek or Shot Creek, are sufficiently high that use of the drinking water guideline as a site-specific water quality objective (SSWQO) is not likely to be achievable, unless compliance with the SSWQO is only required in the main basin of Yellowknife Bay some distance from the outlets.

6.3 Effects on Water Quality in Yellowknife Bay

Key findings from the plume dispersion modelling in Yellowknife Bay are as follows:

- For both scenarios, arsenic requires the longest mixing zone to reach guideline levels within Yellowknife Bay (i.e., all other parameters considered in the assessment are predicted to meet water quality guidelines in Yellowknife Bay with less mixing than that required for arsenic).
- For the Baker Creek outlet, the length of the mixing zone for arsenic is predicted to decrease from the existing distance of approximately 650 m to:
  - approximately 500 m with the on-site scenario (i.e., a ~23% decrease); and,
  - approximately 450 m with the off-site scenario (i.e., a ~31% decrease).
- For the Shot Creek outlet, no change from existing conditions occurs under the on-site scenario. Under the off-site scenario, the mixing zone for arsenic is predicted to increase from less than 10 m to more than 1,500 m, which has implications to how an SSWQO for the Shot Creek outlet would be defined (because guidelines cannot be met at the creek mouth or in the immediate vicinity of the outlet into Yellowknife Bay).

7.0 CLOSURE

This work was carried out under the terms and conditions contained within contract EW702-140228/001/GMP between Golder and PWGSC.

We trust the above meets your present requirements. If you have any questions or requirements, please contact the undersigned.

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APPENDIX A
Technical Review Comment Response Table

Technical Review Details:

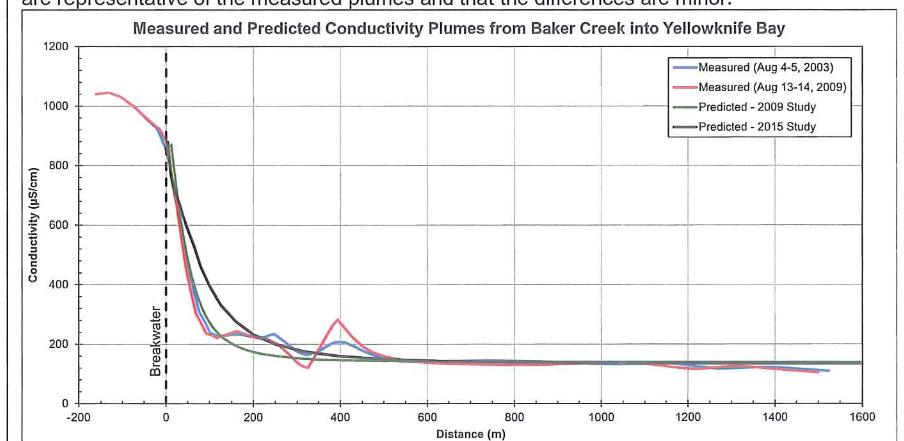
Document that underwent technical review:	**Golder. 2015a. Water Quality Modelling Results for Baker and Shot Creeks, and Yellowknife Bay. Draft technical memorandum submitted June 2, 2015, to Brad Thompson, Public Works and Government Services Canada, Edmonton, AB, Canada.**
Technical Review by:	**Stantec Consulting Ltd.**
Date of Technical Review:	August 14, 2015

Priority

- 1: Comment for information/clarification
- 2: Recommendation for revision to deliverable
- 3: Recommendation for evaluation / inclusion in next phase of project

	Reviewer Comments		Priority	Author Response to Comment	TRC Direction
Comment #	Page/Section	Comment	1 – 2 - 3		
1	-	The scope of work in the Terms of Reference lists tasks to be completed as part of the Phase 1 Gap Analysis as follows: Review of all available reference and site water quality information; Evaluation of Baker Creek Diversion Options; Characterize future water quality conditions; Clarification of Report of Environmental Assessment Measures; and Gathering of background information for identifying parameters of potential concerns. The report does not describe how the 'Clarification of Report of Environmental Assessment Measures' was accomplished or what the result was.	2	Section 2.4 of Golder's work plan (Reference No.: 1313770115-008-WP-Rev2-4000) provides a summary of the activities to clarify REA measures 11, 12, and 13, specifically in regards to compliance locations, use of CCME (2003) vs CCME (2007) protocols for SSWQO derivation, use of guidelines from other jurisdictions, and areas used as drinking water sources as well as plans for the City of Yellowknife drinking water intake. Activities included conversations between Golder, PWGSC, and AECOM to obtain information from public hearings and technical sessions relevant to the interpretation of the REA Measures. In brief, additional consultation with MVLWB will be required during Phase 2 of this study to confirm the appropriateness of using both CCME (2003) and CCME (2007) to derive SSWQOs, to determine the most appropriate compliance locations with regards to protection of all water uses (aquatic life, recreational use, drinking water), and further interpretation of the REA Measures. Phase 2 of this study is related to the development of SSWQOs, and therefore additional work to clarify REA measures 11, 12, and 13 are deferred to the Phase 2 deliverable. No changes will be made to the final technical memorandum (Water Quality Modelling Results for Baker and Shot Creeks, and Yellowknife Bay) in response to this comment.	
2	-	The scope of work in the Terms of Reference lists tasks to be completed as part of the Phase 1 Post-Gap Analysis as follows: Provide an Updated Water Quality Summary; Predict Future Water Quality; Evaluate Mixing for in-Stream Portions of Watershed; Mixing Reach Zero of Baker Creek; and Plume Dispersion Modelling in Yellowknife Bay. The report does not describe how the 'Evaluation of mixing for in-stream portions of the watershed' was accomplished or what the result was.	2	Section 4.4 "In-Stream Mixing Assessment" was added to the final technical memorandum. This additional information did not change the overall key findings of the water quality modelling.	
3	6/3.2.1	Model Configuration: one of the assumptions listed for the modelling approach is that the water quality parameters being considered are conservative (i.e., do not react within the watershed). In Section 3.1.1 on page 3 it is noted that the dataset includes arsenic speciation. Entry of arsenic into surface waters and its subsequent fate and transport is not a conservative process, as speciation demonstrates – how were the species results 'amalgamated' into a single measure for arsenic? Did doing so introduce any uncertainty in the results?	1	Although the datasets included arsenic speciation, the mass balance only considered total arsenic. The modelling assumes arsenic is conserved. This has been clarified in the final technical memorandum (Section. 3.1.2)	
4	5-12/3.2	Mass Balance: the Methods section does not contain any information on model calibration. Model calibration is a key step in model development and application, which usually occurs before model verification (confirmation that the model is numerically calculating outputs correctly) and validation (confirmation that the model meets its requirements, by comparison of model results with numerical data independently derived from observations of the environment). It would be expected that model variables (e.g., parameter concentrations for non-point sources) would be adjusted as part of a calibration process until a best match is achieved with observed concentrations under existing conditions. Ref: STOWA/RIZA, 1999, Smooth Modelling in Water Management, Good Modelling Practice Handbook; STOWA report 99-05, Dutch Dept. of Public Works, Institute for Inland Water Management and Waste Water Treatment report 99.036, ISBN 90-5773-056-1	1	The technical memorandum does not contain a specific discussion of model calibration, because the model does not contain any rate constants or other such variables, and the observed data were used without adjustment. The calibration thus consisted of checking that the mass balance model could reproduce, to a reasonable degree, observed data collected from downstream locations within the system. Since it did, no adjustments to the runoff information were made, and no specific calibration was required. This process is outlined in Section 3.2.5, which was entitled "Model Verification". As noted in the review comment, the term "verification" has a specific definition, and we acknowledge that this term was not used correctly. Consequently, the section has been retitled to read as "Model Check" to more accurately reflect what was done.	

	Reviewer Comments		Priority	Author Response to Comment	TRC Direction
Comment #	Page/Section	Comment	1 – 2 - 3		
5	8/3.2.2-3.2.3	Baker Pond Internal Loadings from Tailings (P3): states that this discharge is added "…to contribute the reported annual arsenic load." The source of this reported loading is a 2005 SRK report, as noted in Section 3.2.3. A follow-on assumption that results from this is stated as "…an arsenic concentration of 20 mg/L (e.g., 20 times the concentration of the overlying water) was used with the assumed flow rate of 4 m^3/d to maintain the reported annual arsenic loading to Baker Pond. A similar assumption was applied to the other parameters… These assumptions may be overestimating the loading due to the capping of Jo Jo Lake at the northern end of Baker Pond that has been completed after the SRK study…" It is unclear why the model calibration step was not used to refine this estimated loading value for P3.	1	As stated in Section 3.2.4, the model currently under-predicts average concentrations of arsenic at downstream locations. Addressing this issue would require a reduction in average flow rates, an increase in average incoming mass or some combination thereof. Increasing the mass flux from the P3 source, as suggested in the comment, would run counter to the expected reality – the capping of Jo Jo Lake should have reduced the loading from this source, not increased it. It is for this reason that this item was not altered in an attempt to improve model performance. More broadly, the suggested approach of altering input parameters to improve model performance is valid. However, it was not applied to this exercise for two main reasons: • The data available to define most model inputs were limited. As such, the selection of which variable to alter would have been somewhat arbitrary and difficult to rationalize; and • There is a positive bias in the water balance that cannot be corrected for or compensated for through adjustments to water quality variables. Once more information becomes available, and additional sophistication is added to the mass balance model (i.e., accounting for lake storage), then a more detailed calibration process could be implemented to achieve the goal identified in the review comment. No changes were made to the final technical memorandum in response to this comment.	
6	9/3.2.4	Typographical error before "Equation 1" title.	2	Acknowledged. This typographical error has been fixed in the final technical memorandum.	
7	10/3.2.5	Flow Verification: it states that flow inputs into the spreadsheet mass-balance model were generated using the GoldSim model. Details on this model (i.e., its methods) are not provided in Section 3. A statement is made that "the spreadsheet model does not account for changes in lake elevation." This statement is confusing: assuming evaporative and subsurface losses to be zero, lake elevations would not be expected to change under hydrostatic conditions (i.e., non-hydrodynamic, which is what a steady-state modelling approach provides).	1	Acknowledged. Clarification on this statement has been added to the final technical memorandum, and an attachment that describes the surface water balance model has been added.	
8	10/3.2.5	Flow Verification: it states that "the model is expected to under-predict some water quality parameters during high flow events", and that "the highest concentrations are expected to occur during low flow periods." While true from a parameter concentration perspective, this may not be the case from a parameter loading perspective, i.e., high flow periods, even at lower parameter concentrations, may introduce greater mass of POPCs to the receiving environment. This case, and its potential implications, bears discussion.	1	The final technical memorandum was updated to discuss impacts on loadings (Section 3.2.5).	
9	11-12/3.2.5	Concentration Verification: predicted and measured average concentrations of arsenic and TDS are compared in Table 4 for 2 monitoring locations (SNP 43-5 and SNP 43-16). The differences (-42% and +17% respectively for the two locations for arsenic, and -31% and +9% for TDS) are attributed to "…inaccurate estimates of effluent flow." The level of accuracy observed at monitoring locations upstream from the effluent discharge is not given, and so this attribution is not supported by the information provided. A statement to the effect that "…the model reasonably predicts upstream concentrations (Tapper Creek)" is given in the text following Table 4, however no numerical information on this 'reasonableness' is provided.	1	Acknowledged. Text in the final technical memorandum has been changed to clarify (Section 3.2.5).	
10	11-12/3.2.5	Concentration Verification: the inaccuracy in modelled versus measured parameter concentrations is not applied to future predictions, i.e., no ranges of uncertainties are given for predicted results, in spite of there being inaccuracies in modelled results of existing conditions.	3	Correct. Ranges of uncertainty are not given, because those identified for existing conditions are not expected to be reflective of the levels of inaccuracy associated with future conditions, as per the text included in Section 3.2.5. In addition, the provision of uncertainty bands would imply that more is known about the variability inherent in the system than actually is. No changes were made to the final technical memorandum in response to this comment.	
11	13-14/3.2.2	Representation of Shot Creek Outlet: bullets 1 and 3 refers to Figure 3, however the figure on the following page is Figure 7.	3	Acknowledged. The figure entitled "Predicted Shape of Discharge Plume from Shot Lake with Diversion of Upper Baker Creek" has been revised to be Figure 3 in the final technical memorandum.	

Reviewer Comments			Priority	Author Response to Comment	TRC Direction
Comment #	Page/Section	Comment	1 – 2 - 3		
12	22-23/4.3.2	Plume Description for Baker Creek: there is no discussion of how the CORMIX modelled plume for existing conditions compares to measured conditions in Yellowknife Bay.	3	Since the updated CORMIX predictions for Baker Creek are largely based on the predictions of the previous study, a comparison of the two was not provided in the memo. The differences in the two studies were: • The discharge flow rate was changed from a measured value in August 2009 (0.144 m³/s) to the predicted average flow in August (0.176 m³/s), and • The ambient velocity was changed to 0.02 m/s based on more recent studies (Stantec 2014a), The figure below compares both predicted plumes to two measured plumes using the same discharge and bay conductivities. The figure demonstrates that both of the predicted plumes are representative of the measured plumes and that the differences are minor. 	
13	5,7/3.1.3	In Table 1 effluent from the ETP is designated as point source P1 – this is shown entering Baker Pond on Figure 1, which matches existing conditions. The future scenarios, however, are described in Section 2.1.2 as containing no effluent discharge to Baker Pond. The table and figure should make the distinction between existing and future condition scenarios.	3	Acknowledged. The final technical memorandum has been updated.	

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APPENDIX B
Stream Mixing Length

1.0 STREAM MIXING ASSESSMENT

Assessments of in-stream mixing were completed at locations with documented channel dimensions. This information was only available for Baker Creek at two locations: Reach 4, and below Lower Martin Lake. Channel dimensions were not available for Trapper Creek or Shot Creek; thus, in-stream mixing assessments were not conducted for these creeks. In addition, it is anticipated that improvements to Shot Creek will be required to allow the conveyance of the diversion flow; therefore, the current channel dimensions for this creek will likely change.

A summary of the available channel dimensions for Baker Creek is provided in Table 1. Dimensions were available for slow moving sections (pools or glides) and fast moving sections (riffles).

Table 1: Summary of Measured Channel Geometry for Baker Creek

Parameter	Lower Baker Creek (Reach 4)		Upper Baker Creek (Below Lower Martin Lake)	
	Glide/Pool	Riffle	Glide	Riffle
Bankfull Width (m)	8.35 to 8.70	8.10	7.25 to 9.90	3.35 to 3.80
Bankfull Depth (m)	0.50 to 0.85	0.60	0.65 to 0.75	0.65 to 0.70
Bank Angles (°)	30	30	45 to 90	55 to 90
Channel Slope	<0.5%	5%	<1%	1% to 5%
Bottom Width (m)[(a)]	6.8	6.0	7.4	3.3

[(a)] Estimated based on a trapezoid channel.
Source: Golder (2010), a copy of which is attached (Attachment A).

The downstream distance required for two joining flows to become completely mixed was based on the following equations (Chapra 1997):

$$L_m = 0.1U\frac{B^2}{E_{lat}}$$

$$E_{lat} = 0.6HU^*$$

$$U^* = \sqrt{gHS}$$

where:

L_m	mixing length (m);
U	stream velocity (m/s);
B	mean channel width (m);
E_{lat}	lateral dispersion coefficient (m^2/s);
H	stream depth (m);
U*	shear velocity (m/s);
S	channel slope (m/m); and
g	acceleration due to gravity (9.8 m/s^2).

Since there were no specific measurements of flow depth and velocity, Manning's equation was used to estimate channel depth (H) and stream velocity (U) under specific flow conditions.

The mixing zone assessment was also based on following assumptions and limitations:

- It only considers surface flows, not the mixing of groundwater into surface water.

- The joining flows were assumed to be large enough to cause turbulent mixing that extended at least one third of the width of the main channel. As such, the mixing length calculations assumed a mid-channel discharge location..
- Stream flows generated by GoldSim for average conditions (Attachment B) were used to estimate mean stream flows.
- A simplified trapezoidal channel geometry was assumed for each creek location.
- Man-made or natural features that may increase in-stream mixing (e.g., culverts, waterfalls, weirs) were not considered. However, it is likely that, whatever is the mixing in the creek prior to these structures, water would be well mixed after passing through these structures (such as the culvert under Highway 4 [Reach 1]).

The assessment considered the three scenarios used in other components of this study (i.e., existing conditions, future conditions with no effluent and no diversion, and future conditions with no effluent and with diversion of Upper Baker Creek to the Shot Creek watershed). Based on the existing information, the location where the channel geometry was measured in the upper portion of Baker Creek is upstream of the proposed diversion. Therefore, the flows at this location are not expected to change as a result of the diversion.

The results of the assessment are provided in Table 15.

Table 1: Summary of Mixing Assessment

Location		Scenario	Flow (m^3/s)	Depth (m)	Velocity (m/s)	Mixing Length (m)
Lower Baker Creek (Reach 4)	Glide/Pool	Existing	0.26	0.083	0.45	700
		No Effluent, No Diversion	0.25	0.080	0.45	720
		No Effluent, With Diversion	0.079	0.041	0.29	1,200
	Riffle	Existing	0.26	0.045	0.96	910
		No Effluent, No Diversion	0.25	0.043	0.94	930
		No Effluent, With Diversion	0.079	0.022	0.60	1,600
Upper Baker Creek (Below Lower Martin Lake)	Glide	All Scenarios	0.18	0.063	0.38	1,000
	Riffle	All Scenarios	0.18	0.061	0.90	200

Based on the analysis and results, the following conclusions are provided;

- In Baker Creek, the mixing length increases with a reduction in flow. The diversion increases the mixing length to a greater extent than the elimination of effluent.
- The mixing length is shorter in the fast moving sections (riffles) of Baker Creek above Baker Lake but longer at Reach 4.
- The mixing length of slow moving sections (pools and glides) is shorter than the mixing length of the fast sections (riffles). This suggests that complete mixing is not expected to occur in the slow moving sections. However, because the creek has periodic fast moving sections (riffles) along with culverts that likely

increase mixing, the overall mixing length of Baker Creek is expected to be between the values reported for the two types of sections.

- The culvert under Highway 4 (Reach 1) is expected to provide complete mixing of creek flow at that location. As a result, the discharge to Yellowknife Bay is expected to be well mixed and can be suitably represented by CORMIX.
- The in-stream mixing length calculations support the well mixed assumption used in the mass-balance modelling.

