GAHCHO KUÉ PROJECT

ENVIRONMENTAL IMPACT STATEMENT

SECTION 8

KEY LINE OF INQUIRY: WATER QUALITY AND FISH IN KENNADY LAKE

December 2010 **09-1365-1004**

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8.1 INTRODUCTION

8.1.1 Context

This section of the environmental impact statement (EIS) for the Gahcho Kué Project (Project) consists solely of the Key Line of Inquiry: Water Quality and Fish in Kennady Lake. In the *Terms of Reference for the Gahcho Kué Environmental Impact Statement* (Terms of Reference) issued on October 5, 2007, the Gahcho Kué Panel (2007) included this topic as a key line of inquiry because of the following concern:

> *"Lowering the water level of the majority of the lake and exposing the lake bottom for 15 or more years is of great concern to relevant government departments and Aboriginal communities."*

This assessment is based on an updated mine plan compared to the plan for which the Terms of Reference was based on. The concern listed above is still generally applicable to the Project but the Water Management Plan will be slightly different and the duration lower due to a shorter mine life. The water level in Kennady Lake will be lowered, but the dewatering process will be staged through areas of the lake based on pit development through the mine operation. At the end of the mine operation, the lake will be refilled.

The potential impacts of the proposed Project on the aquatic environment are spread between three key lines of inquiry presented in Sections 8, 9 and 10 of the EIS. The geographic extent of effects is divided into Kennady Lake (Section 8) and the streams and lakes downstream of Kennady Lake (Section 9). The temporal extent is spread across all three key lines of inquiry. The effects of the construction, operation, and closure and reclamation phases are addressed in detail in Sections 8 and 9. Section 10 provides a comprehensive summary of the long-term effects on both Kennady Lake and downstream lakes and streams during closure and reclamation. Although each section can be understood on its own (i.e., it is stand alone), a holistic understanding of the effect of the Project on aquatic resources is provided by the three key lines of inquiry together.

The Key Line of Inquiry: Water Quality and Fish in Kennady Lake includes the specific effects of changes caused by the Project within Kennady Lake and the Kennady Lake watershed. An analysis of the stability of deposited mine rock and processed kimberlite in excavated pits is included in this key line of inquiry, as well as in the following key line of inquiry and subjects of note:

- Long-term Biophysical Effects, Closure and Reclamation (Section 10);
- Mine Rock and Processed Kimberlite (Section 11.5);
- Permafrost, Groundwater, and Hydrogeology (Section 11.6); and
- Climate Change Impacts (Section 11.13).

Where there is overlap between this key line of inquiry and another key line of inquiry or subject of note, information will be provided in both locations. The most comprehensive analysis with greatest detail will be provided once in the most appropriate location, but summaries will be provided in all other key lines of inquiry and subjects of note as required by the final Terms of Reference. For example, downstream effects will be addressed in detail in the Key Line of Inquiry: Downstream Water Effects. However, a similar requirement for downstream effects is included in the Terms of Reference for the Kennady Lake key line of inquiry. This will be addressed by a summary and a reference to the location of the in-depth analysis.

The Key Line of Inquiry: Water Quality and Fish in Kennady Lake will contain the primary substantive analysis of the effect of the Project on the water quality and fish in Kennady Lake; however, the primary substantive analysis of two closely related topics will be presented in the following subjects of note:

- Mine Rock and Processed Kimberlite; and
- Permafrost, Groundwater, and Hydrogeology.

Substantial summaries will be provided in this key line of inquiry because of their importance to the water quality and fish in Kennady Lake.

8.1.2 Purpose and Scope

The purpose of the Key Line of Inquiry: Water Quality and Fish in Kennady Lake is to meet the Terms of Reference for the EIS issued by the Gahcho Kué Panel. The table for concordance for the Terms of Reference for this key line of inquiry is shown in Table 8.1-1. The entire Terms of Reference document is included in Appendix 1.I of Section 1, Introduction of this EIS. The complete table of concordance for the entire Terms of Reference is provided in Section 1, Appendix 1.II.

Table 8.1-1 Terms of Reference Pertaining to Water Quality and Fish in Kennady Lake

Final Terms of Reference Requirements		Applicable EIS Sub-section
Section	**Description**	
3.1.3 Existing Environment: Water Quality and Quantity	Describe all water bodies, watercourses, and major drainage areas and watersheds potentially affected by the proposed development	8.3.1
	Describe Kennady Lake, including:	
	- lake-bed bathymetry and composition	8.3.8.2.1
	- lake volumes and seasonal variations	8.3.8.2.1
	- freeze/thaw timing	8.3.5.2.1
	- permafrost conditions beneath or around lake	8.3.3.2, 11.6.2.1, Annex D
	- flow patterns	8.3.5.2.3
	Describe existing water quality for each water body identified for use in the proposed development, and those immediately downstream	8.3.6.2.1, 8.3.6.2.2
	Describe existing groundwater resources in the Project area, including quality and quantity, flow patterns, recharge and discharge areas, and interactions with surface water	8.3.4.2.1, 8.3.4.2.2, 8.3.4.2.3, 8.3.4.3
	identify relevant federal, provincial, or territorial guidelines, criteria, or legislation	8.3.6.1
3.1.3 Existing Environment: Fish and Aquatic Life Forms	describe fish-bearing waterbodies and watercourses that may be affected by the proposed development	8.3.8.2.1
	describe potentially affected fish species and local populations, and for each describe:	
	- seasonal and life cycle movements	8.3.8.2
	- habitat requirements for each life stage	8.3.8.2.
	- local and regional abundance, distribution, use of habitat	8.3.8.2
	- known sensitive habitat areas, species or life stage/activity (e.g., spawning, hatching, feeding)	8.3.8.2
	describe key species used for traditional harvesting activities and any ecotourism activities	8.5.2.2
	describe the micro-organism community present in Kennady Lake, including plankton, algae, and benthic invertebrates	8.3.7.2.1, 8.3.7.2.2
	describe any known issues currently affecting fish and aquatic life forms in the proposed development (e.g., contamination of food sources, parasites, disease)	8.3.8.2.10

Table 8.1-1 Terms of Reference Pertaining to Water Quality and Fish in Kennady Lake (continued)

Final Terms of Reference Requirements		Applicable EIS Sub-section
Section	**Description**	
4.1.2 Key Lines of Inquiry: Water Quality and Fish in Kennady Lake	general requirements pertaining to water quality and fish in Kennady Lake include:	
	- the EIS must provide a detailed analysis of all impacts on fish abundance, health, and fitness for consumption including a comprehensive analysis of potential impacts on water quality of Kennady Lake as a result of possible contamination. Particular emphasis must be placed on the ability of the lake ecosystem, particularly fish and fish habitat, to recover from prolonged exposure of the lake-bed and on the viability of the proposed disposal methods for waste rock and kimberlite	8.8, 8.9, 8.10, 8.11, 11.5
	specific requirements pertaining to fish in Kennady Lake include:	
	- describe any impacts associated with the fish-out, fish salvage, and restocking	8.6.2.1, 8.10.3
	- describe habitat destruction and creation, including potential for interrupting fish migration, alterations to natural drainage, and addition of deep water habitat	8.6.2
	- describe possible fish contamination, and wildlife and human health effects from contaminated fish consumption, including pathways and long- and short-term exposure levels and health effects of toxic exposure levels on wildlife and humans.	8.6.2, 8.7.3, 8.9.8.12
	- describe possible changes to fish behaviour including interruption of migration and spawning patterns and associated effects and changes in the behaviour of wildlife species dependent on fish populations	8.6.2, 8.10, 8.11,8.12,
	specific requirements pertaining to water quality in Kennady Lake include:	
	- describe the water balance for Kennady Lake and analysis of related uncertainties	8.4.5, 8.15
	- describe expected changes in turbidity in Kennady Lake with adaptive management options for unexpected turbidity levels (this analysis may use simulation models)	8.8
	- describe the hydrogeological dynamics of the lake bottom under freezing conditions, in particular the potential for highly concentrated deep ground water to be expelled into the remaining ponds during freeze up, as well as an assessment of changes in the thermal regime of the lake bottom and the extent of freezing	11.6
	- provide a description of maintenance procedures for long-term frozen conditions of potentially reactive waste rock and barren kimberlite, including the incorporation of frozen conditions under climate change parameters	8.6, 11.6, 11.13
	- provide a long-term monitoring plan of thermal conditions of frozen waste rock and PK piles	8.11, 11.5
	- describe any interactions between ground water and submerged processed kimberlite and waste rock, including the possibility of the pits being a long-term contamination source	8.6.2.3, 11.6, 11.5

Table 8.1-1 Terms of Reference Pertaining to Water Quality and Fish in Kennady Lake (continued)

Final Terms of Reference Requirements		Applicable EIS Sub-section
Section	**Description**	
4.1.2 (continued)	- describe potential contamination sources including: mill effluent, lake-bed sediments, backfilled pits, use of explosives, spills (including additive effects of minor spills over time), waste rock and processed kimberlite, and deep ground water, including adequate information to evaluate the potential for dust generation from the exposed lake-bed (e.g., substrate characteristics, particle size, sediment chemistry) as well as bench testing of drying behaviour	8.4.6, 11.4, 11.6
	- describe all potential sources for water contamination, particularly hydrocarbon or ammonium nitrate contamination including accidents and malfunctions; this must also include an evaluation of the potential for explosive charges, exploded or unexploded, to contribute to pollution	8.4.6, 8.6
	- provide a detailed Water Management Plan with information on treatment surfactants and reagents with enough detail to assess the capability of the treatment system to protect water quality, including back up options for adaptive management	8.4.3
	- describe any proposed collection system for runoff from processed kimberlite and waste rock storage facilities, including expected contaminant levels and contingency plans	8.4.3
	- describe any proposed monitoring activities, including monitoring of untreated runoff from roads or other structures. (the principles addressed in section 3.2.7 on compliance inspection, monitoring, and follow-up apply)	8.16
	- describe the spatial extent of downstream effects and how these effects may change through time (seasonally and annually)	9
	- describe water balance calculations during present conditions and over time as the Project proceeds is required to compare baseline conditions with future downstream effects	8.4.5
	- describe impacts on riparian vegetation in Kennady Lake, water fowl, semi-aquatic furbearers, terrestrial mammals, and channel stability from downstream effects of water discharges during construction, fluctuating water levels during operation, and reduced water levels while the lake is refilling	8.12, 8.12.2.1.2, 11.12
	- describe impacts on wildlife resulting from a possible change in freeze-up and thaw conditions associated with the de-watering of Kennady Lake	8.12, 8.12.2.1.2, 11.12
	- describe the reversibility of impacts associated with water level changes and the ability of affected ecosystems to recover	8.6, 8.7.4, 8.11
	- describe the effects of lake dewatering and excavation of pits on ground water flow and quality in the Kennady Lake area in the short- and in the long-term as well as details on how groundwater flows will be managed (including simulations)	8.6.2.3, 8.7.3.2, 8.7.3.3, 11.6

Table 8.1-1 Terms of Reference Pertaining to Water Quality and Fish in Kennady Lake (continued)