ATTACHMENT A

09-1427-0006 Baker Creek Field Memo (22Oct10)

Golder Associates

CELEBRATING 50 YEARS in 2010

TECHNICAL MEMORANDUM

DATE	October 22, 2010	**PROJECT No.**	09-1427-0006 (2000)
TO	Nathan Schmidt Golder Associates Ltd.		
CC	Project File		
FROM	Andrew Forbes, Yapo Alle-Ando, Rowland Atkins	**EMAIL**	aforbes@golder.com ratkins@golder.com

RE: GEOMORPHIC RECONNAISSANCE AT BAKER CREEK – GIANT MINE, YELLOWKNIFE, NORTHWEST TERRITORIES

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by Public Works and Government Services Canada (PWGSC) to conduct a geomorphic reconnaissance at Baker Creek in support of the proposed channel restoration/diversion works at the former Giant Mine Site, located approximately 5 km north of Yellowknife in the Northwest Territories.

1.1 Physical Setting

With reference to Figures 1 and 2, Baker Creek generally drains from north to south across the Giant Mine Site and discharges to Great Slave Lake at Yellowknife Bay. The lower reaches of the stream, delineated from previous studies as Reaches 0 through 6 (i.e., from the inlet area at Yellowknife Bay to Baker Pond), have been influenced by past mining activities. In contrast, the channel located upstream of Baker Pond has been largely undisturbed.

The Baker Creek Watershed covers approximately 165 km^2 and is characterized by shield terrain (i.e., Canadian Shield geological region), where resistant bedrock hummocks and the legacy of scour and deposition associated with the most recent glaciations has generated irregular drainage patterns, rolling landscape and frequent lakes, ponds and wetlands. The local geology is dominated by Precambrian bedrock, while lake/stream valleys are primarily drift deposits and organics. Land cover in the area includes bare bedrock, open black spruce forest and peatland (Spence, 2006). Permafrost is widespread and mostly discontinuous in the area (Gibson and Reid, 2010).

The regional climate is characterized by long, cold dry winters and short, cool summers with mean annual precipitation on the order of 281 mm (Gibson and Reid, 2010). Streamflow is generally limited to the months of June through September when mean monthly temperatures are at or above 0^{o}C. The annual hydrograph is typically dominated by the spring freshet (i.e., snowmelt generated runoff). Mine effluent is discharged to Baker Pond on a seasonal basis (via the polishing/settling ponds) and provides low flow augmentation in the summer and early fall.

1.2 Objectives and Approach

The purpose of the geomorphic assessment at Baker Creek was to characterize existing channel conditions through the former Giant Mine Site (i.e., Reach 1 through Reach 6), as well as within a reference reach of Baker Creek located upstream of Baker Pond but downstream of Lower Martin Lake. The characterization was to meet the following specific objectives:

- Identify opportunities and constraints, where appropriate, for channel restoration/diversion and aquatic habitat enhancement; and
- Identify reference analogs regarding characteristic channel geometry and substrate to support new channel design works.

As shown in Table 1 below, the geomorphic assessment generally comprised visual inspections of the various channel reaches (i.e., walkovers and/or aerial reconnaissance via helicopter); undertaken from August 31 through September 3.

Table 1: Geomorphic Assessment at Baker Creek; August 31 through September 3, 2010

Date	Field Team – Golder Staff unless indicated	Visual Surveys	Mode of Inspection
Aug 31/10	Yapo Alle-Ando, Andrew Forbes and Paul Vecsei	Reaches 0 and 1	Walkovers
Sept 01/10	Yapo Alle-Ando and Andrew Forbes	Reaches 2, 3 and 4	Walkovers
	Yapo Alle-Ando, Andrew Forbes and Paul Vecsei	Reference catchment and Reaches 0 through 6	Aerial reconnaissance, incl. walkover (at reference reach immediately downstream of Lower Martin Lake)
Sept 02/10	Yapo Alle-Ando, Andrew Forbes, Paul Vecsei and David Abernethy (PWGSC)	Reaches 4, 5 and 6 and reference reach immediately upstream of Baker Pond	Walkovers
Sept 03/10	Yapo Alle-Ando and Andrew Forbes	Trappers Creek	Walkovers

The visual reconnaissance included measurements of bankfull channel geometry and floodplain extent, the identification of substrate materials, patterns of erosion/deposition and instream controls on sedimentation, and the delineation of drainage patterns and sediment sources in the surrounding catchment area. Observations were documented through field notes and photographs.

As part of the visual inspections, channel substrate was sampled at each of Reaches 1 through 6 to verify field descriptions of bed/bank materials. The sediment samples were submitted for grain size testing at Maxxam Analytics in Edmonton, Alberta. The results of the grain size analysis will be used to support the associated hydrology/hydraulic investigations at the site.

2.0 KEY OBSERVATIONS

The key observations of the geomorphic reconnaissance/assessment are provided in the following sections. The visual inspections were conducted under low flow conditions.

2.1 Reach 1

Reach 1 comprises distinct upper and lower sections (described herein as 'Upper Reach 1' and 'Lower Reach 1') that are separated by the culvert crossing at Highway 4. The channel of Lower Reach 1 (refer to Photograph 1) is approximately 100 m in length and oriented generally southwest to northeast. The channel of Upper Reach 1 is approximately 150 m in length and oriented generally northwest to southeast. Upper Reach 1 is bounded on the left and right banks by Highway 4 and A2 Pit, respectively (Photograph 2). Streamflow at Lower Reach 1 discharges to an estuary-like feature (at Reach 0) that is a transition area between Baker Creek and Yellowknife Bay (see Photograph 3).

Photograph 1: Lower Reach 1 at Baker Creek; View looking upstream on August 31, 2010.

Photograph 2: Upper Reach 1 at Baker Creek; View looking upstream on August 31, 2010.

Lower Reach 1

The key observations within Lower Reach 1 are as follows:

- Bed morphology comprised of several engineered riffle-pool sequences and/or transitional runs over a relatively moderate gradient (approx. 2%);
- Riffle feature located immediately downstream of Highway 4 characteristic of a notched rock weir that appears to support raised water levels at the culvert outfall;
- Channel geometry relatively trapezoidal with bank angles on the order of 40° to 50°;
- Channel straightened and moderately entrenched below the surrounding terrain;

- Bank/instream vegetation relatively minor; and
- Bed and banks composed of mostly angular cobble to gravels; noting, bed materials included sands and finer gravels as a matrix.

Measurements of bankfull width and depth were not obtained at Lower Reach 1 as the channel appeared constructed and therefore not representative of potentially restored (i.e., natural) conditions.

According to Paul Vescei, Lower Reach 1 provides important fish habitat and spawning areas during the spring freshet. In particular, the riffle at the downstream end of the reach (see Photograph 1) supports a critical seasonal feeding ground.

Upper Reach 1

The key observations at Upper Reach 1 are listed below:

- Bed morphology limited (i.e., channel relatively flat bottomed) over a low gradient (< 0.5%);
- Channel geometry trapezoidal with steep banks (> 60°),
- Channel straightened and mostly confined;
- Substrate predominated by angular cobbles and gravels;
- Bank/instream vegetation relatively sparse;
- Beaver dam (approx. 0.4 m in height) identified at upstream end of reach;
  - This area is characterized by a narrow section of channel that appears blasted/excavated through bedrock outcrop); and
- Culvert crossing (and channel at Lower Reach 1) oriented relatively perpendicular to the channel at Upper Reach 1; representing a relatively sharp/abrupt change in channel alignment.

Measurements of bankfull width and depth were not obtained at Upper Reach 1 as the channel appeared constructed and therefore not representative of potentially restored (i.e., natural) conditions.

Anecdotal information from Paul Vescei indicates that ice jam related flooding has been reported at the upstream end of the culvert crossing during spring freshet. A topographic low to the south of the culvert inlet (associated with a small tributary stream) is understood to represent an overflow/backwater area during high flow events.

Proposed Diversion/Restoration at Reach 1

With reference to Photograph 3, a new culvert crossing and associated channel restoration/diversion has been discussed at Reach 1 to facilitate a sweeping bend at the watercourse in place of the sharp/abrupt change in channel alignment under existing conditions. Based on field observations, the proposed diversion appears achievable; noting that the restoration works would improve flow conveyance, as well as enhance overall channel form/function.

Photograph 3: Reach 0 through 2 at Baker Creek; Oblique view looking west circa July, 2010 with arrow showing possible orientation of new culvert crossing and associated channel restoration/diversion.

2.2 Reach 2

The channel at Reach 2 is approximately 200 m in length and oriented generally north to south. The surface water feature is flanked to the east and west by Highway 4 and A1 Pit, respectively (Photographs 4 and 5). Reach 2 is understood to be largely undisturbed by mining activities with perhaps the notable exception of two former road crossings (one is shown in Photo 4).

Photograph 4: Reach 2 at Baker Creek; Oblique view looking northwest circa June, 2010

Photograph 5: Reach 2 at Baker Creek; View looking upstream on September 1, 2010

The key observations at Reach 2 are as follows:

- Largely peat/wetland controlled bed morphology characterized by a slight meandering pattern and instances of multi-threaded channel or extensive ponding;
- Channel well connected with surrounding riparian/floodplain areas;
- Substrate at bed/bank dominated by organics and fine grained materials (with cobble to gravel sized sediment at the occasional riffle or bedrock high point);
- Channel aggraded in places; noting several fine grained depositional features such as medial and side channel bars;
- Channel margins generally lined with dense vegetation (including various grasses and shrubs) and supported ponded water and/or diffuse flows;
- Two tributary channels identified at Reach 2;
  - These surface features capture runoff from the headland areas to the west of the channel and direct the water away from Pits A1 and A2; and
- Two former road crossings identified at the lower and middle portions of the reach;
  - The crossing at the lower end has been breached, while the crossing at the mid-reach location (see foreground in Photograph 4) includes a partially collapsed culvert that conveyed low flows and a breached area of the embankment that likely accommodates higher flow events.

Measurements of bankfull width and depth were not taken as this reach was more like a wetland than a channel.

2.3 Reach 3

Reach 3 is approximately 750 m in length and comprises an engineered diversion channel (Photographs 6 and 7). The majority of the channel is aligned north to south and bounded to the east and west by Pit C1 and a bedrock headland, respectively.

Photograph 6: Reach 3 at Baker Creek; View looking upstream on September 1, 2010

Photograph 7: Reach 3 at Baker Creek; View looking downstream on September 1, 2010

The key observations at Reach 3 are listed below:

- Bed morphology generally limited (i.e., channel relatively flat bottomed) over a low gradient (< 0.5%) with occasional invert controls composed of cobbles/gravels or bedrock;
- Lower portion of reach characterized by a riffle-run section over a moderate gradient (approx. 2%);
- Channel straightened and substantially entrenched/confined;
  - As an exception, the mid to lower section of reach included a modest floodplain along the left bank of channel (see Photograph 7);
- Channel at upper and lower ends of the reach largely excavated/blasted into surrounding bedrock with near vertical banks;
- Bed substrates mostly reflect adjacent bank materials (i.e. weathered/fractured bedrock or angular cobbles and gravels);
- Some fine grained sediment deposition noted along mid to upper portion of reach (silt to fine sands and organic materials);
- Bank/instream vegetation relatively sparse; and
- Lower portion of Reach 3 includes two sharp/abrupt changes in channel alignment (including the tie in with Reach 2).

Measurements of bankfull width and depth were not obtained at Reach 3 as the channel appeared constructed and therefore not representative of potentially restored (i.e., natural) conditions.

Proposed Diversion/Restoration at Reach 3

With reference to Photograph 8, a channel restoration/diversion has been proposed at Reach 3. The preferred alignment includes the existing corridor of Highway 4. Based on field observations, the proposed diversion appears achievable and consistent with the broader valley alignment of Baker Creek. The restoration works would be constrained by the following challenges:

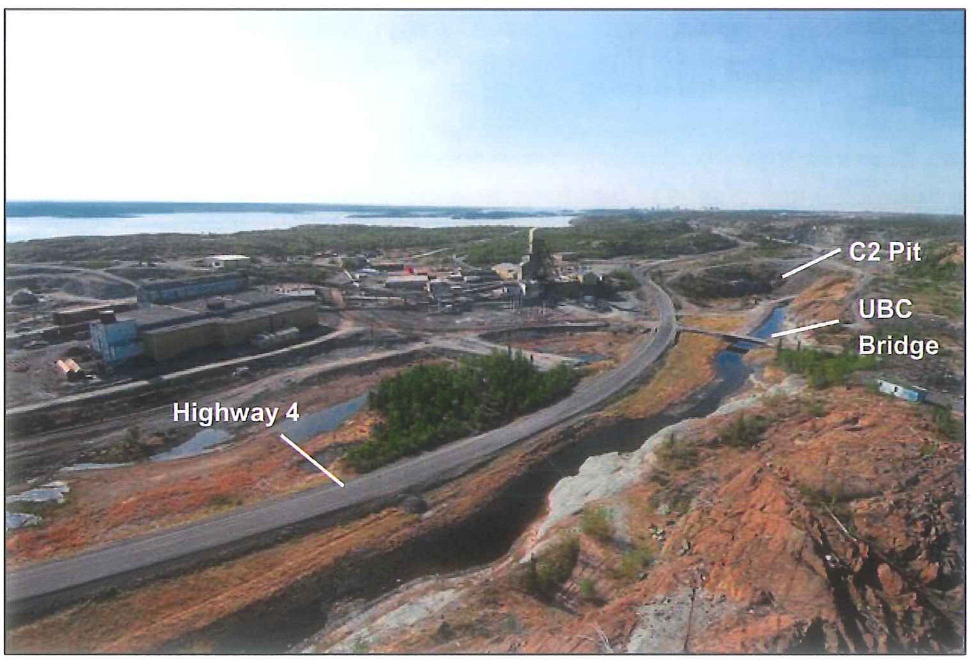
1) The north end of C2 Pit extends to the upstream end of existing Reach 3. As a result, the upper end of the proposed diversion may require tie in at a location upstream of UBC Bridge in Reach 4 (see Photograph 8).

2) The topography is relatively muted at the upper end of the proposed diversion; hence, significant excavation would be required to facilitate a suitable channel gradient.

3) Mine waste and/or tailings influenced drift/overburden is likely present along existing highway alignment and would require removal/management.

4) Underground arsenic chambers are present near the north end of C2 Pit and at the downstream end of the restored channel (Reach 4), thus the proposed channel realignment from Reach 4 to Highway 4 will cross over these chambers.

Photograph 8: Reach 3 and 4 at Baker Creek; Oblique view looking south/downstream circa July, 2010, along preferred channel diversion scenario (i.e., Highway corridor to the south of UBC Bridge).



2.4 Reach 4

Reach 4 is approximately 400 m in length and comprises an engineered/restored channel that was completed in 2007 (Photographs 9 and 10). The channel reach is aligned generally north to south and bounded to the east and west by Highway 4 and a bedrock headland, respectively.

Photograph 9: Reach 4 at Baker Creek; View looking upstream on September 1, 2010.

Photograph 10: Reach 4 at Baker Creek; View looking upstream on September 2, 2010.

The key observations at Reach 4 are as follows:

- Bed morphology characterized by several engineered riffle-pool sequences over a modest channel gradient (0.5% to 1.0%), including a particularly prominent pool/pond area in the mid portion of the reach;
- Cross section geometry relatively broad (compared to the downstream reaches) with respective channel widths and depths of 8 m to 15 m and 0.5 m to 1.5 m;
- Channel and riparian areas well connected at most locations via a two staged floodplain;
  - As an exception, moderate entrenchment was noted at the mid-reach pool/pond area, where the channel is located immediately adjacent to Highway 4 on the left bank (east side) and flanked by a bedrock headland on the west side;
- Bed substrate at riffle and pools composed of angular cobbles to gravels and mostly fine and coarse gravels, respectively.
- Occasional boulders noted at pools (likely installed as velocity shadows/shelters);
- Some trace fine grained deposition (mostly silt and organics) identified at pools;
- Bank substrate dominated by angular cobbles with some gravels; and
- With some exceptions, riparian areas generally well vegetated with mostly grasses.

According to Paul Vescei, Reach 4 provides important fish habitat/refuge, whereby fish typically bypass Reaches 2 and 3 during migration between Reaches 1 and 4. In particular, fish have tended to use the respective (toe of) riffles and glides at Reach 4 for feeding and spawning.

Detailed measurements of bankfull channel geometry and floodplain extent were obtained at representative riffle, pool and glide features at Reach 4 and included the identification of bed/bank materials. The results are presented in Tables 2A and 2B below and will be used to support the channel restoration/diversion works at the site.

Table 2A: Estimated Channel Geometry for Restored/Engineered features at Reach 4

Station [(1)]	Feature	Bankfull Width (m)	Bankfull Depth (m)	Bank Angles (LB / RB)	Channel Gradient	Floodplain Length (m) (LB / RB) [(2)]
4A	Glide [(3)]	8.70	0.50	30° / 30°	<0.5%	10 and 20 / 5
4B	Riffle	8.10	0.60	30° / 30°	5%	10 and 20 / 5
4C	Pool	8.35	0.85	30° / 30°	<0.5%	5 and 18 / 4

[1] Station 4A located at UTM coordinate 11V 635891.9 6932884.4 (NAD83); noting that Station 4B and Station 4C located approximately 10 m and 40 m downstream of Station 4A, respectively.

[2] Left bank floodplain characterized as two staged; noting that the two reported values represent the lateral extent of the respective near-channel (lower) and outlying (upper) portions of the floodplain.

[3] Glide denotes the area immediately upstream of the riffle crest.

Table 2B: General descriptions of bed and bank materials for Restored/Engineered features at Reach 4

Station [(1)]	Bed Substrate	Bank Substrate (LB / RB)
4A	Fine to coarse gravels with trace fines	Mostly cobbles with coarse gravels
4B	Cobbles with fine/coarse gravels and some boulders	Mostly cobbles with coarse gravels
4C	Fine to coarse gravels with some cobbles and trace fines	Mostly cobbles with coarse gravels

Existing Channel Rehabilitation at Reach 4

For the most part, the engineered/restored channel appears to be in relatively stable condition. However, several issues were identified that may require remediation and, as a minimum, should be considered in any future channel restoration works:

1) Tension cracks were identified along the top of bank. This was particularly prominent (i.e., over a distance of 20 m to 40 m) on the left bank of the mid-reach pool/pond area, where the channel is located immediately adjacent to Highway 4 (Photograph 9).