Final Terms of Reference Requirements		Applicable EIS Sub-section
Section	**Description**	
4.1.2 (continued)	- describe the potential interaction between ground water and the open pits, as well as between ground water and submerged waste rock or kimberlite, including the possibility of the pits being a long-term contamination source	8.6.2.3, 11.6, 11.5
	- describe the relationship between taliks (i.e., unfrozen sections of soil beneath water bodies) and ground water flows in the Project area, particularly potential for taliks acting as a pathway for contaminants, including the distribution of taliks in the Project area and any connection or interactions between taliks of different lakes	8.3.4.2.1, 8.3.4.2.2, 8.3.4.2.3, 11.6
	- describe the chemical stability of co-disposed waste rock and processed kimberlite	Appendix 8.I
	- describe the confidence in predictions from long-term modelling has been conducted for permafrost issues, particularly effects of the pits on the thermal regime, and a verification that robust monitoring program will be in place	8.15
7 (Table 7-2) Fish Issues	remaining fish issues pertaining to watershed impacts include:	
	- fish health	8.9
	- fish behaviour (increase and decrease in flow)	8.10
	- migration interruption	8.10
	- water chemistry alterations from deep ground water	8.6, 8.8.4
	- chemistry changes in sediment and water	8.6, 8.8.3, 8.8.4
	- impacts of backfilling on aquatic biota	8.6, 8.10.4
	- fluctuation of water flows	8.7
	remaining fish issues pertaining to road effects include:	
	- ice road construction	8.6
	- erosion	8.7
	- water withdrawal	8.7
	- increased ice thickness	8.7
	- watercourse crossings	8.6, 8.10
	- spills	8.4, Appendix 3.I, Attachment 3.I.1
	remaining fish issues pertaining to operations and construction include:	
	- fish out	8.6, 8.10.3
	- contaminant levels	8.8

Table 8.1-1 Terms of Reference Pertaining to Water Quality and Fish in Kennady Lake (continued)

Final Terms of Reference Requirements		Applicable EIS Sub-section
Section	**Description**	
7 (Table 7-2) Fish Issues (continued)	- freshwater lake impacts	8.7, 8.8.1, 8.10.3, 8.11, 8.13
	- habitat destruction and creation	8.6, 8.10
	- noise and vibration on fish behaviour	8.6.2.2
	remaining fish issues pertaining to data collection include:	
	- baseline data	8.3
	- monitoring	8.16
	remaining fish issues pertaining to long-term effects include:	
	- feasibility of recovery	8.11
	- physical changes to lake	8.6
	- addition of deep water habitat post-mine and impacts on the rest of the lake	8.6, 8.8, 8.10
	remaining fish issues pertaining to reclamation methods include:	
	- alternative water sources	8.6
	- habitat creation	8.6, 10
	- restocking of fish	8.6, 8.11
7 (Table 7-3) Water Issues	remaining water issues pertaining to water quality include:	
	- end of pipe contamination	8.8.3
	- pits as long-term contamination sources	8.6, 8.8.4, 11.6, 11.5
	- turbidity during dewatering and rewatering lake	8.8.4
	- contamination runoff from PKC and waste rock	8.6
	- dust as water contamination	8.8.3
	- hydrocarbon contamination	8.6, Appendix 3.I, Attachment 3.I.1
	- length and adequacy of long-term water quality monitoring	8.16
	remaining Kennady Lake water issues related to public concern include:	
	- implications of water quality on human health	8.12
	remaining Kennady Lake water issues related to surface water and watershed include:	
	- ice quality on Kennady Lake and surrounding lakes	8.3.5.2.1
	remaining Kennady Lake water issues pertaining to water use and management include:	

Table 8.1-1 Terms of Reference Pertaining to Water Quality and Fish in Kennady Lake (continued)

Final Terms of Reference Requirements		Applicable EIS Sub-section
Section	**Description**	
	- alterations to natural drainage	8.7
3.2.7 Follow-up Programs	The EIS must include a description of any follow up programs, contingency plans, or adaptive management programs the developer proposes to employ before, during, and after the proposed development, for the purpose of recognizing and managing unpredicted problems. The EIS must explain how the developer proposes to verify impact predictions. The impact statement must also describe what alternative measures will be used in cases were a proposed mitigation measure does not produce the anticipated result.	8.16
	The EIS must provide a review of relevant research, monitoring and follow up activities since the first diamond mine was permitted in the Slave Geological Province to the extent that the relevant information is publicly available. This review must focus on the verification of impact predictions and the effectiveness of mitigation measures proposed in previous diamond mine environmental impact assessments. In particular the developer must make every reasonable effort to verify and evaluate the effectiveness of any proposed mitigation measures that have been used, or are similar to those used at other diamond mining projects in the Mackenzie Valley.	8.3.4.2.3, 8.3.4.3.2, 8.3.7.2.1, 8.4.6.3.1, 8.6.2.3, 8.8.3.1.1, 8.10.2.4, 8.10.3.2, 8.10.3.3, 8.15
	The EIS must include a proposal of how monitoring activities at the Gahcho Kué diamond mine can be coordinated with monitoring programs at all other diamond mines in the Slave Geological Province to facilitate cumulative impact monitoring and management. This proposal must also consider reporting mechanisms that could inform future environmental assessments or impact reviews. The developer is not expected to design and set up an entire regional monitoring system, but is expected to describe its views on a potential system. The developer must also state its views on the separation between developer and government responsibilities.	8.11, 8.16

Source: Terms of Reference for the Gahcho Kué Environmental Impact Statement (Gahcho Kué Panel 2007).

EIS = environmental impact statement.

This key line of inquiry includes a detailed assessment of direct impacts to Kennady Lake, including inlets, outlets, and riparian zones. Impacts are included for the construction (i.e., drawdown), operation, and closure and reclamation phases. A comprehensive analysis of impacts on water quality of Kennady Lake resulting from potential Project-related contamination is incorporated. The potential for subsequent effects of contamination on fish, wildlife, and human health is considered. This assessment also includes impacts on fish abundance, health, and fitness for consumption. More detailed information on the requirements for this key line of inquiry can be found in Table 8.1-1.

8.1.3 Study Area

8.1.3.1 General Location

The Project is situated north of the north-eastern arm of Great Slave Lake in the Northwest Territories (NWT) at Longitude 63° 26' North and Latitude 109° 12' West. The Project site is about 140 kilometres (km) northeast of the nearest community, Łutselk'e, and 280 km northeast of Yellowknife (Figure 8.1-1).

The Project is located in the watershed of Kennady Lake, a small headwater lake within the Lockhart River system. Kennady Lake discharges to the north, via a series of small lakes, into Kirk Lake and thence into Aylmer Lake located on the main stem of the Lockhart River. The Lockhart River system drains into the north-eastern arm of Great Slave Lake (Figure 8.1-1).

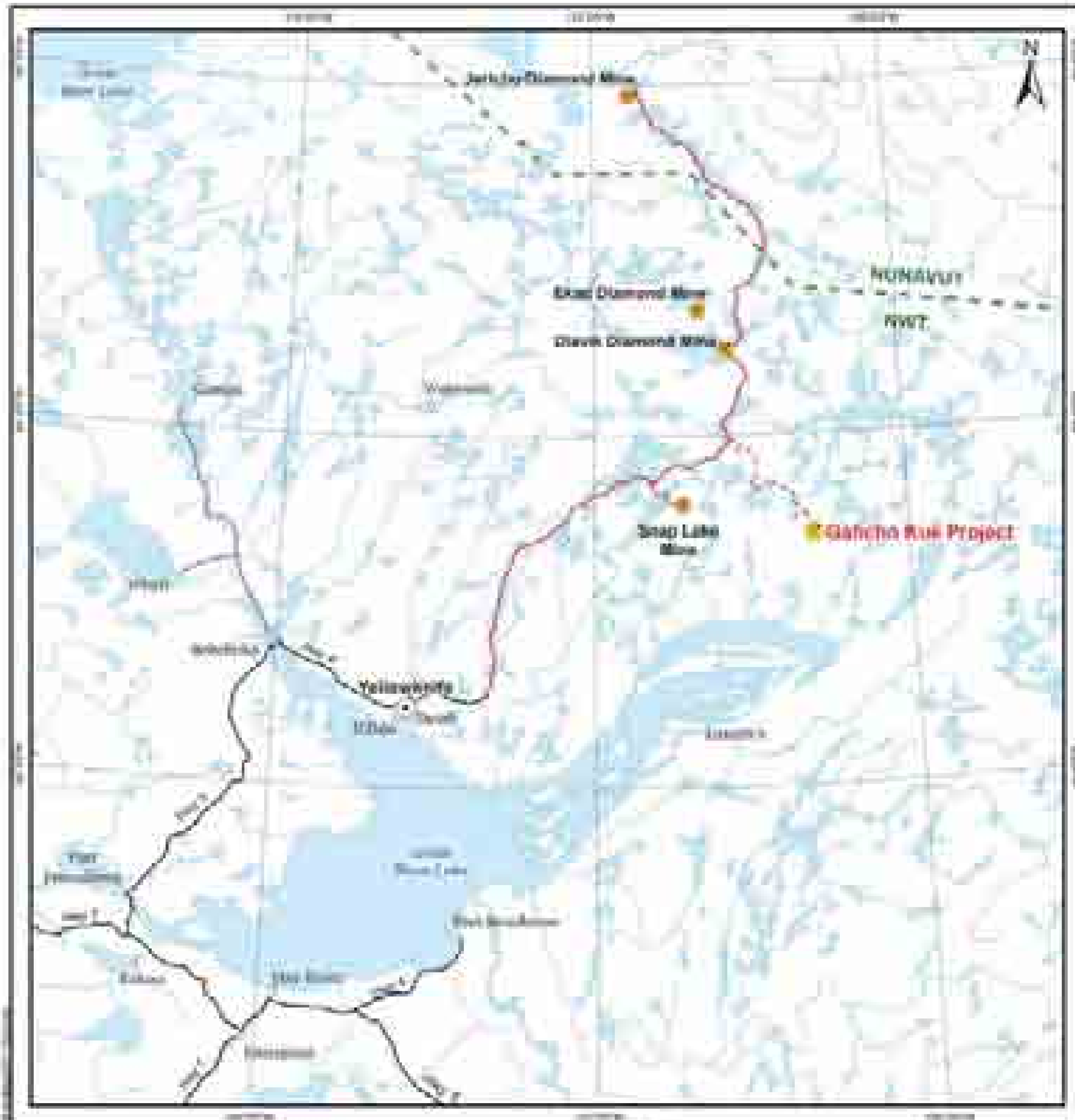
8.1.3.2 Study Area Selection

To assess the potential effects of the Project on the water quality and fish in Kennady Lake, it is necessary to define appropriate spatial boundaries. The study area for this key line of inquiry was identified in the Terms of Reference as follows:

> "The geographic scope for the analysis of this Key Line of Inquiry includes Kennady Lake itself, along with its inlets, outlets, and riparian zones."

Baseline studies were completed before the Terms of Reference were issued; the boundaries for most of the baseline field work were based on two concepts:

- watersheds; and
- expected extent of the Project-related effects.



LEGEND

- Gahcho Kué Project
- Existing Mine
- Territorial Capital
- Populated Place
- Highway
- Existing Winter Road
- Tibbitt-to-Contwoyto Winter Road
- Winter Access Road
- Watercourse
- Waterbody
- Territorial/Provincial Boundary

NOTES
Base data source: The Atlas of Canada

GAHCHO KUÉ PROJECT

Location of the Gahcho Kué Project

PROJECTION: Canadian Lambert Conf. Conic	DATUM: NAD83		
Scale 1:3,000,000			
FILE No: B-Heritage-001-GIS			DATE: September 20, 2010
JOB No: 09-1365-1004	REVISION No: 0		**Figure 8.1-1**
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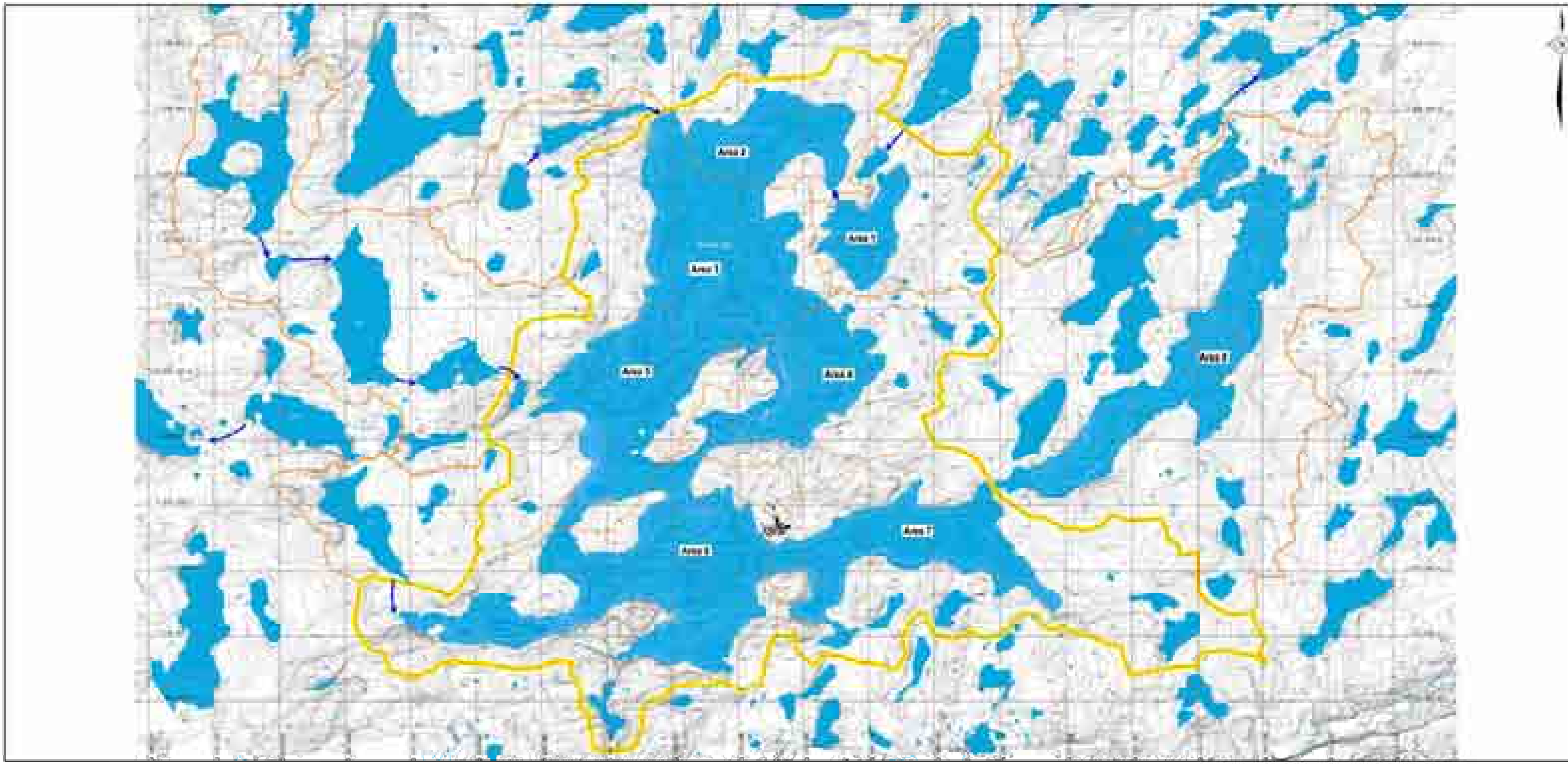
The boundaries were set so that all the expected direct and indirect effects of the Project would lie within the boundaries. The Local Study Area (LSA) in the baseline studies extended from Kennady Lake watershed to the outlet of Kirk Lake and included all the watersheds that could potentially be affected between these points.

The study area identified by the Gahcho Kué Panel (2007) for this key line of inquiry forms the upper headwater region of the baseline LSA. Therefore a new study area, the Kennady Lake Study Area, has been defined that is specific to the Key Line of Inquiry: Water Quality and Fish in Kennady Lake (Figure 8.1-2). The baseline studies were sufficient to address the Terms of Reference requirements for the new study area within this key line of enquiry.

8.1.3.3 Kennady Lake Study Area

The Kennady Lake Study Area includes the seven areas of Kennady Lake (Areas 1, 2, 3 and 5, 4, 6, 7, and 8, and the Kennady Lake watershed. The structure of the study area has been altered from that presented in the water quality baseline program (Annex I) where Kennady Lake was delineated by Basins (i.e., K1, K2, K3, K4 and K5). A comparison of the lake area and basin segregation is provided in Section 8.3. The Kennady Lake watershed is 32.5 square kilometres (km^2). The downstream limit of the study area is the Kennady Lake outflow in Area 8 (i.e., Stream K5). As required by the Terms of Reference (Gahcho Kué Panel 2007), the study area includes Kennady Lake itself, along with its inlets, outlets, and riparian zones (located in the Kennady Lake watershed). All waterbodies (and associated riparian areas) downstream of Kennady Lake up to Great Slave Lake will be addressed in the next key line of inquiry on downstream water effects (Section 9).

Kennady Lake watershed represents an appropriate study area for the surface water disciplines, including hydrology, water quality, riparian vegetation, lower trophic levels in the lake (e.g., benthic invertebrates, plankton), and fish. However, the boundaries for deep groundwater are different. Kennady Lake and the proposed Project footprint are located in the central part of the hydrogeology baseline LSA, which covers an area of some 222 square kilometres (km^2) (see also Figure 11.6-1). Major local lakes act as the controlling features of the deep groundwater flow. Therefore, the hydrogeology analysis will draw on information beyond the Kennady Lake Study Area to address the effects of the Project on Kennady Lake.



GAHCHO KUÉ PROJECT

Kennady Lake Study Area

LEGEND

- Existing Ground Contours 5m Index + 1m Intermediate
- Bathymetry Contours 5m Index + 1m Intermediate
- Controlled Area Boundary
- Marsh Area
- Scrub
- Sub-watershed Boundary
- Drainage Flow Direction

PROJECTION: UTM Zone 12		DATUM: NAD83	
FILE No: E-SWQ-004-CAD			DATE: November 22, 2010
JOB No: 09-1365-1004	REVISION No: X		Figure 8.1-2
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NOTES

Base data source: EBA Figure 4.5 - Stage 2 - Water Management During Mine Operation Years 1 to 3 (2015 to 2017)

8.1.3.4 Content

This introduction is followed by details of the impact analysis and assessment related to water quality and fish in Kennady Lake. The headings of these sections are arranged according to the sequence of steps in the assessment. The disciplines relevant to this key line of inquiry are presented in a logical order with progressively longer pathways between the original sources and the receptors. The following briefly describes the content under each heading of this key line of inquiry:

- **Existing Environment** summarizes relevant baseline information, beginning with the general environmental setting in which the Project occurs, followed by a summary of baseline methods and results for specific components, including permafrost, groundwater, surface water quantity, surface water quality, aquatic habitat, lower trophic level communities, fish, and wildlife and human use (Section 8.3).
- **Water Management Plan Summary** presents a conceptual Water Management Plan and water balance during Project construction, operations, and closure, including a description of potential substance sources, and accidents and malfunctions relevant to water management (Section 8.4).
- **Assessment Approach** provides details on specific aspects of the assessment approach (described in Section 6 of the EIS) that are particularly relevant to the assessment of effects to water quality and fish in Kennady Lake (Section 8.5).
- **Pathway Analysis** identifies all potential pathways by which the Project could affect water quality and fish in Kennady Lake, and provides a screening level assessment of each pathway after applying environmental design features and mitigation that reduce or eliminate Project-related effects (Section 8.6).
- **Effects to Water Quantity** explains the scientific methods that were used to predict the changes to water levels, flows, and bank stability in the Kennady Lake watershed, and presents the results of the analysis of effects to water quantity during the construction, operations, and closure phases of the Project (Section 8.7).
- **Effects to Water Quality** explains the scientific methods, including modelling, that were used to predict the changes to Kennady Lake's water quality during the construction, operations, and closure phases. It then presents the results of the analysis of effects to water quality as a result of the Project (Section 8.8).
- **Effects to Aquatic Health** explains the scientific methods that were used to predict the potential effects related to changes to water quality

and to acidifying emissions, and presents the results of the analysis of effects to aquatic health as a result of the Project (Section 8.9).

- **Effects to Fish and Fish Habitat** explains the methods that were used to predict the changes to Kennady Lake's aquatic habitat, lower trophic level communities, and fish, and presents the results of the analysis of effects to fish resulting from the Project (Section 8.10).
- **Recovery of Kennady Lake and its Watersheds** explains the methods used, including a literature review, and the results related to the rate of recovery of Kennady Lake and the nature of the final ecosystem (Section 8.11).
- **Related Effects to Wildlife and Human Use** presents the results of the analysis of related effects to wildlife and human health that flow from any of the other effects to Kennady Lake, identified in other EIS sections, which are predicted to occur as a result of the Project (Section 8.12).
- **Residual Effects Summary** summarizes the effects to Kennady Lake that are predicted to remain after all measures (e.g., environmental design features) to eliminate or reduce negative effects have been incorporated into the Project design (Section 8.13).
- **Residual Impact Classification** describes methods used to classify residual effects, and summarizes the classification results (Section 8.14).
- **Uncertainty** discusses sources of uncertainty surrounding the predictions of impacts to Kennady Lake's water quality and fish and how this uncertainty is addressed by the Project (Section 8.15).
- **Monitoring and Follow-up** describes proposed monitoring programs, contingency plans, and/or adaptive management strategies related to Kennady Lake (Section 8.16).
- **References** list all documents and other material used in the preparation of this section (Section 8.17).
- **Glossary, Acronyms, and Units** explains the meaning of scientific, technical, or other uncommon terms used in this section. In addition, acronyms and abbreviated units are defined (Section 8.18).

8.2 SUMMARY

Background

The proposed Gahcho Kué Project (Project) is a diamond mine located in the watershed of Kennady Lake, a headwater lake within the Lockhart River system, located about 280 kilometres (km) northeast of Yellowknife, Northwest Territories (NWT). The Lockhart River drains into the East Arm of Great Slave Lake. Water quality and fish in Kennady Lake were identified in the *Terms of Reference for the Gahcho Kué Environmental Impact Statement* as a key line of inquiry because of concerns from several government departments and Aboriginal communities related to its proposed dewatering, and subsequent refilling.

The Key Line of Inquiry: Water Quality and Fish in Kennady Lake includes the specific effects of changes caused by the Project within Kennady Lake and the Kennady Lake watershed. Impacts are included for the construction (i.e., Kennady Lake dewatering), operation, and closure (i.e., refilling and recovery of Kennedy Lake) phases. The study area includes Kennady Lake itself, along with its inlets, outlets, and riparian zones, to the Kennady Lake outflow in Area 8 (Stream K5). The area downstream of Kennady Lake to Great Slave Lake is included in the Key Line of Inquiry: Downstream Water Effects (Section 9).

Existing Environment

Components of the existing environment that are relevant to this key line of inquiry include climate, permafrost, hydrogeology, surface water quantity, surface water quality, physical aquatic habitat, lower trophic levels, fish, and wildlife. Where available, historical baseline data in Kennady Lake and streams and lakes in its watershed were reviewed and summarized; multi-year, seasonal baseline sampling was conducted to supplement existing information.