2) Rill/gully erosion was observed at several locations along the banks. In particular, a gully feature with a approximate width and depth of 0.5 m and 0.3 m, respectively, was identified on the left bank (east side) of the channel at a location approximately 50 m upstream of the UBC bridge crossing. This area supported limited vegetation cover.

3) Riffle collapse was identified at a location immediately upstream of the UBC bridge crossing (Photograph 10). The feature had apparently failed due to land and/or permafrost subsidence.

Photograph 9: Reach 4 at Baker Creek; View looking upstream at tension cracks – September 2, 2010.

Photograph 10: Reach 4 at Baker Creek; Sideview of collapsed riffle structure – September 2, 2010.

2.5 Reach 5

The channel at Reach 5 is approximately 400 m in length and oriented generally north to south. The surface water feature is bounded by B2 Pit at the southern end of the reach (Photograph 11), but understood to be largely undisturbed by mining activities (Photograph 12).

Photograph 11: Reach 5 at Baker Creek; Oblique view looking west on September 1, 2010.

Photograph 12: Reach 5 at Baker Creek; View looking upstream on September 2, 2010.

The key observations at Reach 5 are as follows:

- Mostly peat/wetland controlled morphology reflected by a slight meandering pattern, poorly defined stream banks and multi-threaded channel.
- Bedrock controls noted at the downstream end of the reach, characterized by a series of riffle/cascades that were flanked by engineered berms/embankments (composed of angular cobbles to gravels).
- Channel well connected with surrounding riparian/floodplain areas;
- Bed substrate dominated by organics and fine grained materials (with cobbles/gravels and/or bedrock at the downstream end of the reach);
- Channel margins and instream areas generally lined with dense vegetation including various grasses and shrubs; and
- Beaver dam (approx. 0.8 m in height) identified at upstream end of reach;
  - This area was characterized by a narrow section of channel that represented the outlet area of Baker Pond.

Measurements of bankfull width and depth were not taken as this reach was more like a wetland than a channel.

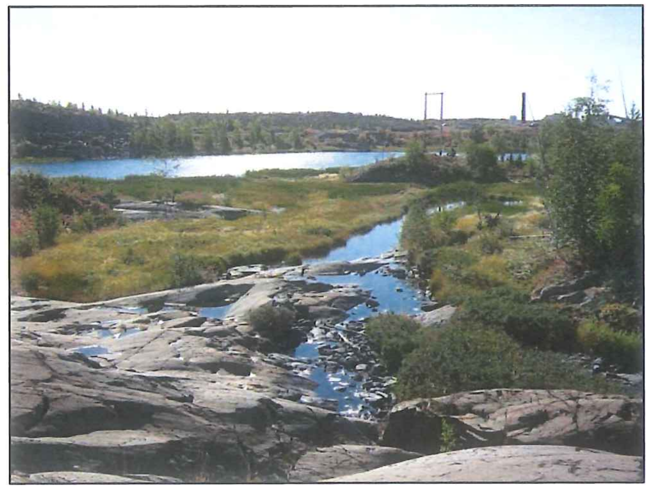
2.6 Reach 6

Reach 6 represents Baker Pond with a surface area of 6 Ha and a maximum depth of approximately 1.5 m to 2.0 m. Baker Pond receives seasonal inflows from the following:

- Baker Creek (upstream catchment and reference reach) from the west;
- Trapper Creek from the north; and
- Mine effluent (via polishing/settling ponds) from the northeast.

Photograph 13: Reach 6 (Baker Pond); View looking north/upstream on September 1, 2010.

Photograph 14: Reach 6 (Baker Pond); View looking east from the inlet area of Baker Creek Reference on September 2, 2010



The key observations at Baker Pond are as follows:

- Well vegetated along pond margins; and
- Substrate comprised of mostly organics and fine grained materials.

2.7 Baker Creek Reference - Baker Pond to Lower Martin Lake

As previously described, the portion of Baker Creek located upstream of Baker Pond has been largely undisturbed by anthropogenic activities and considered characteristic of background/reference conditions. The channel reach between Baker Pond and Lower Martin Lake, in particular, was largely well-defined/incised (Photographs 15 and 16) and subsequently targeted to evaluate reference analogs of channel geometry for the proposed restoration/diversion works at the site. This section of channel totals approximately 2.6 km in length and is described herein as 'Baker Creek Reference'.

To assist with the field observations described herein, Baker Creek Reference was subdivided into the three components shown in Table 3 based on the characteristic biophysical or geologic controls and relative channel gradient:

Table 3: Baker Creek Reference Sub-Reaches

Sub-Reach	Length (m)	General Location	Biophysical/ Geologic Controls	Relative Channel Gradient
Lower	650	Immediately upstream of Baker Pond	Bedrock	Moderate to High
Middle	1350	Baker Creek Plateau near Pocket Lake	Peat/wetland	Low
Upper	600	Immediately downstream of Martin Lake	Bedrock	Low to Moderate

Photograph 15: Baker Creek Reference – Upper sub-reach (downstream of Lower Martin Lake); View looking upstream on September 1, 2010.

Photograph 16: Baker Creek Reference – Middle sub-reach (Baker Creek Plateau near Pocket Lake); View looking downstream on September 1, 2010.

The key observations at the Upper and Lower sub-reaches are listed below:

- Bed morphology generally characterized by riffle-pool to riffle-run sequences and/or bedrock cascades;
- Channel gradients relatively modest at Upper sub-reach (<1.0%) and moderate to high at Lower sub-reach (approximately 2% to 10%);
- Channel geometry relatively broad at Upper sub-reach (with bankfull width and depth on the order of 8.0 m and 0.7 m) and comparably narrow at Lower sub-reach (with bankfull width and depth on the order of 3.5 m and 0.7 m)
- Channel well connected with overbank areas (where applicable);
- Bed substrate comprised of sub-angular cobble to coarse gravels and occasional boulders with a matrix of coarse sand to fine gravels or bedrock;
- Bank substrate mostly comprised of organics and fine grained materials (silt and sand) or bedrock; and
- Riparian areas well vegetated with mostly grasses and shrubs.

As described by Paul Vescei, the prominent cascade areas located at the Lower sub-reach of Baker Creek Reference represent barriers to fish passage (i.e., immediately upstream of Baker Pond and immediately downstream of the Baker Creek Plateau).

The key observations at the Middle sub-reach are as follows:

- Mostly peat/wetland controlled morphology characterized by a marked meandering pattern, poorly defined stream banks and instances of multi-threaded channel or extensive ponding;

- Channel gradients relatively low (<0.5%);
- Channel well connected with surrounding floodplain areas; noting riparian zone supports standing water and/or diffuse flows;
- Substrate composed of mostly fine grained materials (organics with silt and sand) and occasional sub-angular cobble/boulder sized materials or bedrock; and
- Channel margins and instream areas generally lined with dense vegetation including various grasses and shrubs.

At the time of the reconnaissance, Baker Creek Reference supported negligible streamflow. A surface water flow rate of 0.5 L/s was roughly estimated at the outlet of Lower Martin Lake; however, standing water and/or dry channel conditions were observed at various locations further downstream.

Detailed measurements of bankfull channel geometry and floodplain extent were obtained at six (6) representative locations at Baker Creek Reference and included the identification of bed/bank materials. Stations 1 through 3 were located at Upper Baker Creek Reference, while Stations 4 through 6 were located at Lower Baker Creek Reference. The results are presented in Tables 3A and 3B below and will be used as reference analogs of channel geometry to support the channel restoration/diversion works at the site. Channel and substrate conditions at Stations 2 and 4 are shown in Photographs 17 through 20.

Table 4A: Estimated Channel Geometry at Reference Baker Creek, located downstream of Martin Lake

Station	UTM NAD83 Zone 11V		Bankfull Width (m)	Bankfull Depth (m)	Bank Angles (LB / RB)	Channel Gradient	Floodplain Length (m) (LB / RB)
	Easting	Northing					
1	633341.7	6934016.0	7.50	0.75	45° / >80°	<1%	10 / nil
2	633417.1	6933909.0	9.90	0.70	40° / 20°	<1%	15 to 20 / nil
3	633439.9	6933884.7	7.25	0.65	90° / 75°	<1%	5 to 10 / nil
4	635641.5	6933903.9	3.35	0.65	70° / 70°	1% to 2%	5 / 15
5	635709.8	6933828.9	3.80	0.65	55° / 90°	4% to 5%	15 to 20 / 2
6	635796.0	6933697.1	3.60	0.75	80° / 90°	3% to 4%	nil / 5

Table 4B: General descriptions of bed and bank materials at Reference Baker Creek, located downstream of Martin Lake

Station	Bed Substrate [1]	Bank Substrate (LB / RB)
1	Cobbles with gravels and some boulders	Bedrock / Silt loam with organic materials
2	Cobbles and some boulders	Silt loam with organic materials / Bedrock
3	Cobbles with gravels and some boulders	Silt loam with organic materials / Bedrock
4	Cobbles with boulders	Organics with silt and sand on both sides
5	Cobbles with boulders	Organics with silt and sand on both sides
6	Cobbles with boulders	Organics with silt and sand on both sides

[1] Fine grained matrix noted at all stations and largely characterized by fine gravels with medium to coarse sand

Photograph 17: Station 2 at Baker Creek Reference; View looking upstream on September 1, 2010.

Photograph 18: Station 2 at Baker Creek Reference; View of channel substrate on September 1, 2010.

Photograph 19: Station 4 at Baker Creek Reference; View looking upstream on September 1, 2010

Photograph 20: Station 4 at Baker Creek Reference; View of channel substrate on September 1, 2010.

Reference Catchment Upstream of Lower Martin Lake

The catchment area located upstream of Lower Martin Lake was bedrock dominated and characterized by an extensive network of lakes and peat/wetland areas (Photographs 21 and 22). The topography of the surrounding terrain was muted to gently rolling, dissected by mostly low profile valleys. Surface water connections were largely absent throughout the system; noting that a few shallow, poorly defined stream channels were identified along the West Bay Fault Line (i.e., geologic feature expressed by a string of lakes that trend northwest-southeast in a linear pattern). The drainage system upstream of Lower Martin Lake likely supports diffuse flows on a relatively seasonal basis (i.e., during spring freshet and following large rainfall events), whereby surface water connectivity and associated catchment size is highly variable and largely dependent on the variations in lake levels.

Photograph 21: West Bay Fault near Vital Lake; View looking north/upstream on September 1, 2010.

Photograph 22: Duckfish Lake; View looking north on September 1, 2010.

2.8 Trapper Creek

Trapper Creek drains to the north end of Baker Pond via a largely engineered channel that originates at Trapper Lake (Photographs 23 and 24). The channel is oriented generally north to south and bounded at the upstream end by Northwest Pond and a local road to the respective east and west.

Photograph 23: Trapper Creek; View looking downstream toward Baker Pond on September 2, 2010.

Photograph 24: Trapper Creek; View looking upstream toward Trapper Lake on September 2, 2010.

The key observations at Trapper Creek are as follows:

- Bed morphology relatively subdued.
- Upper portion of the reach largely represented by a peat/wetland area;
- Channel gradients, where applicable, ranged from approximately <0.5% to 2%;
- Channel geometry, where applicable, largely trapezoidal with bank angles on the order of 40° to 50°; noting, an incised thalweg channel (with an approximate bankfull width and depth of 0.5 m and 0.5 m) was entrenched within the larger ditch/channel feature for the majority of the reach;
- Substrate predominated by fine grained materials (silt and sand) with occasional angular cobbles and gravels;
- Banks and riparian areas well vegetated; and
- Two culvert crossings identified; noting, the one nearest Baker Pond was completely plugged at the downstream end.

Minor flows (~ 0.25 L/s) and/or standing water were identified along the extent of Trapper Creek (i.e., from Baker Pond to Trapper Lake) at the time of the reconnaissance. The sustained flows and/or ponded water at Trapper Creek likely reflect surface water flows from Trapper Lake coupled with subsurface contributions from Northwest Pond.

AF/RA

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References:

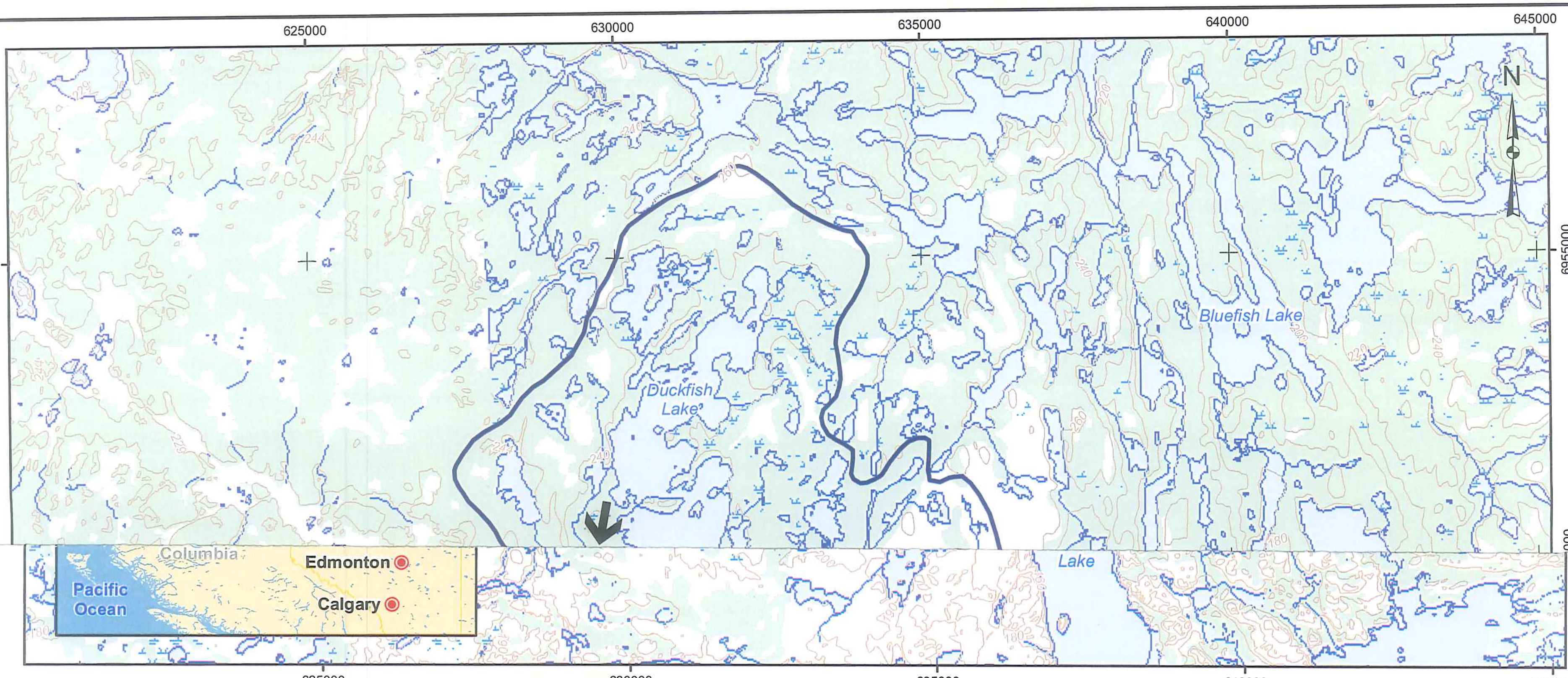
Gibson, J.J. and Reid, R. 2010. Stable isotope fingerprint of open-water evaporation losses and effective drainage area fluctuations in a subarctic shield watershed. Journal of Hydrology 381, 142-150.

Spence, C. 2006. Hydrological processes and streamflow in a lake dominated watercourse. Hydrological Processes 20, 3665-3681.

Attachments:

Figure 1

Figure 2



LEGEND

- Lake Inlet
- General Flow Direction
- Highway 4
- Watercourse
- Contours
- Baker Creek Watershed
- Waterbody
- Wooded Area
- Wetland

REFERENCE

Base data obtained from Natural Resources Canada (NTS 085J07/08/09/10)
Projection: UTM Zone 11 Datum: NAD 83

3 0 3
SCALE 1:100,000 KILOMETRES

PROJECT
GIANT MINE SITE
YELLOWKNIFE, NWT

TITLE
BAKER CREEK WATERSHED

Golder Associates
Greater Vancouver Office, B.C.

PROJECT NO. 09-1427-0006			PHASE No. 2000	
DESIGN	ME	21 Oct. 2010	SCALE AS SHOWN	REV. 0
GIS	ME	21 Oct. 2010	FIGURE: 1	
CHECK	AF	21 Oct. 2010		
REVIEW	AF	21 Oct. 2010		

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Photograph 23: Trapper Creek; View looking downstream toward Baker Pond on September 2, 2010.

Photograph 24: Trapper Creek; View looking upstream toward Trapper Lake on September 2, 2010.

The key observations at Trapper Creek are as follows:

- Bed morphology relatively subdued.
- Upper portion of the reach largely represented by a peat/wetland area;
- Channel gradients, where applicable, ranged from approximately <0.5% to 2%;
- Channel geometry, where applicable, largely trapezoidal with bank angles on the order of 40° to 50°; noting, an incised thalweg channel (with an approximate bankfull width and depth of 0.5 m and 0.5 m) was entrenched within the larger ditch/channel feature for the majority of the reach;
- Substrate predominated by fine grained materials (silt and sand) with occasional angular cobbles and gravels;
- Banks and riparian areas well vegetated; and
- Two culvert crossings identified; noting, the one nearest Baker Pond was completely plugged at the downstream end.

Minor flows (~ 0.25 L/s) and/or standing water were identified along the extent of Trapper Creek (i.e., from Baker Pond to Trapper Lake) at the time of the reconnaissance. The sustained flows and/or ponded water at Trapper Creek likely reflect surface water flows from Trapper Lake coupled with subsurface contributions from Northwest Pond.

AF/RA

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LEGEND

R0 Reach ID
Flow Direction
Reach Break

300 0 300
SCALE 1:11,000 METRES

REFERENCE
Base data obtained from Natural Resources Canada (NTS 085J07/08/09/10)
Imagery - Public Works and Government Services Canada
Projection: UTM Zone 11 Datum: NAD 83

PROJECT
GIANT MINE SITE
YELLOWKNIFE, NWT

TITLE
BAKER CREEK
REACHES 0 THROUGH 6

Golder Associates
Greater Vancouver Office, B.C.