Water Management Plan

A Water Management Plan has been developed for the Project. The primary purpose of this plan is to reduce the effect of the Project on the aquatic ecosystem of Kennady Lake and downstream environments during construction, operations, and closure phases.

The most significant water-related activity that will take place during the Project will be the dewatering of a large portion of Kennady Lake (Areas 2 to 7) to allow access to the lake bed and underlying kimberlite pipes, and the subsequent refilling and restoration of the lake upon completion of mining. To facilitate the dewatering process, natural drainage from the upper portion of the Kennady Lake watershed will be diverted to an adjacent watershed (N watershed) by the establishment of several earth filled dykes and the raising of a number of upper watershed lakes. The most downstream basin of the lake (Area 8) will be separated from the rest of Kennady Lake by the construction of a water retaining dyke (Dyke A).

During operations, Project activities associated with the Water Management Plan will be designed to minimize the discharge of site water to downstream waterbodies unless specific water quality criteria are met, and to recycle process water to the greatest extent possible. At closure, after mining has been completed, the natural drainage system in the Kennady Lake watershed, which has not been modified by the Project, will be restored and refilling of the dewatered lake beds will begin.

Assessment Approach

Pathway analysis identified and screened the linkages between Project components or activities and the potential effects to receptors within the aquatic environment. Pathways were determined to be primary, secondary (minor), or as having no linkage, using scientific and traditional knowledge, logic, and experience with similar developments, and environmental design features and mitigation. All primary pathways were carried forward in the assessment for detailed effects analysis.

The selection of valued components (VCs) specific to this key line of inquiry resulted from issues scoping sessions for the Project with community members, federal and territorial regulators, and other stakeholders. For this key line of inquiry, water quality and select fish species were identified as VCs, with the following being identified as the assessment endpoints:

- Suitability of Water Quality to Support a Viable Aquatic Ecosystem
- Abundance and Persistence of Desired Population(s) of Lake Trout
- Abundance and Persistence of Desired Population(s) of Northern Pike
- Abundance and Persistence of Desired Population(s) of Arctic Grayling

Effects to Water Quantity

During construction and operation, the dewatering process is not expected to result in effects to natural channel or bank stability; however, the exposed lake bed within the dewatered Kennady Lake may be subject to erosion, depending on the bed substrate. The construction of diversion dykes will increase water levels and surface areas in a number of the diversion lakes, block the existing outlet of another lake (Lake B1) with no change in water levels, and cause the cessation of flows downstream of the dykes for most of the year. However, as mean annual water level variation in the upper watershed lakes is expected to be similar or reduced from pre-diversion conditions, erosion potential and sediment sourcing will be minimized. The flow paths and constructed diversion channels that link the diverted lakes to the adjacent watershed, if required, will be designed to prevent erosion and maintain stability.

Runoff from project surface infrastructure in watersheds that drain to Areas 2 to 7 will be conveyed to the Water Management Pond (WMP) by the site water management system. Runoff from project surface infrastructure in watersheds that drain to Area 8 will be free-draining and no measurable effect on the quantity of inflow to Area 8 of Kennady Lake is anticipated. Project surface infrastructure, including the two mine rock piles, the Coarse Processed Kimberlite (PK) Pile, and the Fine PKC Processed Kimberlite Containment (PKC) Facility, will be located almost entirely within the controlled area boundary and all drainage will be managed. No effects on natural channel or bank stability are anticipated.

During the construction phase, dewatering of Area 7 will be directed to Area 8. The resultant flows downstream of Area 8 will be generally increased from baseline conditions; however, flows will be limited so that discharge will not exceed the 1:2 year flood discharge volume. During operation, flows through Area 8 will be decreased from baseline conditions due to the closed-circuiting of the watershed upstream of Dyke A. The alterations in water levels in Area 8 will correspond with the flow changes; no adverse effects to channels or bank stability are anticipated.

At closure, the diverted watersheds, with the exception of the A watershed, will be restored, and pumping from Lake N11 will occur to supplement the refilling of Kennady Lake. No effects on channel or bank stability are expected during refilling, and erosion will be prevented at discharge points by armouring of outfalls and use of diffusers. No water from the refilled areas will be released to Area 8 until the water level is at the naturally armoured shoreline elevation, and water quality meets specific criteria. During the refilling of Kennady Lake, flows at the Area 8 outlet (Stream K5) will continue to be reduced similar to operations.

Beyond closure, the water balance will change for the Kennady Lake watershed resulting in the increase of mean annual water yield by 8.9 percent (%). The reduction in the surface area of Kennady Lake of 14.1% means that flood peak discharges will increase post-closure due to less storage in the lake.

Water Quality

Potential influences to water quality in the main areas of Kennady Lake (Areas 2 to 7) and Area 8 include the following:

- air emissions from the Project (e.g., fugitive dust, vehicle emissions);
- isolation of Areas 2 and 7 from Area 8;
- drainage in the controlled area that comes into contact with the Fine PKC Facility, mine rock piles and the Coarse PK Pile; and
- the open Hearne and Tuzo pits

Dust and associated metal deposition on water quality from Project air emissions were evaluated for a subset of lakes within the Kennady Lake watershed; changes to total suspended solids (TSS) and trace metals (e.g., aluminum, cadmium, chromium, copper, iron, mercury, and silver) concentrations resulting from deposition will potentially exceed average baseline concentrations in two or more lakes adjacent to the Project area during construction and operations by greater than 100%. The effects on TSS and metal concentrations are expected to be localized in the immediate vicinity of the Project and temporally restricted to the period during and after freshet. Based on the evaluation of acidifying emissions during construction and operations, project-related deposition of sulphate and nitrate in the Kennady Lake watershed is not predicted to result in lake acidification.

To estimate the water quality in Kennady Lake (i.e., Areas 2 to 7) and Area 8 through the closure phase (i.e., the refill period), which includes the post-closure period once Kennady Lake is refilled and Dyke A is breached, a dynamic, mass-balance water quality model was developed in GoldSim™. Water quality in Area 8 will remain similar to background conditions during operations and closure, before the removal of Dyke A, because this area will remain isolated from the main areas of Kennady Lake. Water quality in Area 8 during the post-closure period will be driven by the water flowing from Kennady Lake after Dyke A is breached, with additional dilution from the Area 8 sub-watershed.

Concentrations of total dissolved solids (TDS) and major ions in the main areas of Kennady Lake are projected to increase during the operations phase due to the management of water within the controlled area (e.g., runoff, groundwater inflows, process water) and decrease during the closure phase when the lake is refilled. In the post-closure period, concentrations are predicted to continue to decline. Concentrations of TDS and major ions in Area 8 are predicted to increase when Dyke A is breached; concentrations are predicted to peak within five years of Dyke A being breached, as water in Area 8 is replaced with water from the refilled Kennady Lake. Over time, concentrations of TDS and major ions are generally predicted to decline, but for some parameters (e.g., potassium), concentrations are predicted to increase during the post-closure period and reach a long-term steady state concentration within a few decades.

TDS and all major ions are predicted to remain above background conditions, but below levels that would affect aquatic health.

Nutrient levels are predicted to increase in Areas 2 through 7 during operations, with nitrogen projected to decrease during the closure phase as nitrogen residue in the stored PK and mine rock from blasting deplete. By the time Dyke A is breached, modelled nitrate and ammonia concentrations are expected to be at, or below, water quality guidelines and decline thereafter to near background levels. In Area 8, all forms of nitrogen are expected to peak in concentration in Area 8 within five years of breaching Dyke A, then return to near-background concentrations. Water quality modelling results suggest that there is a potential for phosphorus levels to increase in Kennady Lake as a result of runoff from the reclaimed mine site. The runoff waters mobilize phosphorus from the mine rock, coarse PK and fine PK as they travel through the external structures, with the fine PK being the largest source of phosphorus. De Beers is currently evaluating a variety of environmental design features and mitigation measures to limit contact between site runoff waters and the fine PK located within the Fine PKC Facility and other potential sources. The effectiveness of these environmental design features and mitigation measures is uncertain and requires further analysis. Accordingly, the amount of phosphorus that may be released into the environment is uncertain at this time. As a result, potential effects related to phosphorus have not been presented and will not be available until such time as additional analysis is completed. This analysis will be provided to the Panel in 2011 following additional work that will be undertaken over the next few months.

Of the 23 trace metals that were modelled for the assessment, three patterns are predicted in modelled concentrations of the main areas of Kennady Lake over construction and operations, and closure:

- Some metals are predicted to increase in concentration during the operations phase, then steadily decline in concentration as the lake is flushed during the post-closure period. These include chromium, cobalt, iron, lead, manganese, mercury, selenium, silver, thallium, uranium and zinc, in which chromium and iron are projected to exceed water quality guidelines in the post-closure phase.

- Some metals are predicted to increase in concentration relatively steadily throughout the operations phase, rise or fall during the closure period, and then remain fairly constant throughout the post-closure period. These metals include aluminum, antimony, arsenic, cadmium, copper, nickel and vanadium, in which cadmium and copper are projected to exceed water quality guidelines in the post-closure period. Because the primary loading sources of these metals is groundwater and geochemical flux, the majority of these metals will be in the dissolved form.

- Some metals are predicted to increase after closure, reach steady state conditions in Kennady Lake within about 40 years. These metals include barium, beryllium, boron, molybdenum and strontium; none of these five metals are projected to exceed water quality guidelines in the post-closure period.

As groundwater and geochemical sources are the primary contributors of these metals**,** dissolved fraction of these metals is predicted to comprise the majority of the total concentrations.

Concentrations of trace metals in Area 8 are predicted to remain similar to background concentrations until Dyke A is breached, after which it will take approximately five years for metals concentrations to peak and then follow the general trends described for Kennady Lake in post-closure. Of the 23 modelled trace metals, cadmium, chromium, and copper are projected to exceed water quality guidelines in the post-closure period in Area 8.

A long-term analysis evaluated the stability of the stratification (meromictic conditions) in the Tuzo Pit following the refilling of Kennady Lake, and concluded that the saline bottom layer will remain stable and will not overturn. The water quality in Kennady Lake above Tuzo Pit will, therefore, be primarily determined by the upper 20 metres (m) of fresh water, which will be subject to temperature and wind-driven summer seasonal stratification.

Effects to Aquatic Health

Potential effects to aquatic health were assessed based on the changes to water quality from Project emissions, and Project activities. During construction and operation, predicted maximum concentrations of suspended solids and some metals from Project air emissions disposition are predicted to increase above water quality guidelines because of dust and metal deposition in some lakes, some of which are fish-bearing. Given the conservatism in the predicted concentrations, and the short length of the exposure to elevated concentrations, the potential for adverse effects from dust and metals deposition is considered to be low. At the end of operations, the Project is no longer a notable source of dust and metal deposition and, therefore, a return to existing conditions is anticipated.

As a result of Project activities, changes to water quality in Kennady Lake and Area 8 during closure and post-closure are expected. For direct waterborne exposure, predicted maximum concentrations for most substances of potential concern (SOPCs) were lower than the corresponding chronic effects benchmark (CEB), with the exception of total copper, iron, and strontium. Despite the predicted exceedances of the CEB, the potential for copper, iron, and strontium to cause adverse effects to aquatic life in Kennady Lake and Area 8 was considered to be low. Follow-up monitoring will be undertaken to confirm this evaluation. For the indirect exposure pathway, predicted fish tissue concentrations are below toxicological benchmarks for all substances considered in the assessment except silver. Given the modest predicted increase, and that both baseline and predicted tissue concentrations only marginally exceed the available no-effect concentration, the potential for predicted silver concentrations to cause effects to fish is concluded to be low. Based on the above results, changes to concentrations of all substances considered in this assessment are predicted to result in negligible effects to aquatic health in Kennady Lake.