PROJECT NO. 09-1427-0006			PHASE No. 2000	
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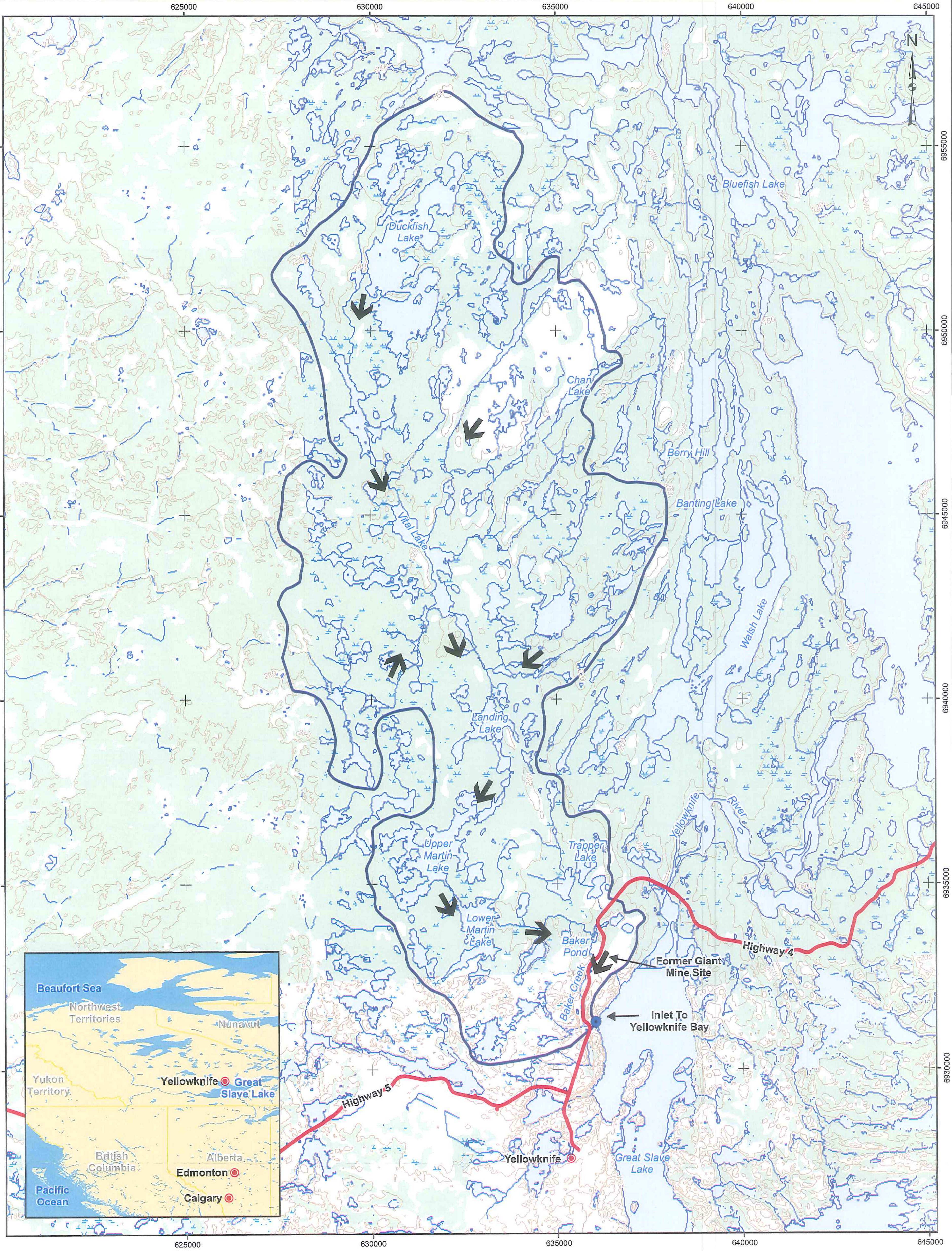
CHECK	AF	21 Oct. 2010		
REVIEW	AF	21 Oct. 2010		



LEGEND

- Lake Inlet
- General Flow Direction
- Highway 4
- Watercourse
- Contours
- Baker Creek Watershed
- Waterbody
- Wooded Area
- Wetland

REFERENCE

Base data obtained from Natural Resources Canada (NTS 085J07/08/09/10)
Projection: UTM Zone 11 Datum: NAD 83

3 0 3
SCALE 1:100,000 KILOMETRES

PROJECT

GIANT MINE SITE
YELLOWKNIFE, NWT

TITLE

BAKER CREEK WATERSHED

Golder Associates
Greater Vancouver Office, B.C.

PROJECT NO. 09-1427-0006			PHASE No. 2000	
DESIGN	ME	21 Oct. 2010	SCALE AS SHOWN	REV. 0
GIS	ME	21 Oct. 2010	FIGURE: 1	
CHECK	AF	21 Oct. 2010		
REVIEW	AF	21 Oct. 2010		

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APPENDIX C
Surface Water Balance Goldsim Model

Golder Associates

TECHNICAL MEMORANDUM

DATE 25 November 2015 **PROJECT No.** 13-1377-0115

TO Adwoa Cobbina
Golder Associates Ltd. (Internal)

CC Nathan Schmidt

FROM Julien Lacrampe; Jeremy Greshuk **EMAIL** julien_lacrampe@golder.com

SURFACE WATER BALANCE GOLDSIM MODEL

1.0 INTRODUCTION

A surface water balance model was developed for Baker Creek, upstream of Yellowknife Bay, to provide surface water flow estimates to the water quality team for further water quality assessment, not discussed herein. The water quality team requested three climate scenarios, including a wet year, an average year, and a dry year scenario.

This technical memorandum describes each climate scenario, as well as the water balance model including input data, model structure, and results. An overview of the Baker Creek watershed, separated into sub-watersheds relevant to the water balance model, is presented in Figure 1.

2.0 CLIMATE

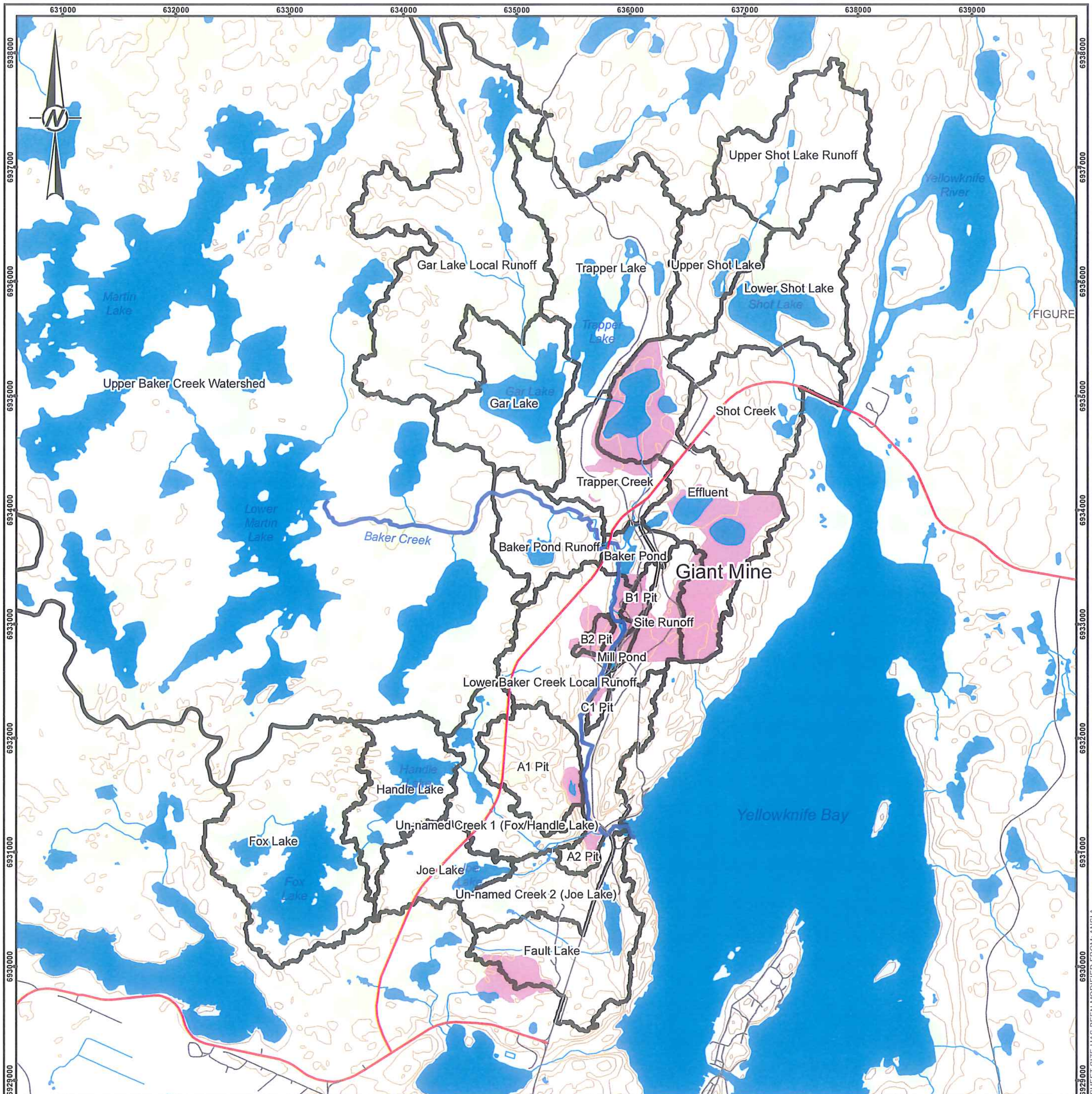
2.1 Meteorological Data

Mean daily temperature, rainfall, and snowfall data were available from Environment Canada station 2204100 (i.e., Yellowknife A) from 1942 to April 2015 (Government of Canada 2015a).

The regional records are comprised of years with major data gaps (i.e., defined for the purpose of this model as a year with less than 340 days of available precipitation and temperature data) and years with minor data gaps (i.e., incomplete years with more than 340 days of available precipitation and temperature data). A cutoff of 340 days was chosen to separate years with major data gaps from years with minor data gaps based on a review of regional datasets. This method was intended to reduce the uncertainty related to the use of partial regional datasets requiring detailed analysis for infilling.

During the period of 1942 to 2015 at Yellowknife, years with major data gaps include 1942, 1944 and 2013, while years with minor data gaps include 1943, 1945, 1946, 1947, 1949, 1951, 1993, 1996, 2008, 2009, 2012 and 2014.

All minor data gaps were infilled based on the closest regional climate station with available data, including Yellowknife CS (Station 2204155), Yellowknife Hydro (Station 2204200) and Yellowknife Henderson (Station 2204110). Years with major data gaps were discarded from the analysis.



LEGEND

- BAKER CREEK
- HIGHWAY
- ROAD
- CONTOUR
- WATERCOURSE
- SUB-WATERSHED
- INDUSTRIAL AREA
- WETLAND
- WATERBODY

0 1 2

1:50,000 KILOMETERS

REFERENCES
1. DATUM: NAD 83; PROJECTION: UTM ZONE 11
2. BASE DATA OBTAINED FROM GEOGRATIS

CLIENT
PUBLIC WORKS AND GOVERNMENT SERVICES CANADA

PROJECT
GIANT MINE REMEDIATION PROJECT

CONSULTANT
Golder Associates

YYYY-MM-DD	2015-07-02
DESIGNED	KM
PREPARED	KM
REVIEWED	
APPROVED	

TITLE

PROJECT NO.	CONTROL	REV.	FIGURE
13-1377-0115		A	1

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25mm

Rainfall and snowfall data were corrected for undercatch, based on the Adjusted Historical Canadian Climate Data (AHCCD) database (Government of Canada 2010). Undercatch correction factors were developed on a month-to-month year-to-year basis and applied to the daily rainfall and snowfall data.

Annual lake evaporation data were available from local evaporation studies at Pocket Lake, from 1994 to 2003, with a mean annual lake evaporation of 414 mm for that period (Reid and Faria 2004).

2.2 Climate and Discharge Scenarios

Three climate scenarios were developed, including a wet scenario, average scenario, and dry scenario. These scenarios were primarily based on total annual precipitation; however, these scenarios were not applied to areas upstream of the outlet of Lower Martin Lake which were based on available hydrometric data from Environment Canada (Government of Canada 2015b).

The water quality team requested that the climate scenarios would be provided as a daily time series based on the hydrologic year (i.e., water year or flow year), instead of the calendar year. Based on the Canadian Climate Normals (1981-2010) of the station Yellowknife A (Government of Canada 2015a), the majority of the rainfall occurs during the summer months (May to October) with very little precipitation falling in November and December (less than 1% of the total precipitation in both months falls as rain). It was assumed that the hydrologic year would start at the beginning of November and continue until the end of October the next year (i.e., November 1 to October 31).

2.2.1 Martin Lake Sub-Basin

The Martin Lake Sub-Basin is a complex drainage network composed of a chain of lakes connected by short stream reaches and has very highly variable connectivity. The runoff response within the Martin Lake Sub-Basin is governed by various tributaries and lakes with flashy, regular and attenuating runoff patterns that are dependent on the current storage within each lake at the time of runoff. This complex network of lakes has a direct influence on the flows within Baker Creek during the spring freshet as well as during significant summer rainfall events. Due to evaporation, storage and attenuation in this complex system of lakes, there are instances wherein a high precipitation event may not necessarily yield a high flow rate in Baker Creek.

For the above reason, the Martin Lake Sub-Basin was not modeled explicitly in the Goldsim model. Instead, the recorded flows at Environment Canada station 07SB013 were grafted to the other modeled sub-basins, discussed in Section 2.2.2.

Environment Canada station 07SB013 (Baker Creek at Outlet of Lower Martin Lake) is located just downstream of Martin Lake, with a reported drainage area of 121 km^2, and a period of record of 1983 to present. It should be noted that the drainage area for station 07SB013 is closer to 155 km^2 (based on personal communication with Chris Spence of Environment Canada) and that the drainage area of 121 km^2 is underestimated. However, the Martin Lake Sub-Basin was not modeled explicitly, and this uncertainty in drainage area does not affect the results of the analysis.

Similar to the climate scenarios, as described in Section 2.2.2, wet, average, and dry year scenarios were based on representative years of the hydrometric data. However, years selected to represent the wet, average, and dry year based on Baker Creek recorded flows are not the same years selected to represent the wet, average, and dry year based on precipitation at Giant Mine due to the upper watershed characteristics. The Baker Creek flows and the precipitation quantities were grafted together in this way to give a plausible representation of a characteristic wet or dry year based on the available data.

The wet, average, and dry year scenarios of the Martin Lake Sub-Basin were derived based on a frequency analysis of long-term Baker Creek flow data at station 07SB013 for the period of 1968 to 2014[1]. Flow corresponding to the 2- (i.e., median), 5-, 10-, 25-, 50-, 100-, 200-, and 500-year wet and dry return periods were derived and are presented in Table 1.

Table 1: Frequency Analysis of Annual Runoff Volume and Annual Peak Flow Rate for Baker Creek

Return Period (Year)		Annual Runoff Volume (m^3)	Annual Peak Flow Rate (m^3/s)
Dry	500	70,000	0.11
	200	139,000	0.12
	100	233,000	0.13
	50	394,000	0.15
	25	668,000	0.19
	10	1,361,000	0.30
	5	2,391,000	0.52
Median	2	5,596,000	1.38
Wet	5	10,529,000	3.07
	10	13,776,000	4.34
	25	17,713,000	6.02
	50	20,504,000	7.30
	100	23,174,000	8.57
	200	25,745,000	9.84
	500	29,019,000	11.5

The wet, average, and dry year scenarios were based on representative years of hydrometric data. The wet year scenario was based on Hydrologic Year 1991-1992 with a total runoff volume of 14,001,000 m^3 and an annual peak flow of 5.99 m^3/s, corresponding approximately to the 1 in 25-year wet year. The average year scenario was based on Hydrologic Year 1997-1998 with a total runoff volume of 5,062,000 m^3 and an annual peak flow of 1.40 m^3/s, corresponding approximately to the 1 in 2-year median. The dry year scenario was based on Hydrologic Year 1999-2000 with a total runoff volume of 504,000 m^3 and an annual peak flow of 0.15 m^3/s, corresponding approximately to the 1 in 50-year dry year. The three scenarios are presented in Figure 2.

Discharges of the three scenarios were grafted to the corresponding climate scenario of other sub-basins, discussed in Section 2.2.2.

[1] Inclusive of data from Environment Canada Station 07SB009 from 1968 to 1982 transferred upstream by drainage area to Station 07SB013.

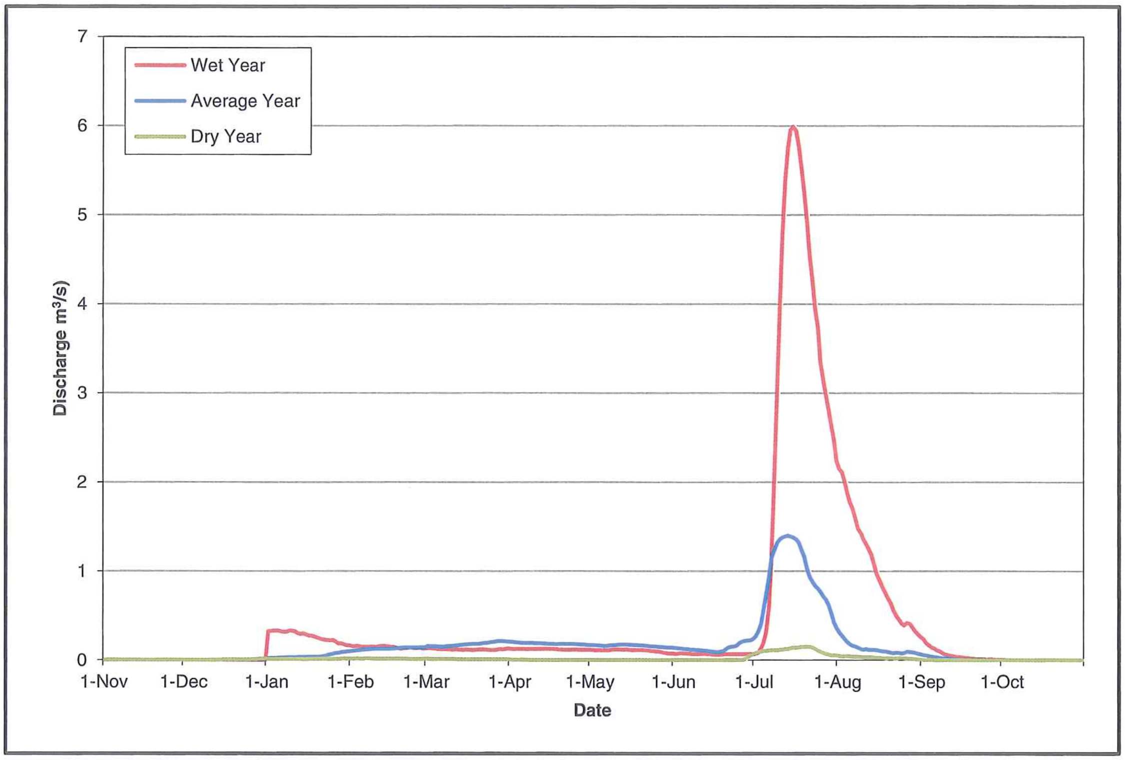


Figure 2: Discharge Scenarios, at the Outlet of Lower Martin Lake

2.2.2 Other Sub-Basins

The flow inputs to the water quality model were required to be a daily time series based on the hydrologic year. Average temperature, average evaporation, and wet, average, and dry rainfall and snowfall were required as time series for the Goldsim model.