Fish and Fish Habitat

Changes to fish habitat will occur from the footprint of the project (e.g., excavation of the mine pits, placement of mine rock, placement of PK, dykes, and other construction activities). The affected habitat areas include the following: portions of Kennady Lake and adjacent lakes within the Kennady Lake watershed that will be permanently lost (194.56 hectares [ha] of lake area of 0.51 ha of watercourse area in tributaries to Kennady Lake); portions that will be physically altered after dewatering and later submerged in the refilled Kennady Lake (83.32 ha of lake area), and portions that will be dewatered (or partially dewatered) but not otherwise physically altered before being submerged in the refilled Kennady Lake (435.90 ha of lake area and 0.23 ha of watercourse area in tributaries to Kennady Lake). The affected habitat areas were quantified in the Conceptual Compensation Plan, which also describes the various options considered for providing compensation, and presents a proposed fish habitat Conceptual Compensation Plan to achieve no net loss of fish habitat. The options for compensation include: construction of impounding dykes to raise lake levels; construction of finger reefs in Kennady Lake; construction of habitat structures on the decommissioned mine pits/dykes; and widening the top bench of pits to create shelf areas where they extend onto land. The compensation ratio provided by the proposed compensation plan (gains:losses calculated based on total area of permanently lost habitat and physically altered and re-submerged habitat) is 0.65 for operations and 1.37 for closure.

To minimize the waste of fish caused by dewatering activities, fish salvage will be conducted to remove fish from Areas 2 to 7 before and during dewatering. A combination of gear types would be used to maximize capture efficiency. Dewatering will result in the temporary loss of fish habitat within Areas 2 to 7 of

Kennady Lake; however, it is expected that a self-sustaining fish population will be present in Kennady Lake post-closure.

In the diversion watersheds, fish habitat downstream of the dykes will be dewatered and lost to fish residing in upstream lakes; the loss of habitat resulting from the placement of the dykes and the dewatering of downstream stream segments and lakes is included in the Conceptual Compensation Plan. Raising water levels in Lakes A3, D2, D3, and E1 will result in increased lake habitat area, which is likely to benefit fish residing in these lakes. Negligible effects on fish and fish habitat would be expected from shoreline erosion. Although the dykes will isolate fish populations within the B, D, and E watersheds for the duration of mine operations (and permanently in Lake A3), it is expected that the diversion watersheds will support self-sustaining populations of fish species, such as, Arctic grayling (*Thymallus arcticus*), northern pike (*Esox lucius*), burbot (*Lota lota*), slimy sculpin (*Cottus cognatus*), and ninespine stickleback (*Pungitius pungitius*).

Isolation of Area 8 from the remainder of Kennady Lake during operations and closure is predicted to result in a small increase in nutrient concentrations, which is expected to result in a slight increase in productivity of plankton and benthic invertebrate communities. The residual fish community in Area 8 of Kennady Lake is anticipated to consist of small-bodied fish species (i.e., lake chub [*Couesius plumbeus*], ninespine stickleback, and slimy sculpin), as well as Arctic grayling, northern pike and burbot. As a result of the existing overwintering limitations in Area 8 and the elimination of alternative overwintering refugia in Areas 2 through 7, lake trout (*Salvelinus namaycush*) and round whitefish (*Prosopium cylindraceum*) may not continue to persist in Area 8 throughout the operational period, as they are less tolerant of low dissolved oxygen concentrations.

Effects of TSS from dust and particulate deposition from windborne dust from Project facilities and exposed lake bed sediments on fish and fish habitat are expected to be localized in the immediate vicinity of the Project and temporally restricted to the period during and after freshet. The potential for adverse effects to aquatic health from dust and metals deposition was considered in the aquatic health assessment to be low and therefore, no effects to fish populations or communities are expected to occur from changes in aquatic health.

At closure, the water levels in the raised lakes will return to baseline levels and the fish and lower trophic communities will adjust to the new lake levels. Habitat conditions for spawning, rearing and overwintering will be similar to pre-Project conditions.

The Project is expected to have low or negligible effects on aquatic health in Kennady Lake and Area 8 from changes in the chemical constituents of water quality; therefore, no effects to fish populations or communities are expected to occur from changes in aquatic health.

Recovery of Kennady Lake

An aquatic ecosystem will develop within Kennady Lake after refilling and reconnection of its basins. The physical and chemical environment in Kennady Lake is expected to be in a state that will allow re-establishment of an aquatic ecosystem, although the re-established communities may differ from pre-development communities.

The expected time frame for recovery of the phytoplankton community is estimated to be approximately five years after refilling is complete, taking into account that the community will begin to develop during the refilling period. Zooplankton community development is predicted to follow recovery of the phytoplankton community (i.e., likely within five to ten years of Kennady Lake being completely refilled). Recovery of the benthic invertebrate community in Kennady Lake is expected to be slower than that of the plankton communities, with an estimated time for recovery of about ten years after refilling is complete. The benthic invertebrate community is expected to be different from the community that currently exists in Kennady Lake and in surrounding lakes; the community may be of higher abundance and biomass, depending on final nutrient levels in the refilled system, and will likely be dominated by midges and aquatic worms.

The re-establishment of the fish community within Kennady Lake, and the speed at which it will occur, will depend on the ability of fish to re-colonize the refilled lake, the habitat conditions within the lake, and how succession takes place within the refilled system after it has been fully connected to the surrounding environment. It is expected that a fish community will become re-established in Kennady Lake; however, the fish community may be different than what exists currently.

The B, D, and E watersheds are likely to be the primary source of initial migrants into the refilled lake. As conditions improve, and water depths increase, the early migrants will become permanently established. During refilling, exclusion measures will be used to limit the initial migration of large-bodied fish into the lake. Following the removal of Dyke A, fish will also enter from Area 8. The final fish community of Kennady The Lake will likely continue to be characterized by low species richness (less than 10 species), containing a small-bodied forage fish community and large-bodied species, such as northern pike, Arctic grayling, burbot, and possibly longnose sucker. Total lake standing stock and annual production may be increased over what currently exists in the lake. However, the composition of the fish community is highly dependent on the nutrient and limnological characteristics that develop in the refilled lake. The analysis of nutrient levels in the refilled lake is on-going, with results expected in 2011. Conclusions with respect to the nature of the fish community in the refilled Kennady Lake will be put forward at that time.

Overall, it is the life history attributes of Arctic grayling, northern pike, and burbot that will ultimately determine the duration of the complete recovery of the Kennady Lake aquatic ecosystem. Northern pike is expected to be one of the last fish species to re-establish a stable, self-sustaining population in Kennady Lake (i.e., approximately 50 to 60 years following the complete refilling of Kennady Lake). If habitat conditions are in fact suitable for lake trout in the refilled lake, it is expected that this species will also require a long time to re-establish a stable, self-sustaining population (i.e., approximately 60 to 75 years following the complete refilling of Kennady Lake).

Residual Impact Classification

The classification was carried out on residual impacts (i.e., impacts with environmental design features and mitigation considered). Residual impacts were classified for two time periods: from the initiation of the Project to 100 years later; and future conditions after 100 years from Project initiation. Projected impacts were then evaluated to determine if they were environmentally significant.

The projected impacts of the Project on the suitability of water within the Kennady Lake watershed to support a viable and self-sustaining aquatic ecosystem are considered to be not environmentally significant for both time periods. Water quality is predicted to change, but is expected to result in negligible effects to aquatic health in Kennady Lake.

The projected impacts on the abundance and persistence of Arctic grayling, lake trout, and northern pike are considered to be not environmentally significant for both time periods. Arctic grayling and northern pike will be affected by the loss of habitat in Kennady Lake during the life of the mine, but will continue to persist in Area 8 and the diverted watersheds. For lake trout, migration into Kennady Lake may be impaired and they are not likely to persist in Area 8 during the life of the mine; however they will have access to immigrate over time. Competition with other predatory species and the rate at which they re-colonize may influence the size of the resulting lake trout population. It is expected that self-sustaining populations of these fish species will become established in the refilled lake.

The potential effects of changes to nutrient levels in Kennady Lake have not been presented. They are the subject of continuing evaluation and are therefore not included at this time in the determination of environmental significance for these assessment endpoints. Once the continued analysis is complete, the significance determination outlined herein will be updated as appropriate and required.

8.3 EXISTING ENVIRONMENT

The following section provides a brief description of the existing environment in Kennady Lake and the Kennady Lake watershed that is directly relevant to the Key Line of Inquiry: Water Quality and Fish in Kennady Lake. Components of the existing conditions discussed herein include climate, permafrost, hydrogeology, surface water quantity, surface water quality, physical aquatic habitat, lower trophic levels, fish, and wildlife. The focus of the descriptions below is on baseline results for each component. For more details on methods or results, supplementary information regarding the existing environment of Kennady Lake and the Kennady Lake watershed is provided in the following annexes:

- Annex D (Bedrock Geology, Terrain, Soil and Permafrost Baseline);
- Annex F (Wildlife Baseline);
- Annex G (Hydrogeology Baseline);
- Annex H (Climate and Hydrology Baseline);
- Annex I (Water Quality Baseline); and
- Annex J (Fisheries and Aquatic Resources Baseline).

8.3.1 General Setting

The Gahcho Kué Project (Project) is located within the Kennady Lake watershed at Kennady Lake, a small headwater lake of the Lockhart River watershed in the Northwest Territories. Kennady Lake is 84 kilometres (km) east of the Snap Lake Mine, the only other active mine in the Lockhart River watershed. The Diavik and Ekati diamond mines are located in the Coppermine River watershed, about 127 km and 158 km northeast of Kennady Lake, respectively. The Project site is located at an elevation of approximately 420 metres above sea level (masl).

Kennady Lake is located in the sub-Arctic tundra, north of the treeline, and near the southern limit of continuous permafrost. Topography around Kennady Lake is characterized by low relief with occasional rocky ridges. Muskeg is the dominant vegetation, but willow shrubs (i.e., *Salix* spp.) exist in riparian areas and black spruce (i.e., *Picea* spp.) are found in valley depressions where wind exposure is reduced.