2.2.2.1 Average Year

The average year was defined based on a historical year with similar precipitation regimes, including mean monthly and maximum daily precipitation statistics, as the derived historical record for the period of 1942 to 2014 (excluding years with major gaps).

The selected historical year was further validated based on a comparison of monthly precipitation distribution, and temperature regimes, to the derived historical record.

Derived mean monthly and maximum daily precipitation statistics are presented in Table 2 for the period of 1942 to 2014 at Giant Mine. Long-term mean annual precipitation (i.e., average of total annual precipitation, based on the hydrologic year, over the period of 1942 to 2014) was estimated to be 348.3 mm, and mean maximum annual daily precipitation (i.e., average of maximum daily annual precipitation for the period of 1942 to 2014) was estimated to be 27.7 mm.

Based on these statistics, Hydrologic Year 1971-1972 was preliminarily selected to represent average precipitation conditions, with annual precipitation of 350 mm, and maximum daily precipitation of 19.1 mm. A comparison of precipitation regimes is presented in Figure 3, showing similar precipitation regimes between Hydrologic Year 1971-1972 and the historical record.

Comparisons of mean daily temperature statistics are presented in Figure 4, and indicate similar temperature regimes between Hydrologic Year 1971-1972 and the historical record.

As such, daily temperatures and precipitation from Hydrologic Year 1971-1972 were selected to represent conditions of an average year in the water balance model.

Table 2: Mean Monthly and Mean Maximum Daily Precipitation (mm) for the Average Year at Giant Mine

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Monthly	22.5	19.3	19.9	14.3	20.0	26.2	40.4	44.5	37.9	39.5	38.1	26.7	348.3
Mean Maximum Daily	7.1	6.3	6.3	6.6	8.8	11.2	15.5	16.1	13.3	12.0	10.0	7.4	27.7

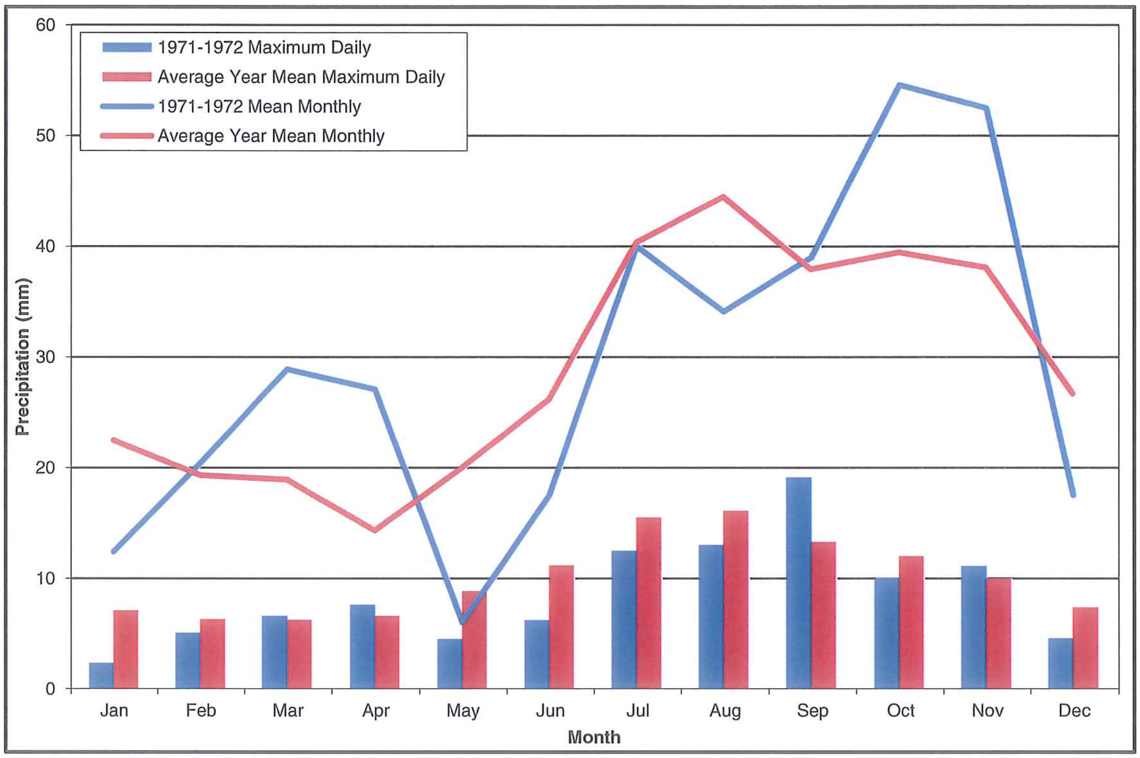


Figure 3: Comparison of Precipitation Regimes between Hydrologic Year 1971-1972 and the Period of 1942 to 2014

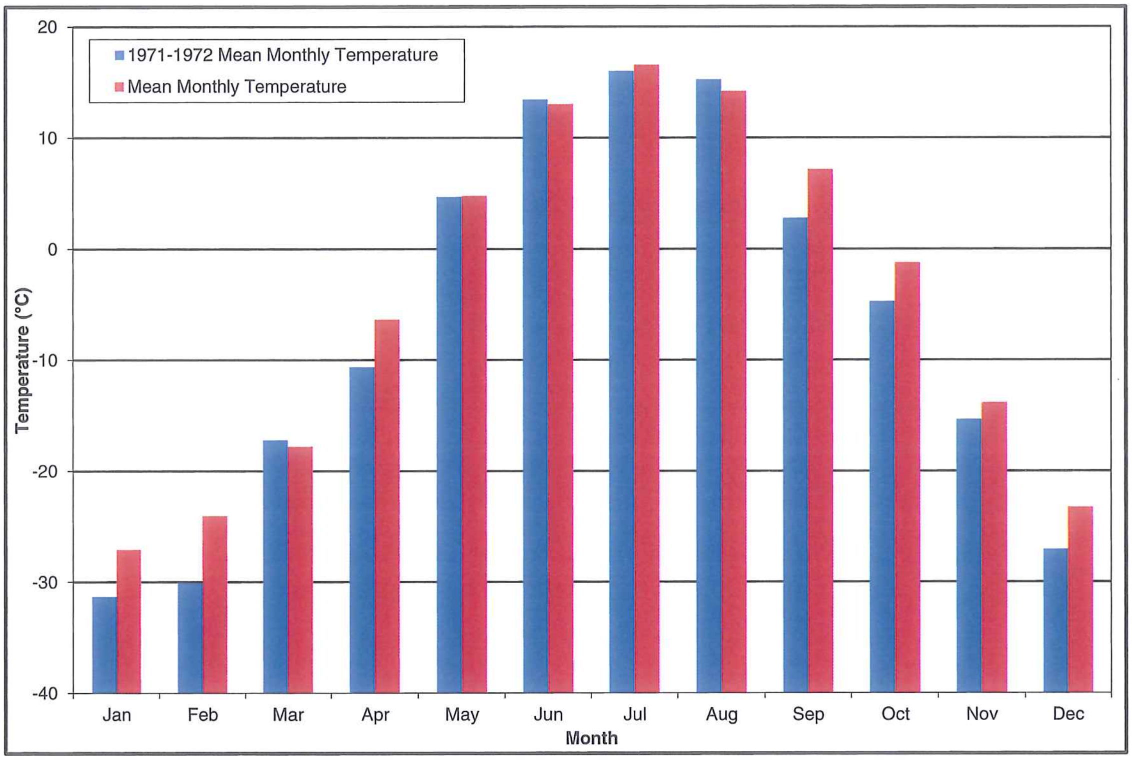


Figure 4: Comparison of Mean Temperature Statistics between Hydrologic Year 1971-1972 and the Period of 1942 to 2014

2.2.2.2 Wet and Dry Years

The wet and dry year scenarios were determined based on a frequency analysis of the total annual precipitation and maximum daily precipitation and selecting a year within the period of record to represent the wet and dry year scenarios.

A frequency analysis of long-term precipitation data at Giant Mine for the period of 1942 to 2014 was conducted on the maximum daily total precipitation and the total annual precipitation. Other frequencies including the 2- (i.e., median), 5-, 10-, 25-, 50-, 100-, 200-, and 500-year wet and dry statistics were also derived to be consistent with other frequency analyses presented for Giant Mine in Baker Creek, and to provide context. Results of the frequency analysis are presented in Table 3.

Table 3: Frequency Analysis of Maximum Daily and Total Annual Precipitation for Giant Mine

Return Period (Year)		Maximum Daily (mm)	Total Annual (mm)
Dry	500	11.9	160.1
	200	12.5	177.0
	100	13.1	191.3
	50	13.9	207.4
	25	14.7	225.9
	10	16.4	256.0
	5	18.4	285.8
Median	2	23.9	347.2
Wet	5	33.6	413.9

Return Period (Year)		Maximum Daily (mm)	Total Annual (mm)
	10	42.1	449.8
	25	55.7	487.5
	50	68.4	510.8
	100	83.9	530.6
	200	102.6	547.6
	500	133.8	566.4

Typically a rare event (e.g., 100-year wet and dry) would be more representative of the wet and dry year, however, the largest total annual precipitation in the period of record occurs during 1973-1974 with a total annual precipitation of 493.0 mm, equivalent to a 25-year total wet annual precipitation, and the smallest total annual precipitation occurs during 1946-1947 with a total annual precipitation of 204.8 mm, equivalent to a 50-year total dry annual precipitation.

A least squares approach was also conducted on the total annual precipitation and the monthly precipitation for each year in the 1942-2014 period of record at the Yellowknife A station. The least squares method is a standard approach where the overall solution minimizes the sum of the squares of the errors made in the results of every equation.

The least squares method was used to identify the differences between the monthly precipitation amounts to the total monthly maximum and minimum precipitation. The differences between the monthly precipitation and the total monthly maximum and minimum precipitation were summed. The hydrologic year that had the smallest sum was selected to be representative of the wet and dry year, respectively.

The least squares method was conducted to rule out a hydrologic year that had a maximum/minimum total annual precipitation that may have been influenced by only a few months that had significantly large/small precipitation amounts. This was done to select a hydrologic year that not only had the largest/smallest total annual precipitation but also had monthly precipitation amounts that were as close to the maximum/minimum monthly precipitation for all months.

It was found that Hydrologic Year 1973-1974 also had monthly precipitation amounts that were as close to the maximum monthly precipitation of the entire period of record. Similarly Hydrologic Year 1946-1947 also had monthly precipitation amounts that were as close to the minimum monthly precipitation.

The temperatures and evaporation rates for both the wet and dry years are based on temperatures and evaporation rates derived for the average year (Section 2.2.2.1).

2.2.2.3 Goldsim Model Climate Input Summary

The wet, average, and dry year scenarios were primarily based on total annual precipitation. Thus, the wet year scenario was based on available rainfall and snowfall data from Hydrologic Year 1973-1974, corresponding to the 1 in 25-year wet total annual precipitation, the average year scenario on Hydrologic Year 1971-1972 (1 in 2-year total annual precipitation), and the dry scenario on Hydrologic Year 1946-1947 (1 in 50-year dry total annual precipitation). Total annual rainfall and snowfall depths are summarized in Table 4 for the wet, average, and dry year scenarios, and shown in Figure 5 (rainfall), and Figure 6 (snowfall), based on the hydrologic year. A mean temperature time series was applied for all three scenarios, based on Hydrologic Year 1971-1972 (Table 4), as shown in Figure 7.

A mean monthly lake evaporation time series was applied for all three scenarios, based on a mean annual lake evaporation of 414 mm (Reid and Faria 2004), and a monthly distribution based on baseline data available from the Dominion Diamond Jay Project (Dominion Diamond 2014), located approximately 315 km northeast of the Giant Mine. The time series is shown in Figure 8.

Table 4: Representative Years of Rainfall, Snowfall, and Temperature for Modeled Scenarios

Scenario	Rainfall		Snowfall		Temperature: Representative Year
	Total Annual (mm)	Representative Year	Total Annual (cm)	Representative Year	
Wet	262.0	1973-1974	225.8	1973-1974	1971-1972
Average	131.7	1971-1972	217.8	1971-1972	1971-1972
Dry	100.0	1946-1947	105.0	1946-1947	1971-1972