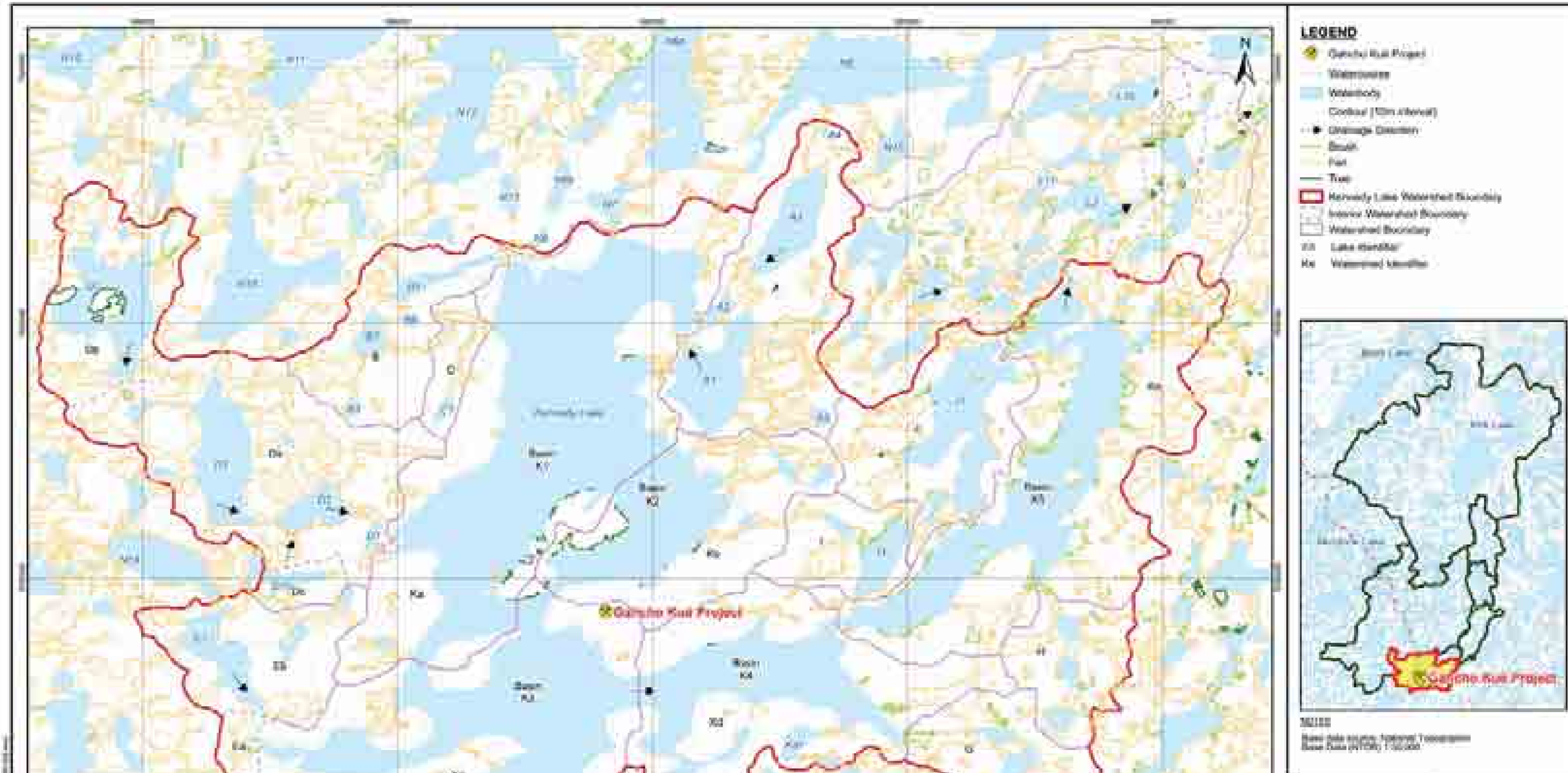
Kennady Lake is a small (815 hectares [ha]), oligotrophic, tundra lake that can be roughly divided into five main basins (Figure 8.3-1) based on key morphometric features. Four of these basins, referred to as Basins K1, K2, K3, and K4, have relatively deep zones, and are connected by deep-water (more than 5 metres [m]) channels. They represent approximately 82 percent (%) of the total surface area of Kennady Lake. The fifth basin (referred to as Basin K5) is located at the outlet of Kennady Lake is shallow (average depth is less than 4 m), long (about 4 km), and narrow (less than 500 m wide) compared to the other basins. Kennady Lake has a mean depth of 5 m and a maximum depth of 18 m.

For this EIS, modifications have been made to the delineation of Kennady Lake from basins to areas (Figure 8.3-2). Eight areas, which include a portion of the A watershed, replace the five basins. These areas have an alignment to the basin delineation, with the exception of the Areas 1 and 2, which are linked to portions of the A watershed and the northeast corner of Kennady Lake that will become the Fine Processed Kimberlite Containment (PKC) Facility.

Area 1 includes Lakes A1 and A2. Area 2 constitutes a small portion of the northeast embayment of Kennady Lake, which was formerly the northern part of Basin K1. Areas 3 and 5 comprise the remaining part of Basin K1 and Basin K2. Area 6 is equivalent to Basin K3 and Area 7 is equivalent to Basin K4. Area 8 replaces Basin K5, which contains the lake outlet draining Kennady Lake to the north (Stream K5). The key morphological characteristics of the lake areas compared to the basins are detailed in Table 8.3-1.

There are also numerous small (less than 20 ha), shallow (less than 3 m) lakes within the Kennady Lake watershed. Most of these lakes are non-fish-bearing and are connected to Kennady Lake only during the spring freshet.

Kennady Lake drains northeast to north for about 70 km through Kirk Lake and into Aylmer Lake. Aylmer Lake is located on the mainstem of the Lockhart River, approximately halfway between the Kennady Lake watershed and Great Slave Lake. The Lockhart River then drains southeast from Aylmer Lake through Clinton Colden and Artillery lakes into the East Arm of Great Slave Lake. The Kennady Lake watershed is 37 square kilometres (km^2) and comprises 0.14% of the 27,500 km^2 Lockhart River watershed.



GAHCHO KUÉ PROJECT

Kennady Lake Study Area Basin Delineation of Kennady Lake (prior to 2010)

Figure 6.3-1

GAHCHO KUÉ PROJECT

Kennady Lake Study Area
Area Delineation of Kennady Lake
(2010)

Figure 8.3-2

Table 8.3-1 Summary of Kennady Lake Morphometry

Sub Basin	Lake Area (km^2)	Lake Area	Lake Area (km^2)	Lake Volume (Mm^3)	Lake Volume (%)	Maximum Lake Depth (m)	Local Watershed Drainage Area (km^2)
-	-	Area 1[a]	-	-	-	-	-
Basin K1	3.19	Area 2	0.61[b]	18.3	48	14	13.78
		Areas 3 and 5	2.56[c]				
Basin K2	0.76	Area 4	0.76	4.4	11.5	14	2.14
Basin K3	1.78	Area 6	1.78	8.6	22.6	18	5.17
Basin K4	0.99	Area 7	0.99	3.3	8.7	12	3.82
Basin K5	1.43	Area 8	1.43	3.5	9.2	9	7.56
Total	**8.15**		**8.15**	**38.1**	**100**	**-**	**32.47**

[a] Area 1 lies within the A watershed, upstream of Kennady Lake.

[b] The volume of Area 2 is 2.3 Mm^3.

[c] The volume of Area 2 is 16.0 Mm^3.

km^2 = square kilometre; Mm^3 = million cubic metre; m = metre; % = percent; - = not applicable.

The Project is accessed in the winter by a 120 km Winter Access Road that extends from the Tibbitt-to-Contwoyto Winter Road at MacKay Lake to Kennady Lake. The Winter Access Road to Kennady Lake crosses Reid, Munn, Margaret, and Murdock lakes, and several smaller lakes and streams. The Winter Access Road typically operates for less than 70 days each year between November and March (De Beers 2002). The Project will also be accessed by air.

8.3.2 Climate

The following section provides a description of the climate conditions for Kennady Lake and the Kennady Lake watershed. For additional information regarding climate, the reader is referred to Annex H (Climate and Hydrology Baseline).

8.3.2.1 Methods

The description of climate at Kennady Lake focuses on the following parameters that are important in the hydrological cycle:

- air temperature;
- precipitation, including rainfall and snowfall;
- lake evaporation;
- evapotranspiration;

- relative humidity; and
- solar radiation and net radiation.

Long-term mean values and variability of air temperature, precipitation, and lake evaporation are based on climate data collected at the Project site (2004 to 2005) and long-term (1959 to 2005) regional data (combined data from the Lupin Airport and Contwoyto Lake station). Relative humidity, soil temperature and heat flux, solar radiation, and net radiation results are based on short-term data (2004 to 2005) collected at the Project site. Evapotranspiration is calculated using the calibrated long-term mean water balance.

8.3.2.2 Results

8.3.2.2.1 General Climate

The Project is located in a sub-Arctic climate, characterized by long, cold winters and short, cool summers. Temperatures typically fall to below freezing by early October and remain so until mid- to late May. Monthly mean temperatures persist below -20 degrees Celsius (°C) from December through March, with daily means occasionally reaching below -40°C. The warmest month is July, with a mean temperature of about 12°C. Measured mean annual precipitation in the region is approximately 270 millimetres (mm) with about half falling as snow during the October to May winter period.

8.3.2.2.2 Air Temperature

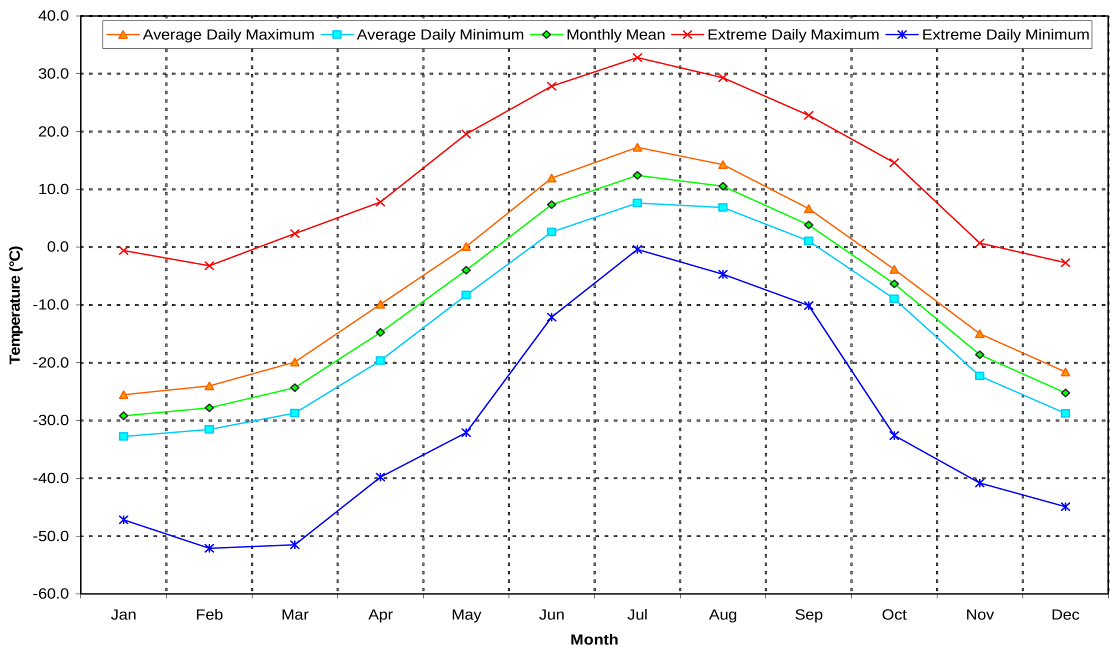
Monthly mean air temperatures at Lupin Combined (Lupin Airport and Contwoyto Lake stations) were used to derive long-term air temperature characteristics, as presented in Table 8.3-2. This shows that mean monthly temperatures are above freezing only for the four months of June through September. Mean temperatures are below -20°C from December through March. On average, January is the coldest month, but the most extreme low temperatures tend to occur in February. The annual mean temperature is estimated at -9.7°C. The data in Table 8.3-2 are shown graphically in Figure 8.3-3.

Table 8.3-2 Estimated Long-term Air Temperature Characteristics (°C), 1959 to 2005

Month	Extreme		Monthly Mean		Mean Monthly
	Maximum	Minimum	Maximum	Minimum	
January	-0.6	-47.2	-25.5	-32.8	-29.2
February	-3.2	-52.1	-24.0	-31.6	-27.8
March	2.4	-51.5	-19.9	-28.7	-24.3
April	7.8	-39.8	-9.9	-19.6	-14.7
May	19.6	-32.1	0.1	-8.3	-4.0
June	27.9	-12.1	11.9	2.6	7.3
July	32.8	-0.4	17.3	7.6	12.4
August	29.3	-4.7	14.3	6.9	10.5
September	22.8	-10.1	6.7	1.1	3.8
October	14.6	-32.6	-3.9	-9.0	-6.3
November	0.7	-40.8	-15.0	-22.3	-18.6
December	-2.7	-44.9	-21.6	-28.8	-25.2
Annual	32.8	-52.1	17.3	-32.8	-9.7

Source: Based in part on Environment Canada (2005) data from Lupin Airport and Contwoyto Lake stations.
°C = degrees Celsius.