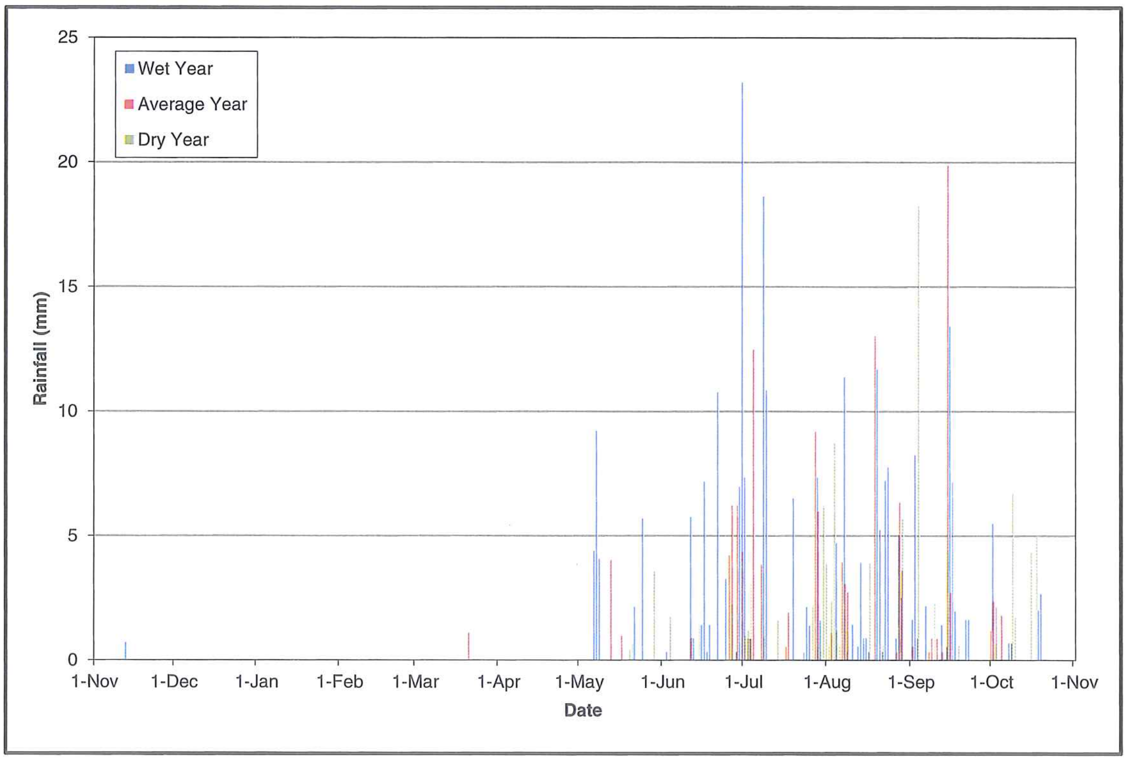


Figure 5: Rainfall Scenarios

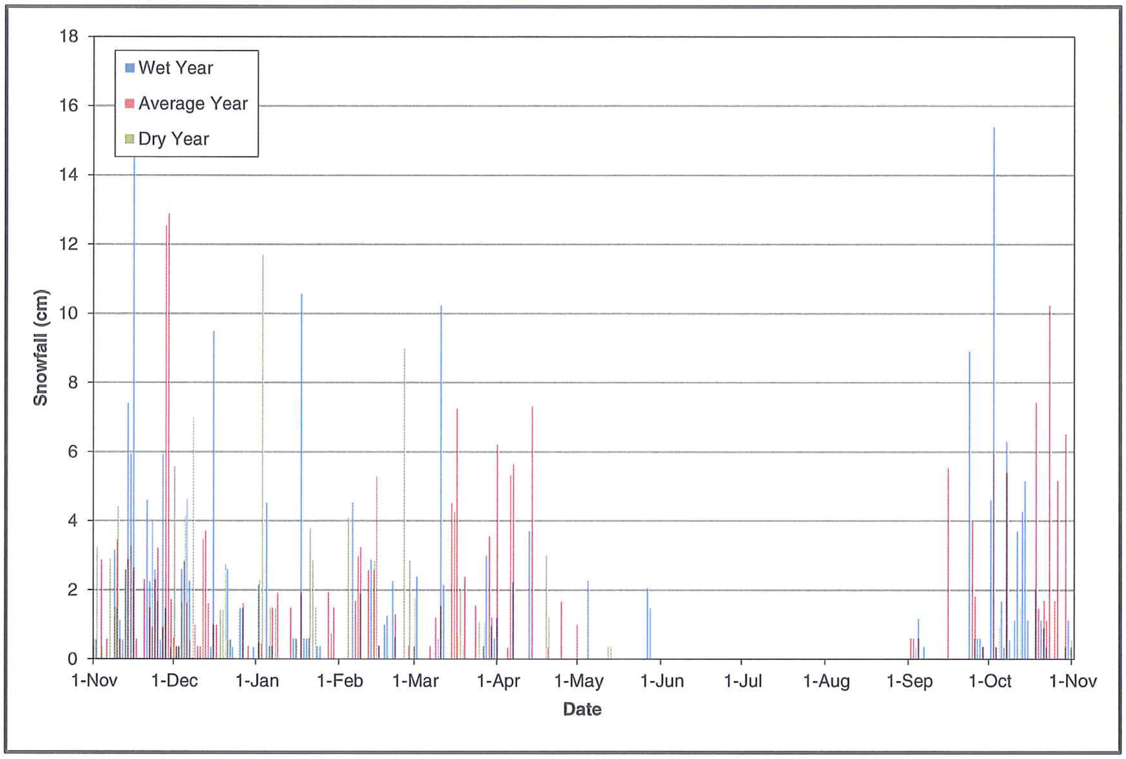


Figure 6: Snowfall Scenarios

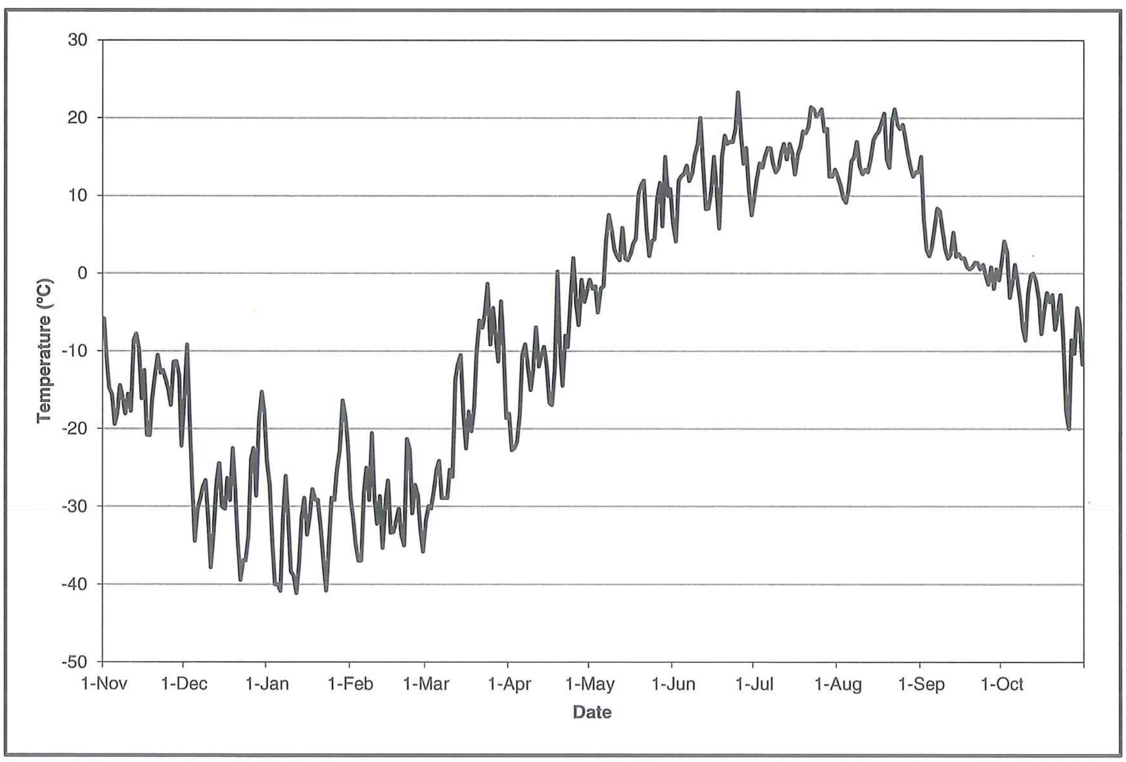


Figure 7: Temperature (All Scenarios)

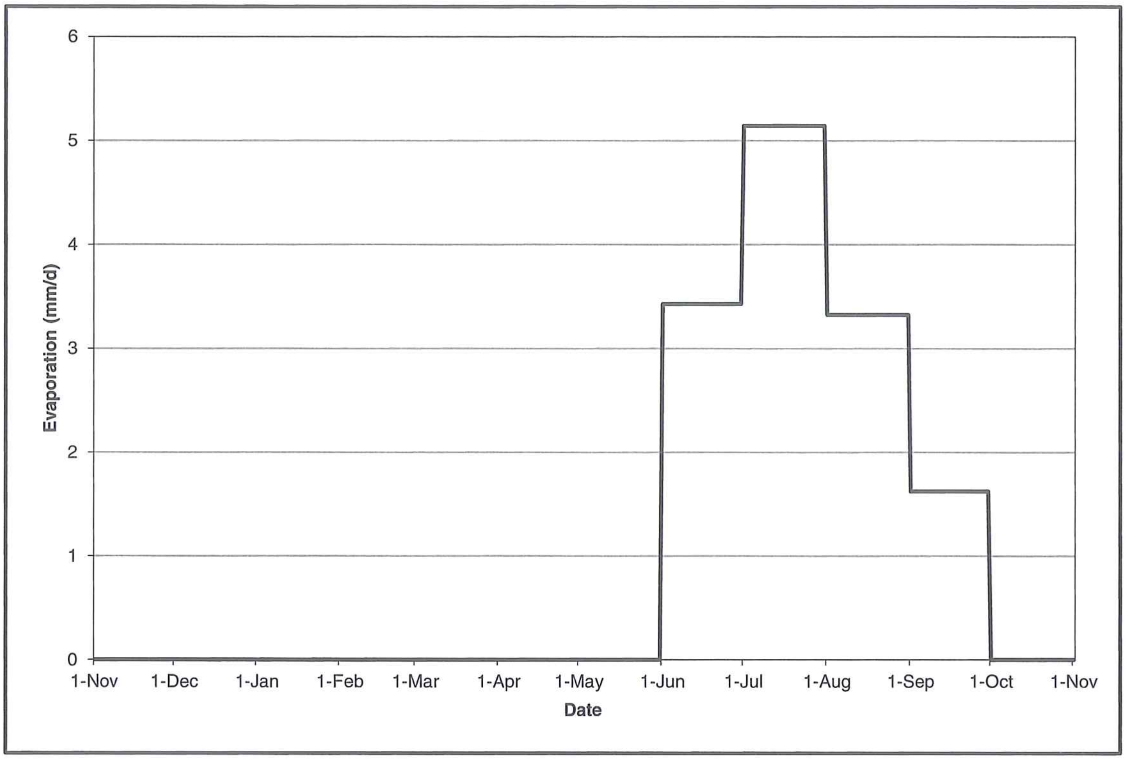
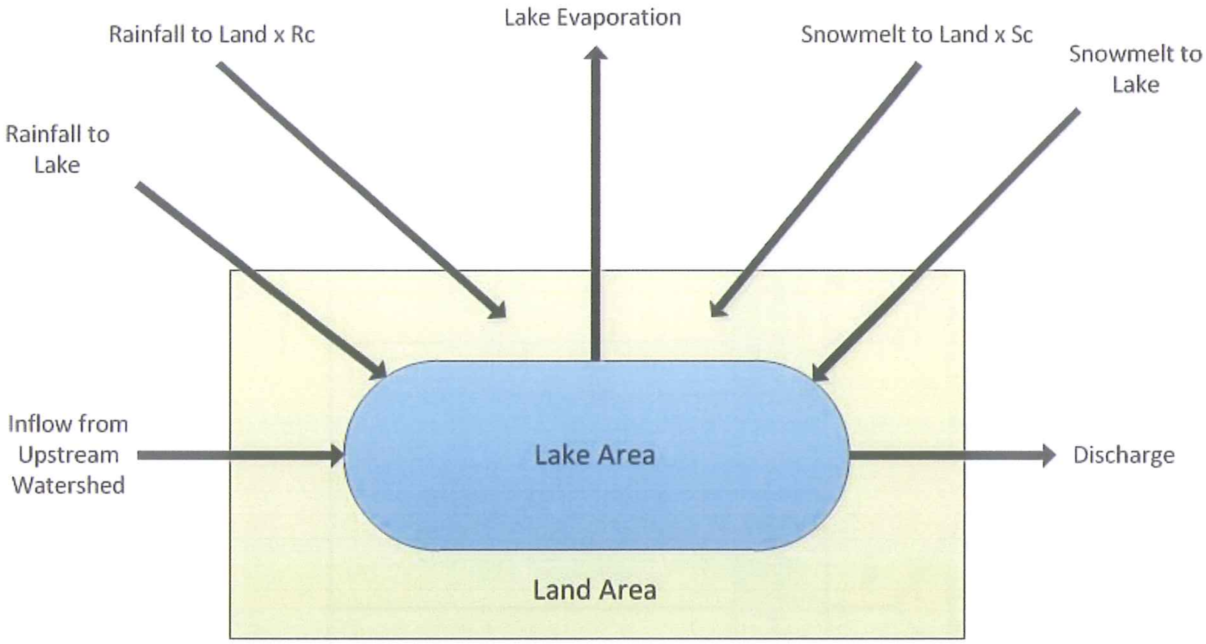


Figure 8: Lake Evaporation (All Scenarios)

3.0 MODEL STRUCTURE

Each lake in the Baker Creek basin with a surface area greater than 6 hectares (ha) (refer to Basin Characteristics, Appendix A) was modeled as a reservoir as described in the schematic diagram (Figure 9), downstream of Lower Martin Lake. While Bake Pond has a lake surface of 3.7 ha (i.e., less than 6 ha), it was of particular interest to the water quality team, and was also modeled as a reservoir. Inflows to the reservoir consisted of inflows from upstream basins and local basin rainfall and snowmelt, including a runoff coefficient to account for infiltration and evapotranspiration losses. Snow water equivalents were calculated based on a sublimation coefficient to account for snowpack losses, and snowmelt rates were calculated using a degree-day model. Outflows consisted of lake outlet discharges and evaporative losses. Modeled lakes accounted for differences between inputs and outputs by calculating corresponding changes in lake storage volumes.

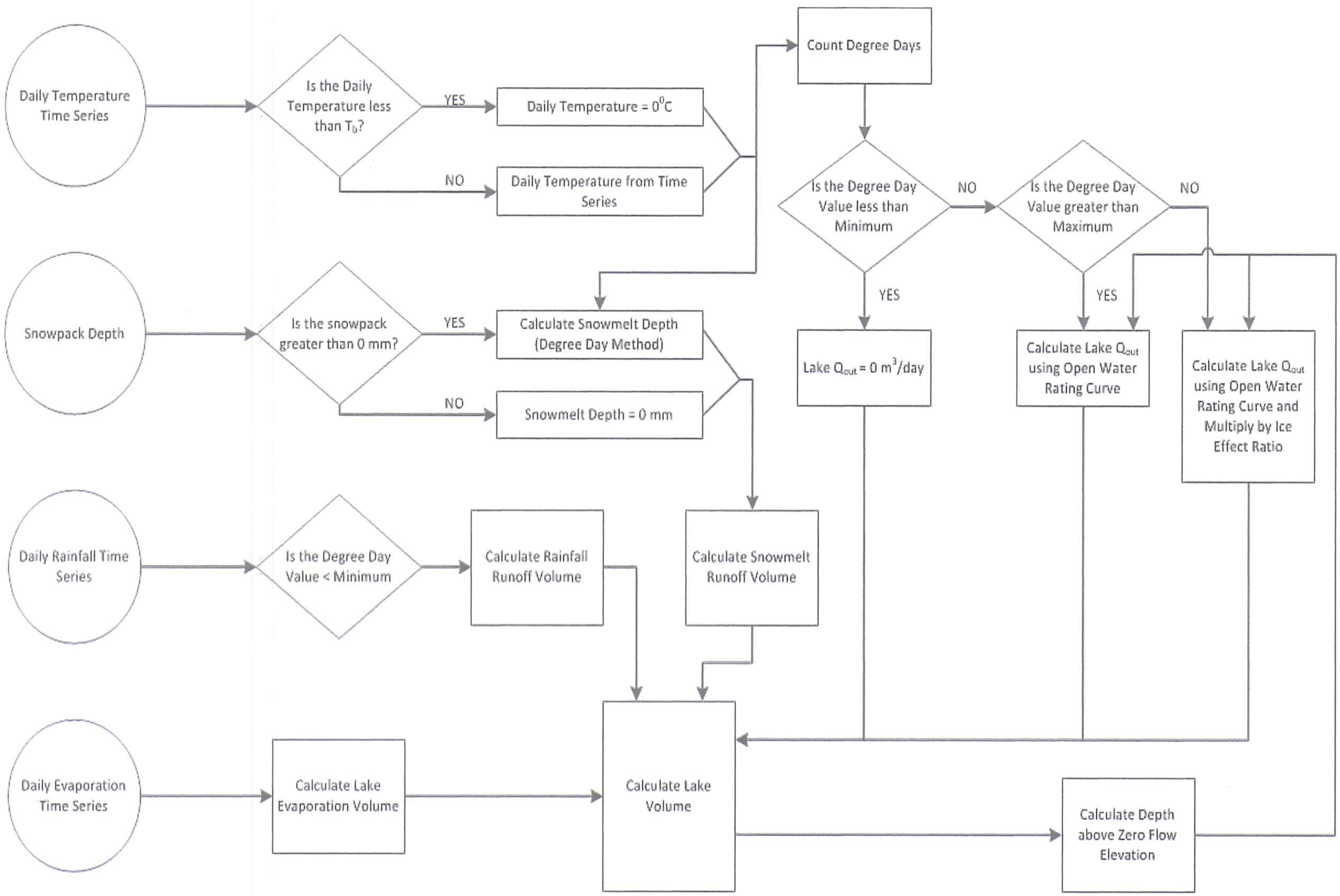
A key assumption of the model is that losses to deep groundwater and changes to shallow groundwater storage are not significant, due to the local permafrost regime and the associated low connectivity of shallow and deep groundwater systems.



RC = rainfall runoff coefficient; SC = snowfall runoff coefficient

Figure 9: Schematic of Typical Lake Reservoir Model

The lake inflows and outflows were calculated according to the flowchart shown in Figure 10.



°C = degrees Celsius; mm = millimetre; T_b = base temperature; Q_{out} = discharge out; m^3/day = cubic metres per day.

Figure 10: Water Balance Model Flowchart

4.0 BASIN CHARACTERISTICS

The Baker Creek basin has an approximate drainage area of 177 km^2, including 34 km^2 of lake surface area, and 143 km^2 of land surface area.

4.1 Sub-Basins

Lake, land, and tributary areas of each modeled sub-basin of the Baker Creek watershed are presented in Appendix A.

4.2 Outlet Rating Curves

With the exception of Martin Lake, lake-outlet rating curves of each modeled lake were derived based on available LiDAR data, cross-section surveys of Upper Baker Creek upstream of Baker Pond (Stantec 2014) and Manning's equation. Cross-sections were based on survey and/or LiDAR data, as applicable, slopes were derived from LiDAR data, and Manning's equations assumed a channel roughness (i.e., Manning's n) of 0.035 for all outlets and creeks. Flows from Lower Martin Lake were based on Environment Canada hydrometric station 07SB013 (Government of Canada 2015b), as discussed further in Section 2.2.1.

The water quality team required high level routing of rainfall and snowmelt runoff through sub-basins based on annual quantities, and the magnitude and timing of peak flows was of less importance. While timing and magnitude of peak flows are quantified by the model, these are based on assumptions (discussed further) and can only be accurately calibrated using field data, not available for this modeling task.

4.3 Ice Effects on Lake Outlets

The formation of ice in winter constricts outflow channels and reduces lake discharge rates. Large lake outlets such as the outlet of Lower Martin Lake will have reduced flow rates during periods of ice cover. The outlets for small lakes become constricted with ice and eventually freeze completely from approximately October to May each year. A numerical relationship between lake outlet discharge and cumulative degree days was estimated to account for ice effects in the freezing period in water balance modelling.

The degree-day method was used to simulate the effect of ice conditions on discharge at each lake outlet. Degree-days were added above a base temperature of 0 degrees Celsius (°C) based on daily mean temperatures, which typically begin to exceed 0°C in early June.

The effect of ice on discharge was quantified by the following ratio:

$$\text{Ice Effect Ratio} = Q_{actual} / Q_{predicted}$$

where

Q_{actual} = Discharge measured at the outlet under ice conditions; and,

$Q_{predicted}$ = Discharge predicted using an open-water rating curve for the specific outlet.

The degree-day method determined the timing of outlet freeze-up in the fall and outlet break-up in the spring. The modelling parameters were based on experience at other northern mining sites, as summarized for the Dominion Diamond Jay Project (Dominion Diamond 2014) located approximately 300 km north east of Yellowknife, as presented in Table 5.

This degree-day method was applied to all sub-basins, with the exception of sub-basins downstream of Lower Martin Lake. For basins downstream of Lower Martin Lake, open water conditions were assumed for the entire year, and the degree-day method was not applied.

Table 5: Model Parameters for Break-up and Freeze-Up Degree Day Methods

Model Element	Value
Outlet break-up - closed	15.0
Outlet break-up - open	40.0
Outlet freeze-up - open	76.5
Outlet freeze-up - closed	1.4

4.4 Snowmelt and Runoff Coefficients

Snowmelt is generated predominantly by the melting of the accumulated snowpack during the period of spring freshet. The spring freshet occurs over a period of several weeks and is a major contributor of overall annual precipitation and lake inflows in northern environments.

Snowfall that occurs after freshet in the spring and before consistent freezing temperatures in the fall is modeled as reporting directly to the receiving waterbodies as snowmelt.

4.4.1 Method

In the model, snowfall from the derived climate data accumulates as snowpack during fall and winter when temperatures are below freezing. A 34% reduction was applied to the modeled snowpack to represent sublimation losses. This 34% reduction was based on a previous local study discussing the surface water drainage infrastructure at Giant Mine (Golder 2011).

Snowmelt begins when the daily average temperature rises above the base temperature (T_b). The snowmelt rate is determined in Equation 1.

Equation 1: Snowmelt Equation

$$\text{Daily Snowmelt Runoff} = S_c \times M_f \times (T - T_b)$$

Where

S_c = Snowmelt runoff coefficient (dimensionless);

M_f = Melt factor (mm/°C);

T = Mean daily air temperature (°C); and

T_b = Base temperature (°C).

A melt factor of 1.5 millimetres per degree Celsius (mm/°C) and a base temperature -2.0°C were applied, based on a previous local study (Golder 2011).

A snowmelt runoff coefficient S_c of 1.0 and a rainfall runoff R_c coefficient of 0.57 were applied based on the Dominion Diamond Jay Project (Dominion Diamond 2014). Values of 1.0 were applied for both coefficients for direct precipitation.

5.0 RESULTS

Results are presented for Gar Lake, in Figure 11 under existing conditions and in Figure 12 under diversion conditions, for the wet, average, and dry year scenarios. Results are also presented for Baker Pond (Figure 13, existing conditions; Figure 14, diversion conditions), and for Lower Shot Lake (Figure 15, existing conditions; Figure 16, diversion conditions), for the three scenarios.