Figure 8.3-3 Estimated Long-term Air Temperature Characteristics, 1959 to 2005



°C = degrees Celsius.

8.3.2.2.3 Precipitation

Precipitation at the Project site, including rainfall, snowfall, and total precipitation, was characterized by applying regional adjustments to the Lupin Combined data set for the period 1959 to 2005. Undercatch adjustments were also applied to account for trace and other rainfall and snowfall events not measured by instruments. The mean values of monthly rainfall, snowfall, and precipitation are summarized in Table 8.3-3.

Frequency analysis of annual rainfall, snowfall, and total precipitation (undercatch adjusted values) for Kennady Lake was conducted to describe the natural variability of these parameters. The frequency analysis results for rainfall, snowfall, and total precipitation are shown in Tables 8.3-4, 8.3-5, and 8.3-6, respectively. These analyses are based on a hydrological year, rather than a calendar year, to consider the amount of precipitation available for runoff in an open-water season.

Table 8.3-3 Estimated Long-term Precipitation Characteristics (Undercatch Adjusted Values), 1959 to 2005

Month	Rainfall (mm)	Snowfall (cm)	Precipitation (mm)
January	0.0	11.1	11.2
February	0.0	11.7	11.7
March	0.0	15.0	15.1
April	0.4	16.1	16.6
May	7.0	16.0	23.0
June	28.1	5.0	33.0
July	45.0	0.3	45.4
August	57.4	2.6	60.0
September	27.8	18.6	46.4
October	2.6	35.2	37.9
November	0.1	21.4	21.5
December	0.0	16.4	16.5
Annual	168.5	169.6	338.1

Source: Modified from Lupin Airport and Contwoyto Lake station data (Environment Canada 2005).

Note: Total precipitation values are slightly different due to rounding.

mm = millimetres; cm = centimetres.

Table 8.3-4 Undercatch Adjusted, Annual Rainfall Depth and Frequency

Condition	Return Period (years)	Annual Rainfall Depth (mm)
Wet	100	319
	50	293
	25	266
	10	231
	5	203
Median	2	161
Dry	5	129
	10	116
	25	103
	50	96.0
	100	89.9

mm = millimetres.

Table 8.3-5 Undercatch Adjusted, Annual Snowfall Depth and Frequency

Condition	Return Period (years)	Annual Snowfall Depth (cm)
Wet	100	232
	50	227
	25	222
	10	211
	5	199
Median	2	171
Dry	5	140
	10	123
	25	105
	50	92.8
	100	82.0

cm = centimetres.

Table 8.3-6 Undercatch Adjusted, Annual Total Precipitation Depth and Frequency

Condition	Return Period (years)	Annual Precipitation Depth (mm)
Wet	100	553
	50	516
	25	478
	10	428
	5	388
Median	2	328
Dry	5	284
	10	265
	25	247
	50	237
	100	228

mm = millimetres.

The values in Tables 8.3-4 and 8.3-5 for annual rainfall extremes and annual snowfall extremes cannot simply be added together to obtain annual total precipitation extremes. Annual total precipitation extremes must be derived from the annual total precipitation series, as was done for the values reported in Table 8.3-6.

Snow water equivalent (SWE) values available for spring snowmelt were estimated by assuming that no runoff occurred over the October through May winter period, and that 30% of the accumulated precipitation was lost to sublimation (e.g., the process whereby ice changes directly into water vapour without melting), based on field data collected in 2004 and 2005. The results of a frequency analysis of estimated spring SWE values are listed in Table 8.3-7.

Table 8.3-7 Derived Spring Snowpack Snow Water Equivalent and Frequency

Condition	Return Period (years)	Snowpack Snow Water Equivalent (mm)
Wet	100	162.1
	50	159.1
	25	155.2
	10	147.7
	5	139.2
Median	2	119.8
Dry	5	98.1
	10	86.2
	25	73.4
	50	65.0
	100	57.4

mm = millimetres.

A frequency analysis of short-duration (n-day) rainfall data was conducted using daily rainfall data for the Lupin Combined Station. No adjustments were made for undercatch, because undercatch is generally not substantial for extreme rainfall events at a daily time scale. No regional adjustment factor was applied, as the derived factor applies only to annual and monthly values. The results are summarized in Table 8.3-8.

Table 8.3-8 N-day Extreme Rainfall (mm)

Return Period (years)	Duration (days)				
	1	3	5	10	30
2	22.7	28.0	31.3	39.5	66.4
10	37.6	45.1	49.5	64.0	104.3
50	50.6	60.1	65.3	85.5	137.4
100	56.1	66.4	72.0	94.6	151.5
200[(a)]	61.0	–	–	–	–
500[(a)]	68.0	–	–	–	–
Point PMR	208.0	245.5	262.5	353.3	551.7

Source: Derived from Lupin Airport and Contwoyto Lake station data (Environment Canada 2005).

(a) Values shown for 200- and 500-year periods are derived by graphical extrapolation.

PMR = Probable Maximum Rainfall; mm = millimetres; - = not available.

Short-duration (up to 24 hour) rainfall intensity data are not available for the Lupin Combined Station. The closest station with available data is Yellowknife Airport, and these were obtained from Environment Canada, based on tipping bucket data analysis for the period 1963 to 1990. The values presented in Table 8.3-9 are considered to be conservatively large. The higher rainfall intensities may be due to the Yellowknife station's proximity to Great Slave Lake, as well as its warmer summer temperatures.

Table 8.3-9 Short Duration Rainfall Intensities (mm/h) at Yellowknife Airport

Return Period (years)	Duration					
	10 minute	30 minute	1 hour	6 hours	12 hours	24 hours
2	31.2	15.8	9.6	3.1	1.9	1.1
5	48.4	24.2	14.5	4.8	2.9	1.8
10	59.8	29.8	17.7	5.9	3.6	2.2
25	74.1	36.8	21.8	7.3	4.4	2.7
50	84.8	42.0	24.8	8.3	5.0	3.1
100	95.3	47.2	27.8	9.3	5.6	3.5

Source: Yellowknife data, 1963 to 1990 (Environment Canada 2005).

mm/h = millimetres per hour.

8.3.2.2.4 Lake Evaporation

Lake evaporation was characterized by evaluating local and regional data to derive mean annual and monthly mean values for typical lakes near the Project site. Recommended values are presented in Table 8.3-10 and are plotted in Figure 8.3-4, where values derived by others for the Mackenzie River basin are presented for comparison. Inter-annual variability of lake evaporation is expected to be low relative to precipitation and primarily related to the length of the open water season.

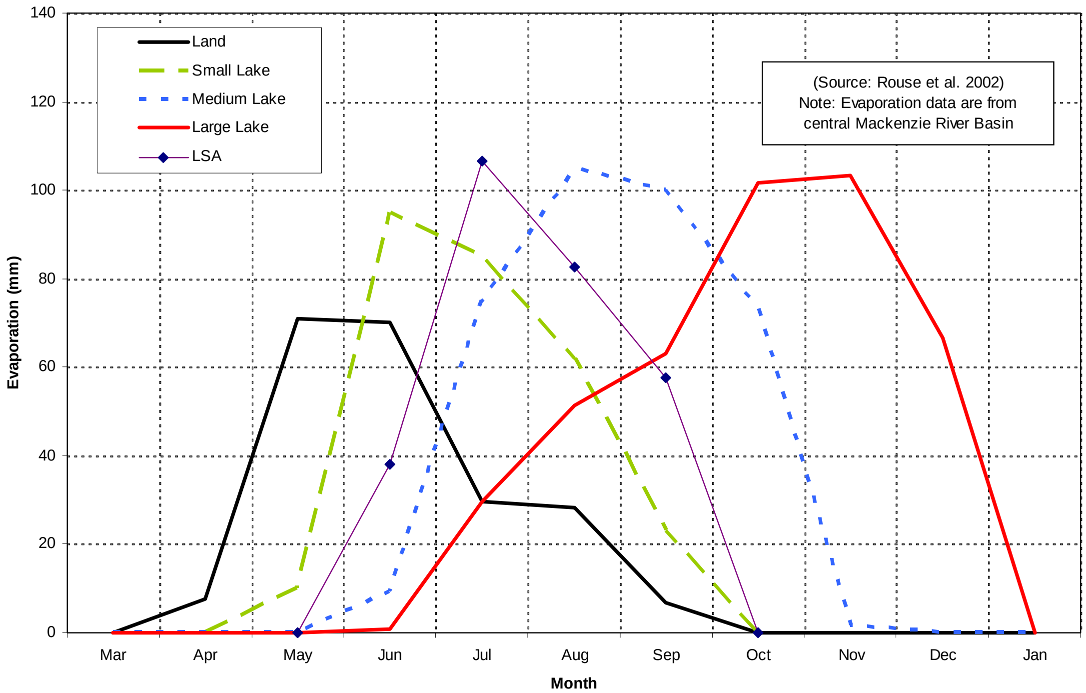
Table 8.3-10 Estimated Long-term Mean Small Lake Evaporation in the Local Study Area

Month	Lake Evaporation (mm)	Fraction of Annual
June	38.1	0.13
July	106.7	0.37
August	82.7	0.29
September	57.5	0.20
Annual	285.0	1.00

Source: Derived in part from Rouse et al. (2002).

mm = millimetres.

Figure 8.3-4 Seasonal Mean Monthly Lake Evaporation for Different Sized Lakes in the McKenzie Basin



Note: The Small Lakes within the Local Study Area (shown in Table 8.3-9) are represented by the LSA line in the graph.
mm = millimetre; LSA = Local Study Area.

8.3.2.2.5 Evapotranspiration

Evapotranspiration (ET) was derived using a water balance method and examination of the value using theoretical relationships. The value of annual ET derived by using the water balance method was equal to 66.8 mm. This value appears low, and may be due to overestimated sublimation losses from the winter snowpack.

8.3.2.2.6 *Relative Humidity*

No long-term regional data set of relative humidity is available. Relative humidity results (Table 8.3-11) are based on hourly data collected at the Project climate station for the period June 2004 to September 2005.

Table 8.3-11 Relative Humidity Summary, June 2004 to September 2005

Month	Mean Relative Humidity (%)	
	2004	2005
January	no data	74.6
February	no data	76.7
March	no data	82.6
April	no data	87.8
May	no data	87.0
June	66.3	67.7
July	64.5	71.6
August	77.7	76.0
September	84.8	81.4
October	87.9	no data
November	85.8	no data
December	75.6	no data

% = percent.

8.3.2.2.7 *Solar and Net Radiation*

Solar-radiation is the incoming solar radiation arriving at the earth's surface from above. It is also termed global radiation to indicate that it consists of all short-wave radiation arriving from direct sunlight as well as from diffused sky radiation. Net radiation is the difference between all incoming and outgoing radiation of both short- and long-wave lengths (i.e., it is a measure of the energy absorbed at the earth's surface).

No long-term regional data set of solar or net radiation is available. Solar and net radiation results are based on data collected at the Project climate station for the period June 2004 to August 2005. Monthly data are presented in Table 8.3-12 and daily data are shown in Figure 8.3-5.