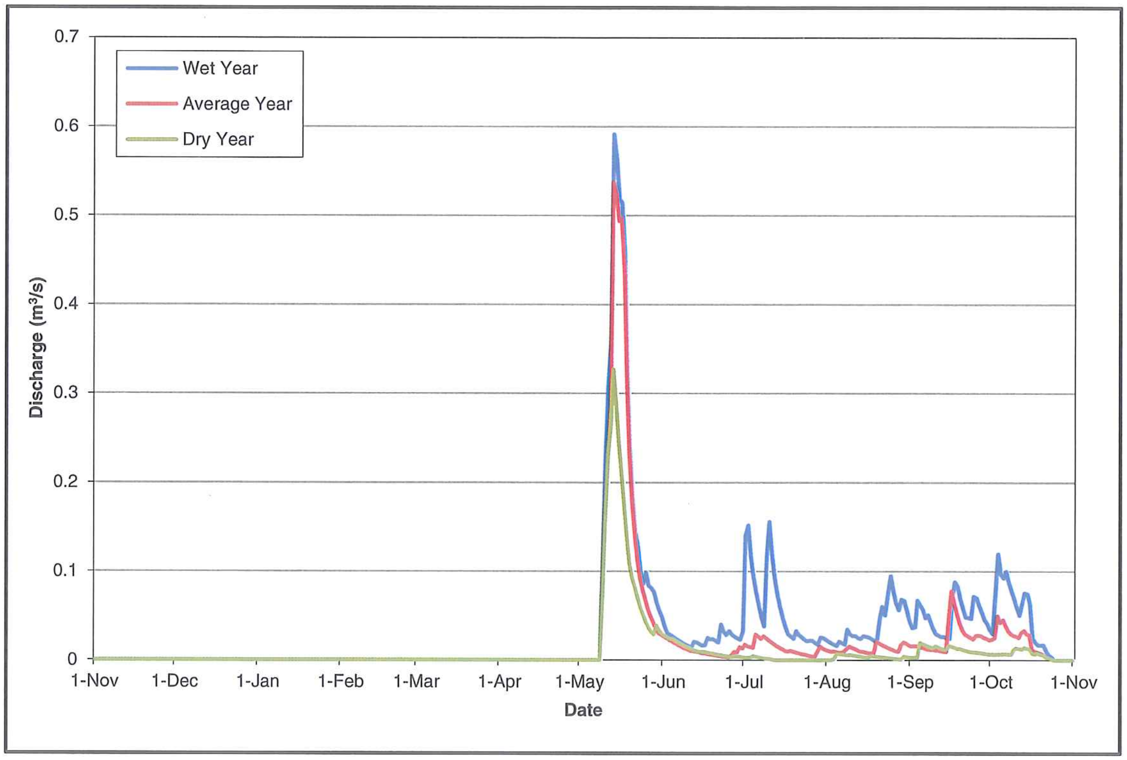


Figure 11: Gar Lake - Existing Conditions

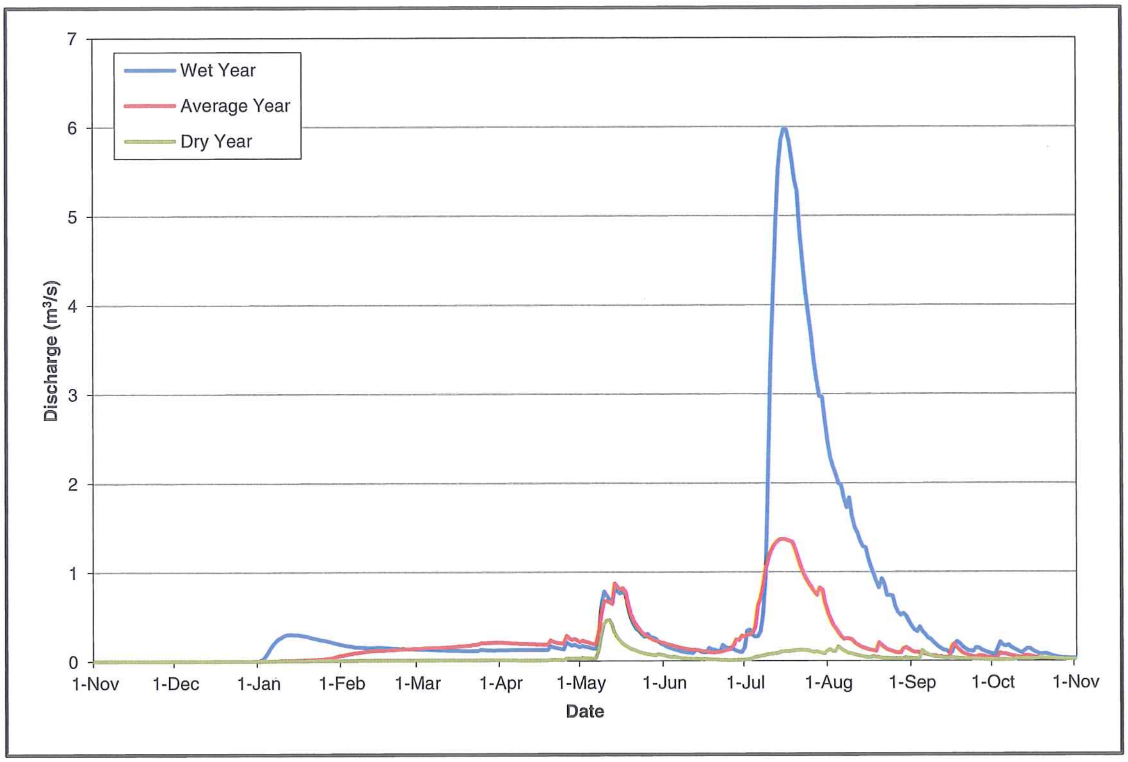


Figure 12: Gar Lake - Diversion Conditions

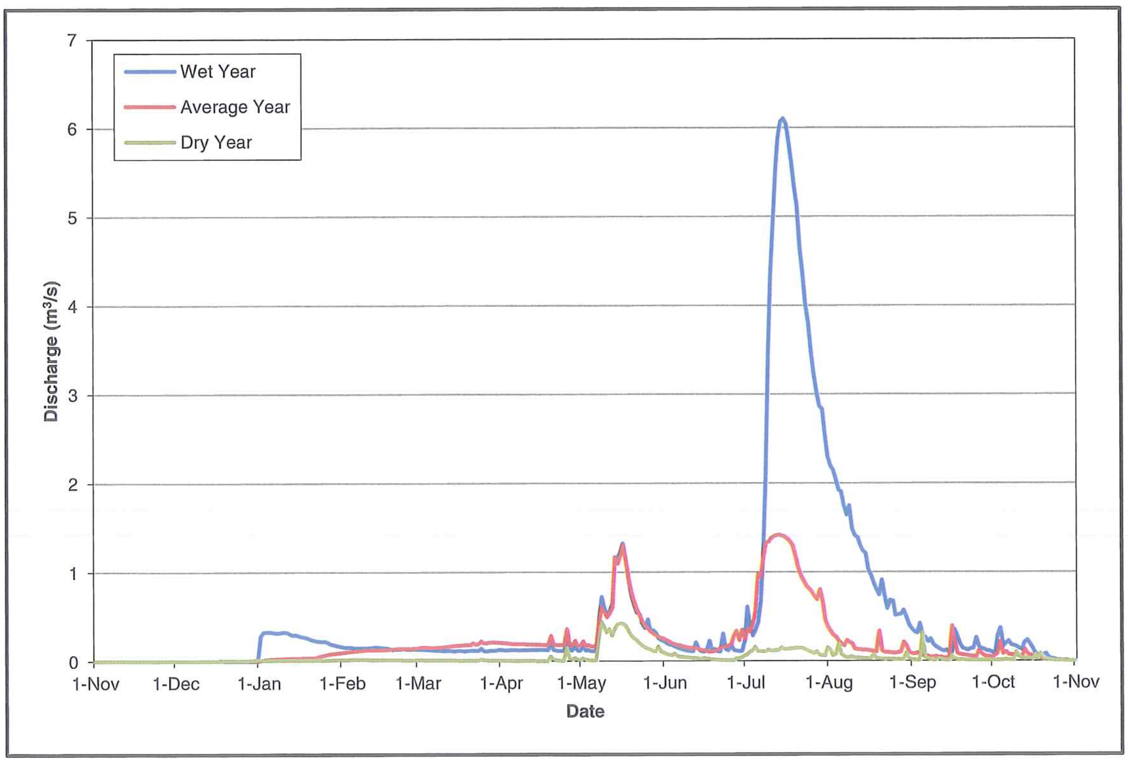


Figure 13: Baker Pond - Existing Conditions

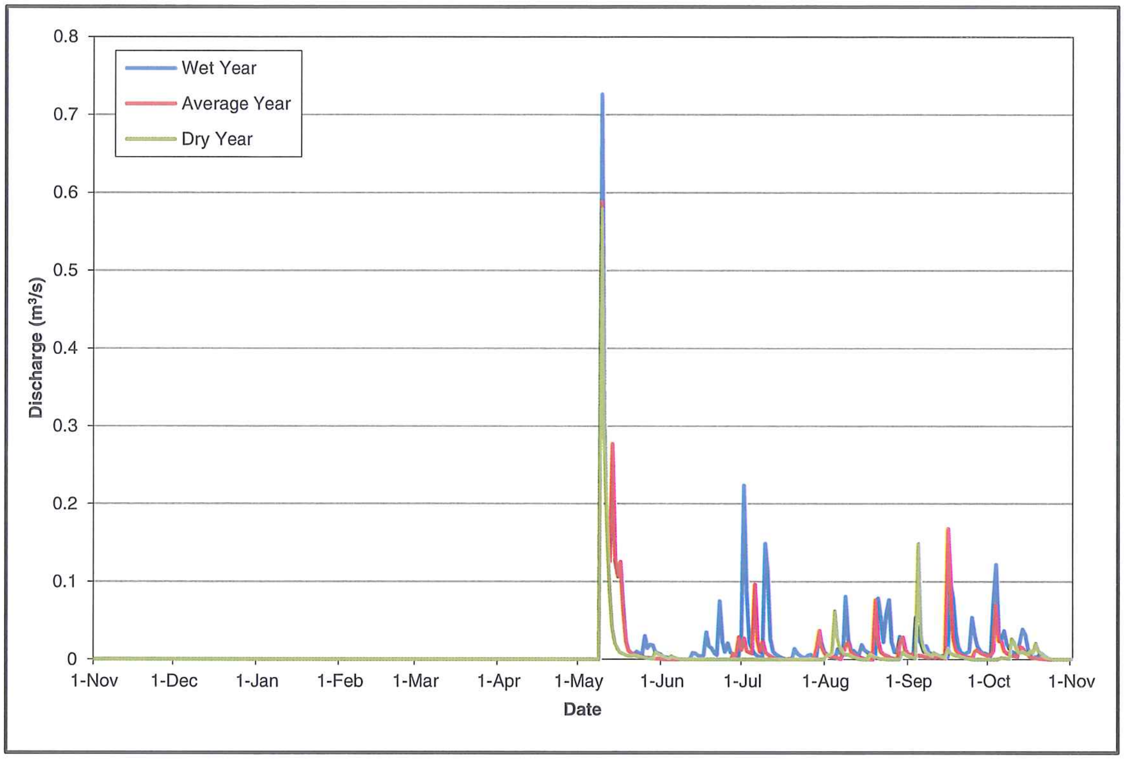


Figure 14: Baker Pond - Diversion Conditions

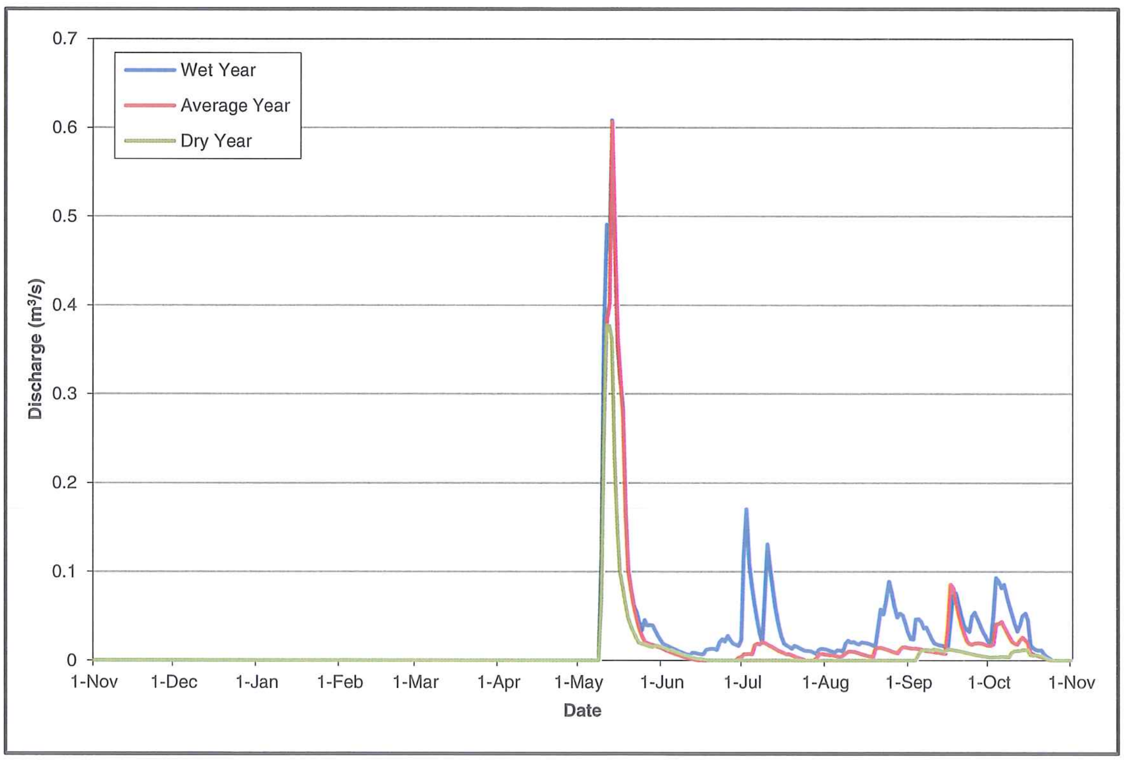


Figure 15: Lower Shot Lake - Existing Conditions

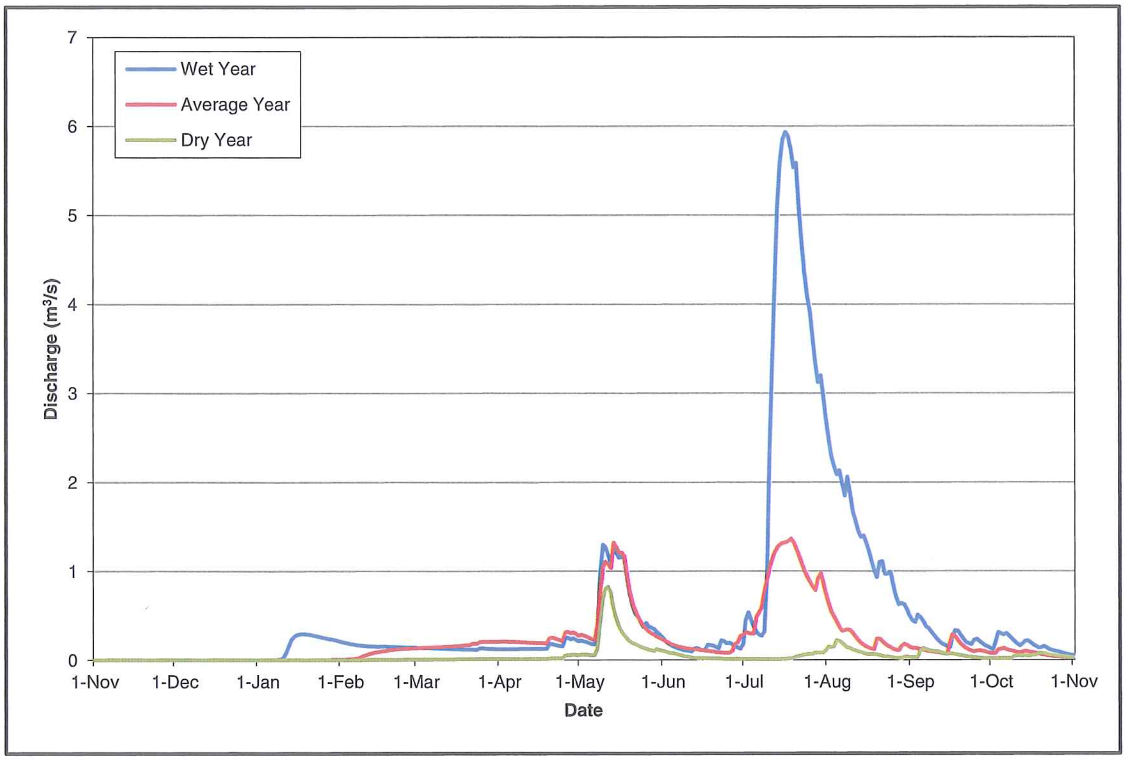


Figure 16: Lower Shot Lake - Diversion Conditions

Conclusion

A surface water balance model was developed for Baker Creek, upstream of Yellowknife Bay, to provide surface water flow estimates to the water quality team for further water quality assessment, not discussed herein. The model was developed to route three precipitation scenarios, including a wet, average, and dry year scenario, through sub-watersheds of interest to the water quality team.

Hydrologic parameters were derived from available geographic data, and a review of literature, and nearby projects, in the absence of site-specific data. Thus, there is a degree of uncertainty associated with the magnitude and timing of peak flows; however, this uncertainty diminishes on a larger temporal scale (e.g., weekly flows) and is not anticipated to be of particular significance for the purpose of water quality modeling. This uncertainty may be reduced, and assumptions validated, by hydrometric field measurements.

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Water Resources Engineer

Nathan Schmidt, Ph.D., P.Eng.
Principal, Senior Water Resources Engineer

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APPENDIX A

Table A-1: Sub-Basin Drainage Areas (Baker Creek Basin)

Name	Land	Lake	Tributary	Total
Baker Pond	0.222	0.0367	0	0.259
Baker Pond Runoff	0.668	0.0479	0	0.716
David Lake	0.490	0.134	0.00513	0.629
Fox Lake	1.64	0.548	0.0642	2.25
Gar Lake	0.893	0.330	0	1.22
Gar Lake Local Runoff	2.51	0.0241	0	2.53
Handle Lake	0.654	0.213	0.013	0.88
Joe Lake	0.545	0.0691	0.00147	0.615
Lower Baker Creek Local Runoff	2.12	0.00655	0	2.12
Site Runoff	0	0	0	0
Trapper Creek	0.58	0	0	0.580
Trapper Lake	1.65	0.313	0.0378	2.00
Unnamed 1	0.666	0.0581	0	0.724
Unnamed 2	0.558	0.00831	0	0.567
Upper Baker Creek Watershed	1.14	0	0	1.14
UBC NorthLake	0.457	0.152	0	0.609
UBC SouthLake	1.66	0.437	0	2.09

Table A-2: Sub-Basin Drainage Areas (Shot Creek Basin)

Name	Land	Lake	Tributary	Total
Lower Shot Lake	1.08	0.246	0	1.33
Shot Creek	1.10	0.0314	0	1.13
Upper Shot Lake	0.631	0.0590	0	0.690
Upper Shot Lake Runoff	1.18	0.0313	0	1.21

APPENDIX B

Supplemental Information

This appendix presents information relevant to the evaluation of each diversion alternative, presented by criterion, when applicable.

B1.0 INCREMENTAL DISTURBANCE

Completed conceptual alignment configurations were only available from the Baker Creek PDR (Golder 2012) for the PDR Reach 3 - Option A, and PDR Reach 3 - Option C diversion alternatives, as shown in figures presented in Section 4.0 of the Baker Creek Diversion Alternative Evaluation Report. The configuration of the Handle Lake - North Route diversion alternative was only previously available up to the west of Ingraham Trail from the Validation of the North Route report (Golder 2016b), and the connection to Yellowknife Bay was never established. The connection to Yellowknife Bay was therefore developed based on input from stakeholders during the MAA Evaluation Workshop held on 17 November 2016, and the following concepts were adopted (and illustrated on Figure B-1):

- Follow topographic lows;
- Bypass A2 Pit to the north; and
- Join the existing Baker Creek alignment at Reach 1.

Disturbance footprints for the three diversion alternatives required for the evaluation were not available from previous studies, and were therefore derived based on available LiDAR data representative of 2015 conditions, and the conceptual channel cross-sectional geometry provided in the PDR (Table 6, Golder 2012), as summarized in Table B-1. Excavation volumes were also derived to support the evaluation under other criteria (i.e., construction complexity and cost).

Based on this exercise, the greatest land disturbance is expected from the Handle Lake - North Route diversion alternative, followed by the PDR Reach 3 - Option A, and the PDR Reach 3 - Option C alternatives. Disturbances from the PDR Reach 3 - Option A diversion alternative are expected to remain fully within the Giant Mine lease area. A minor portion (i.e., 0.4 ha) of disturbance from the PDR Reach 3 - Option C diversion alternative is expected to fall outside of the mine lease. Note that this effect on off-lease lands could possibly be eliminated during detailed design. Disturbance from the Handle Lake - North Route diversion alternative are expected to fall almost completely outside of the mine lease.

Table B-1: Derived Disturbance Footprints

Alternative	Excavation Volume (m^3)	Excavation Area (ha)
PDR Reach 3 - Option A	93,548	2.52
PDR Reach 3 - Option C	824,751	5.01
Handle Lake - North Route	368,834	15.1

Note that the alignment of the lower Handle Lake - North Route diversion is highly conceptual and would require filling of A2 Pit to fully mitigate mine. An alignment to the south of A2 Pit could be considered to eliminate this proximity, but could require that the diversion flow through Fault Lake, located off-lease.

LEGEND

- FLOW DIRECTION
- BAKER CREEK - EXISTING

DIVERSION ALTERNATIVE

- HANDLE LAKE ALIGNMENT
- BREAKWATER
- PIT BOUNDARY
- HIGHWAY
- ROAD
- GIANT MINE LEASE BOUNDARY
- YELLOWKNIFE LANDFILL LEASE BOUNDARY

0 500 1,000

1:20,000 METRES

REFERENCE(S)

HYDROLOGY AND TRANSPORTATION DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED. IMAGERY OBTAINED FROM CLIENT, 2015.

DATUM: NAD 83 PROJECTION: UTM ZONE 11

CLIENT

Public Services and Procurement Canada / Services publics et Approvisionnement Canada

PROJECT

GIANT MINE REMEDIATION PROJECT

TITLE

HANDLE LAKE – NORTHERN ROUTE CONCEPTUAL BAKER CREEK DIVERSION ALTERNATIVE

CONSULTANT

Golder Associates

YYYY-MM-DD	2017-07-28
DESIGNED	JL
PREPARED	SK
REVIEWED	NS
APPROVED	NS

PROJECT NO.	CONTROL	REV.	FIGURE
13-1377-0115	15000	0	B-1

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25mm

B2.0 CHANGES TO WATER QUALITY

Data provided in the main report (Figure 10) corresponds to the Table B-2.

Table B-2: Surface Water Arsenic Concentration at Giant Mine

Sampling Locations	Trapper Lake		Lower Martin Lake		Unnamed Lake 1 and 2		Pocket Lake		Fox Lake		Baker Creek Reach 7 to 11		Handle Lake		Long Lake	
Date Range	2011 to 2014		2011 to 2015		2012 to 2015		2011 to 2015		2014 to 2015		2011 to 2016		2014 to 2016		2014 to 2015	
Parameter	Total Arsenic	Dissolved Arsenic	Total Arsenic	Dissolved Arsenic	Total Arsenic	Dissolved Arsenic	Total Arsenic	Dissolved Arsenic	Total Arsenic	Dissolved Arsenic	Total Arsenic	Dissolved Arsenic	Total Arsenic	Dissolved Arsenic	Total Arsenic	Dissolved Arsenic
Median	192	209	55	49	157	200	1,650	1,630	-	183	34	33	169	165	36	36
Mean	195	204	52	49	172	302	1,560	1,625	-	-	41	36	187	178	37	34
95th Percentile	230	225	59	58	205	657	1,741	1,738	202	183	77	65	303	263	42	40
Min	160	172	39	40	148	113	325	1,410	<200	-	16	13	111	106	26	17
Max	235	227	60	58	210	735	1,750	1,810	202	-	95	76	331	277	58	40
Standard Deviation	32	23	9	9	34	260	312	100	-	-	19	16	63	51	7	6
Non-detect sample Count	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0
Total Sample Count	4	4	4	6	3	5	19	19	2	1	48	45	24	24	21	22

Note: Concentrations are in µg/L (micrograms per litre).

The data presented in Table B-2 were compiled from the following sources. DCNJV reports contain data collected at SNP 43-11 and Pocket Lake:

DCNJV (Deton'Cho/Nuna Joint Venture). 2012. Giant Mine 2011 Surveillance Network Program. Report prepared by Golder Associates Limited for Deton'Cho/Nuna Joint Venture, Yellowknife, NT, Canada. Submitted to Public Works and Government Services Canada. Yellowknife, NT, Canada and Environment Canada, Edmonton, Alberta, Canada.

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Golder. 2015. Water Quality Sampling Program – Baker Creek. Prepared for AECOM Canada Ltd. Edmonton, AB, Canada. July 2015.

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B3.0 IMPLEMENTATION COST

Excavation volumes and surface area quantities were estimated as described in Section B1.0. Unit rate costs were based on previous cost estimating studies for the PDR Reach 3 - Option C diversion alternative, from the following documents:

- Cost Estimate, TA11, Baker Creek, Technical Memorandum, prepared for Public Works Government Services Canada by Golder Associates Ltd., January 13, 2012; and
- Indicative Cost Estimate - Baker Creek, prepared for AECOM Canada Inc. by MAXIOM Consultants Inc., January 31, 2012.

These cost estimates were developed for the purpose of comparing the three diversion alternatives relative to each other based on their estimated physical characteristics (i.e., quantity of material to be moved). Costs that were expected to be common for all three diversion alternatives, with no effect on conclusions of this study, were not included in these estimates: these include costs for mobilization/demobilization, detailed engineering/design, permitting, water management, dredging/disposing of existing contaminated sediments, etc. These cost estimates should be treated as comparative only.

The costs associated with the widening and deepening the existing channel of Baker Creek in Reaches 0, 1, 2, 4, 5 and 6 were not included, as the dredging of contaminated sediments will be required regardless of which diversion alternative is chosen. For instance, if the Handle Lake - North Route diversion alternative were chosen, the existing creek bed would require some additional form of remediation for abandonment (i.e., reclamation into a wetland). Also not included in the cost estimate is the cost of constructing an access road and watercourse crossing at the re-aligned Ingraham Trail crossing for the construction of the Handle Lake - North Route diversion alternative.

Estimated costs are presented in Table A-3 below in 2011 dollars. The estimated cost for the PDR Reach 3 - Option A diversion alternative is approximately $5M. Estimated costs are similar for both the PDR Reach 3 – Option C and Handle Lake - North Route diversion alternatives, at approximately $20M.

Though estimated costs or the PDR Reach 3 - Option C and the Handle Lake - North Route diversion alternatives are similar based on the quantities derived herein, significant additional costs are expected for the Handle Lake - North Route diversion alternative such as access road development costs and land acquisition costs. The Handle Lake - North Route diversion alternative is therefore expected to be the most expensive alternative, followed by PDR Reach 3 - Option C, and PDR Reach 3 - Option A.

Additional assumptions follow Table B-3.

Table B-3: Cost Estimate

	Quantity	Unit	Unit Cost	Total
Option A				
Preliminary Survey	25,230	m^2	$0.14	$3,532
Rock Blast and Remove	124,900	m^3	$22.60	$2,822,736
Soil Excavation	23,387	m^3	$8.78	$205,338
Post Excavation Survey	25,230	m^2	$0.14	$3,532
Bituminous Liner	9,926	m^2	$37.00	$367,266
Till Backfill	13,033	m^3	$19.55	$254,796
Substrate Backfill	26,066	m^3	$45.00	$1,172,975
Floodplain Soil and Planting	16,140	m^2	$8.86	$143,000
As-built Survey	25,230	m^2	$0.14	$3,532
Total				**$4,976,707**
Option C				
Preliminary Survey	50,500	m^2	$0.14	$7,070
Rock Blast and Remove	689,649	m^3	$22.60	$15,586,069
Soil Excavation	206,188	m^3	$8.78	$1,810,328
Post Excavation Survey	50,500	m^2	$0.14	$7,070
Bituminous Liner	12,890	m^2	$37.00	$476,945
Till Backfill	16,925	m^3	$19.55	$330,888
Substrate Backfill	33,850	m^3	$45.00	$1,523,268
Floodplain Soil and Planting	20,960	m^2	$8.86	$185,706
As-built Survey	50,500	m^2	$0.14	$7,070
Total				**$19,934,414**
Handle Lake Option				
Preliminary Survey	151,500	m^2	$0.14	$21,210
Rock Blast and Remove	503,653	m^3	$22.60	$11,382,547
Soil Excavation	92,209	m^3	$8.78	$809,591
Post Excavation Survey	151,500	m^2	$0.14	$21,210
Bituminous Liner	41,168	m^2	$37.00	$1,523,220
Till Backfill	54,054	m^3	$19.55	$1,056,757
Substrate Backfill	108,108	m^3	$45.00	$4,864,865
Floodplain Soil and Planting	66,940	m^2	$8.86	$593,088
As-built Survey	151,500	m^2	$0.14	$21,210
Total				**$20,293,697**

Assumptions:

- Unit costs are based on estimates completed in January, 2012, as such the costs are in 2011 dollars. Costs have not been adjusted for inflation as they are intended only for comparison between alternatives.
- The dimensions and locations of the channel for the three diversion alternatives are based on PDR as presented in documents cited above, and quantities used in this cost estimate are high level estimates only.
- The excavated material will be 25% soil/overburden and 75% rock.
- The channel and floodplain would have to be over-excavated by 2.1 m to accommodate substrate and till backfill. These quantities were not considered in Section B1.0.
- Water management costs would be similar for all three diversion alternatives.
- Cost estimates do not take into account the potential for borrow requirements as part of an overall GMRP material balance, nor do they consider difference in haul distances and costs related to the location of the various alignments.

APPENDIX C

MAA Sensitivity Analysis

Conclusions of the MAA Evaluation Workshop presented in Section 7.2 were assessed using a sensitivity analysis on weightings of categories and criteria, based on three scenarios summarized in Table C-1, and described below:

- Scenario 1: Weightings of categories were kept neutral (i.e., assigned the same relative importance to the GMRP), and the weightings of criteria were based on input from stakeholders provided during the MAA Evaluation Workshop;
- Scenario 2: Weightings of categories and criteria were both kept neutral; and
- Scenario 3: Weightings of categories were based on input from stakeholders provided during the MAA Evaluation Workshop, and the weightings of criteria were kept neutral (i.e., assigned the same relative importance to the GMRP).

Table C-1: Sensitivity Analysis Scenarios

Scenario	Weightings	
	Categories	Criteria
1	Neutral	Workshop
2	Neutral	Neutral
3	Workshop	Neutral

Results of the sensitivity analysis are presented in Figure C-1 (Scenario 1), Figure C-2 (Scenario 2), and Figure C-3 (Scenario 3). These results of the three scenarios are consistent with each other and with those presented in Section 7.2 based on weightings assigned during the MAA Evaluation Workshop. The Handle Lake – Northern Route diversion alternative is the lowest ranked alternative, and the PDR Reach 3 – Option C diversion alternative ranks slightly lower than the PDR Reach 3 – Option A alternative, confirming that conclusions presented in Section 7.2 are not sensitive to assigned weightings.

RESULTS: Scenario 1

WEIGHT	CATEGORY	PDR - REACH 3 OPTION A	PDR - REACH 3 OPTION C	HANDLE LAKE - NORTHERN ROUTE
33%	ENVIRONMENT	5.83	5.42	5.83
33%	FEASIBILITY	8.00	5.50	1.50
33%	SOCIETY	4.29	3.21	0.00
100%	Total	6.03	4.71	2.44

WEIGHT	CRITERIA / INDICATOR	PDR - REACH 3 OPTION A	PDR - REACH 3 OPTION C	HANDLE LAKE - NORTHERN ROUTE
1.0	Footprint Area of Re-Alignment Within Undisturbed Land	5.00	2.50	0.00
2.0	Risk of Underground Flooding	7.50	7.50	10.00
2.0	Changes to Water Quality from Nearby Waterbodies	5.00	5.00	5.00
1.0	Changes to Water Quality from Other Sources	5.00	5.00	5.00
6.0	Total	5.83	5.42	5.83
0.5	Construction Complexity	5.00	2.50	2.50
1.0	Land Ownership and/or Land Rights	10.00	10.00	2.50
1.0	Implementation Cost	7.50	2.50	0.00
2.5	Total	8.00	5.50	1.50
2.0	Traditional Land Use	5.00	2.50	0.00
1.0	Other Land Use	5.00	2.50	0.00
2.0	Perception	5.00	5.00	0.00
2.0	Risk of Human Contact	2.50	2.50	0.00
7.0	Total	4.29	3.21	0.00
	Total	6.03	4.71	2.44

Figure C-1: Results of Scenario 1

RESULTS: Scenario 2

WEIGHT	CATEGORY	PDR - REACH 3 OPTION A	PDR - REACH 3 OPTION C	HANDLE LAKE - NORTHERN ROUTE
33%	ENVIRONMENT	5.63	5.00	5.00
33%	FEASIBILITY	7.50	5.00	1.67
33%	SOCIETY	4.38	3.13	0.00
100%	Total	5.83	4.37	2.22

WEIGHT	CRITERIA / INDICATOR	PDR - REACH 3 OPTION A	PDR - REACH 3 OPTION C	HANDLE LAKE - NORTHERN ROUTE
1.0	Footprint Area of Re-Alignment Within Undisturbed Land	5.00	2.50	0.00
1.0	Risk of Underground Flooding	7.50	7.50	10.00
1.0	Changes to Water Quality from Nearby Waterbodies	5.00	5.00	5.00
1.0	Changes to Water Quality from Other Sources	5.00	5.00	5.00
4.0	Total	5.63	5.00	5.00
1.0	Construction Complexity	5.00	2.50	2.50
1.0	Land Ownership and/or Land Rights	10.00	10.00	2.50
1.0	Implementation Cost	7.50	2.50	0.00
3.0	Total	7.50	5.00	1.67
1.0	Traditional Land Use	5.00	2.50	0.00
1.0	Other Land Use	5.00	2.50	0.00
1.0	Perception	5.00	5.00	0.00
1.0	Risk of Human Contact	2.50	2.50	0.00
4.0	Total	4.38	3.13	0.00
	Total	5.83	4.37	2.22

Figure C-2: Results of Scenario 2

RESULTS: Scenario 3

WEIGHT	CATEGORY	PDR - REACH 3 OPTION A	PDR - REACH 3 OPTION C	HANDLE LAKE - NORTHERN ROUTE
50%	ENVIRONMENT	5.63	5.00	5.00
20%	FEASIBILITY	7.50	5.00	1.67
30%	SOCIETY	4.38	3.13	0.00
100%	Total	5.63	4.44	2.83

WEIGHT	CRITERIA / INDICATOR	PDR - REACH 3 OPTION A	PDR - REACH 3 OPTION C	HANDLE LAKE - NORTHERN ROUTE
1.0	Footprint Area of Re-Alignment Within Undisturbed Land	5.00	2.50	0.00
1.0	Risk of Underground Flooding	7.50	7.50	10.00
1.0	Changes to Water Quality from Nearby Waterbodies	5.00	5.00	5.00
1.0	Changes to Water Quality from Other Sources	5.00	5.00	5.00
4.0	**Total**	**5.63**	**5.00**	**5.00**
1.0	Construction Complexity	5.00	2.50	2.50
1.0	Land Ownership and/or Land Rights	10.00	10.00	2.50
1.0	Implementation Cost	7.50	2.50	0.00
3.0	**Total**	**7.50**	**5.00**	**1.67**
1.0	Traditional Land Use	5.00	2.50	0.00
1.0	Other Land Use	5.00	2.50	0.00
1.0	Perception	5.00	5.00	0.00
1.0	Risk of Human Contact	2.50	2.50	0.00
4.0	**Total**	**4.38**	**3.13**	**0.00**
	Total	5.63	4.44	2.83

Figure C-3: Results of Scenario 3