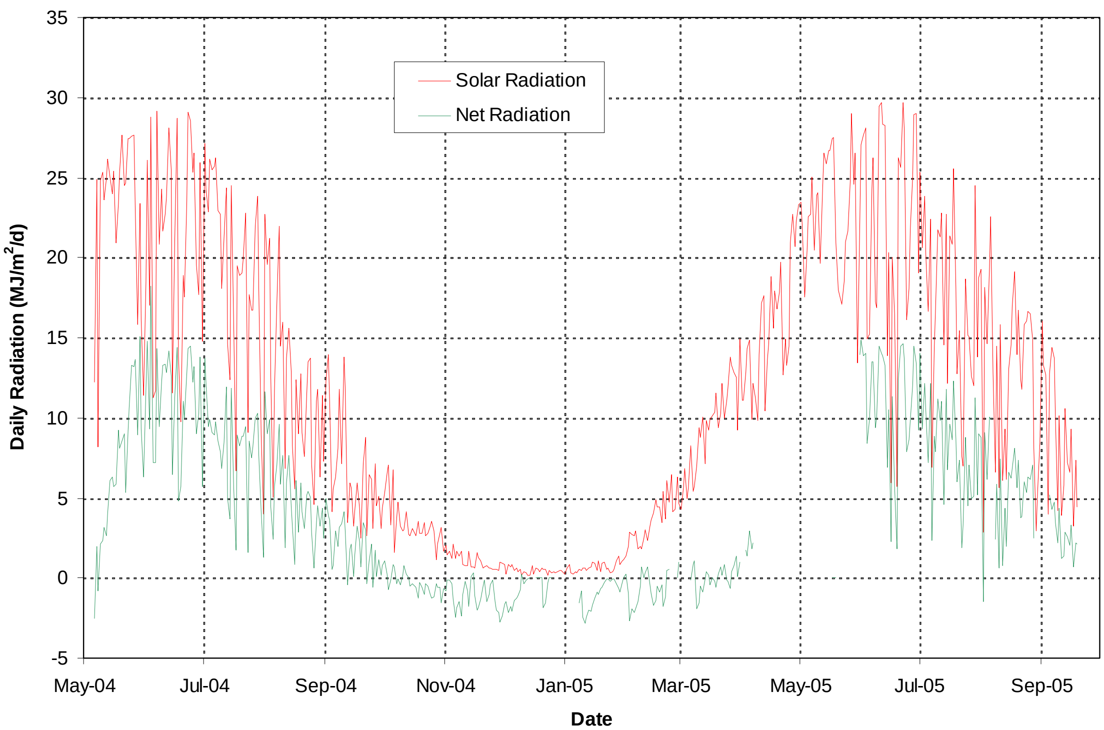
Table 8.3-12 Solar and Net Radiation Summary, June 2004 to August 2005

Month	Mean Solar Radiation ($MJ/m^2/d$)		Mean Net Radiation ($MJ/m^{2/}d$)	
	2004	2005	2004	2005
January	no data	0.67	no data	[a]
February	no data	3.65	no data	[a]
March	no data	9.41	no data	[a]
April	no data	15.56	no data	[a]
May	no data	22.66	no data	13.92
June	21.40	22.11	11.34	11.08
July	19.31	17.46	8.01	8.17
August	12.08	12.81	5.05	5.73
September	6.66	no data	1.87	no data
October	3.38	no data	-0.35	no data
November	1.06	no data	-1.16	no data
December	0.46	no data	[a]	no data

[a] Net radiation sensor data are not reliable.

$MJ/m^2/d$ = megajoules per square metre per day.

Figure 8.3-5 Project Station Daily Solar and Net Radiation, 2004 to 2005



$MJ/m^2/d$ = megajoules per square metre per day.

8.3.3 Permafrost

This following section describes the permafrost conditions and features within the Kennady Lake watershed. The Local Study Area (LSA) for permafrost corresponds to that for bedrock geology, terrain, soils, and vegetation, but the permafrost investigations focused on the Project footprint within the Kennady Lake watershed. For additional information regarding permafrost, the reader is referred to Annex D (Bedrock Geology, Terrain, Soil and Permafrost Baseline).

8.3.3.1 Methods

The existing permafrost conditions and features for the Kennady Lake watershed were established using the following types of evaluation:

- interpretation of aerial photographs for permafrost mapping;
- geotechnical drill program and thermistor installation to measure soil temperature and active layer thickness;
- field reconnaissance program to confirm the aerial photograph interpretation;
- calculation of mean annual soil temperatures; and
- calculation[1] of the active layer and seasonal frost penetration.

8.3.3.2 Results

8.3.3.2.1 Permafrost Features

The Project is located within the Continuous Permafrost Zone (Heginbottom and Dubreuil 1995). The aerial photograph interpretation, field reconnaissance, and drill program determined that permafrost extends over approximately 90 to 95% of the on-land Project area. The following characteristics related to permafrost are described:

- landscape description and permafrost processes;
- mean annual soil temperature;
- thickness of active layer and frost penetration;
- moisture content; and
- permafrost thickness.

[1] Calculations were required for these permafrost parameters because of the limited data set obtained by the drilling program for mean annual soil temperature and thickness of the active layer. This derivation is an applicable technique when field measurements from a drilling program are not available.

8.3.3.2.2 Landscape Description and Permafrost Processes

Various earth processes and phenomena were identified during an air photo review and field reconnaissance. Some of the processes are a result of thawing or freezing, while others are a result of specific soil composition, terrain, topography, and origin of deposits.

Stone channels and polygons are considered to be erosional features that result in part from thawing of permafrost. Snowmelt water and runoff have washed out the soil matrix, leaving stony material (cobbles, boulders, and rock fragments) in the form of stone channels and stone polygons. Because the moraine deposits have a stony composition, formation of stone channels and stone polygons are widespread processes within the study area.

Mud boil polygons are encountered in moist to wet cohesive surficial soils. The formation of the mud boil polygons is a process related to frost cracking, followed by freezing of the active layer downward from the ground surface, perpendicular to the frost cracks, and upward from the active layer base. If the freezing soil is saturated or nearly saturated, the soil within the polygon under high pore water pressure bursts through the surficial frozen layer and freezes at the ground surface.

Landforms associated with ice wedges were frequently encountered in organic deposits of the study area. Formation of the ice wedges is a cyclic process of freezing and thawing. Winter cold causes the frozen soil of the active layer to shrink and crack. During warm spring days, water seeps into the cracks, freezes and expands when it is chilled by the still-frozen soil, forming wedges of ice in the soil. Each winter, cracks form again in the same places and each spring, additional water enters and enlarges the ice wedges as the freezing water expands. This cycle of cracking and freezing continues to enlarge the wedges year after year.

Thermokarst depressions and lakes were found occasionally within peat bogs and organic veneers. Formation of the thermokarst features is due to the process of thawing ice-rich permafrost and, finally, accumulation of water in the resulting subsidence. The soil subsidence can lead to formation of large thermokarst lakes, up to several tens of metres in dimension. Thermokarst processes are often accompanied with thermo-erosion, referred to as soil erosion from combined thermal and mechanical activity of running water in permafrost areas, resulting in formation of gullies.

Results of field investigations undertaken by AMEC Earth & Environmental (AMEC) in summer 2004 suggest that taliks (i.e., patches of unfrozen ground surrounded by permafrost) limited in depth could be encountered within isolated areas of glaciofluvial deposits treed with spruce, willow and high polar birch. Taliks also can be encountered beneath numerous lakes in the study area. Depending on the size and age of the lake, sub-aquatic taliks may either be limited in depth (open to the top talik or closed talik) or penetrate through the entire permafrost thickness (through talik – open to both top and unfrozen layers beneath the permafrost). A through or open talik exists beneath Kennady Lake where water is deeper than 2 m.

8.3.3.2.3 Mean Annual Soil Temperature

The majority of the study area includes glacial veneer over bedrock. Based on thermistor temperature measurements, mean annual permafrost temperatures over the Project site range from -0.5°C to -2.5°C. The highest soil temperature in this range (-0.5°C) corresponds to regions that possess dense polar birch vegetation, while the lowest temperature (-2.5°C) were typically encountered within glacial veneers or blankets with minimum snow cover, which correspond to areas with no shrub vegetation.

Wet areas within peat bogs and peat veneers have mean annual temperatures ranging from about -1.0°C to -1.5°C. The slightly warmer temperatures are mainly due to the low thermal resistance of saturated moss. Slightly cooler annual permafrost temperatures in the range of about -1.5°C could be encountered either in well-drained peat bogs and peat veneers due to the insulating effect of the moss in summer time. Cooler temperatures can also be expected at the summits of eskers and bedrock outcrops where there is minimal snow cover (low insulating effect of snow in winter time).

Areas with a mean annual soil temperature above 0°C (up to 1.5°C) could be encountered within the tall shrub terrain along creeks in the glaciofluvial deposits and at lake banks. The occurrence of the positive temperatures is a result of snow accumulation in tall shrubs.

8.3.3.2.4 Thickness of the Active Layer and Frost Penetration

The maximum thickness of the active layer (3.7 to 4.0 m) was estimated to be in exposed bedrock areas. Deep seasonal thaw is a result of low moisture content in bedrock. A deep active layer (in the range of 3.0 to 3.4 m) was also calculated for the eskers. The thickness of the active layer within the moraine veneer and blanket could vary from 2.6 to 3.2 m and 1.6 to 2.5 m, respectively. Glaciofluvial sand and silt deposits have the thinnest active layer thickness (1.0 to 2.0 m) of the mineral soils within the study area. Seasonal frost penetration within the on-land taliks likely does not exceed 1.5 m, due to a thick snow cover within tall shrubs.

Organic soils (peat) are characterized with the shallowest active layers (0.4 to 0.9 m). The main factors that determine a shallow active layer are high moisture content and insulating effect of the moss cover. Within this range, the deepest thaw that would be expected occurs in dry peat bogs (moisture content about 500% by dry weight of peat) whereas the shallowest thaw is typical for heavy mossy patches of organic veneers.

8.3.3.2.5 Moisture Content

The mineral soils within the Project area have variable, although generally low, ice content. No visible ice was observed in the majority of boreholes advanced at the moraine blanket and glaciolacustrine plain. The moisture contents of these materials were in a range of 3 to 20%, by dry weight of solids. Higher ice contents were observed in glaciofluvial deposits. For instance, ice layers, up to 10 mm thick, were encountered in one borehole (MPV-04-206 in the depth interval from 1.8 to 2.9 m, see Annex D, Bedrock Geology, Terrain, Soil, and Permafrost Baseline for details).

Organic deposits were found to be extremely ice rich. It was estimated that volumetric ice content of the peat could be about 40% to 50% (moisture content of peat, defined as weight of water to weight of dry peat, was in a range of about 500% to 800%). Ice layers in peat were up to 3 mm thick, and were horizontal or wavy in shape. The ice layers were alternated with peat layers also several millimetres thick. Numerous ice lenses and pockets, up to 30 mm in size, were also recorded in the peat.

8.3.3.2.6 Permafrost Thickness

The thickness of the permafrost was measured in three deep boreholes (MPV-04-153, MPV-04-162, and MPV-04-165) located within the study area. At these three locations, the thickness of the permafrost was estimated to be 120, 150, and 310 m, respectively. The first two boreholes were drilled on islands within Kennady Lake at a distance of about 45 to 70 m from the shoreline. The warming effect of Kennady Lake results in the reduced permafrost thickness at these locations. The permafrost thickness of about 310 m encountered in borehole MPV-04-165 is considered a typical permafrost thickness for climate conditions associated with the Project area that are not influenced by lake taliks (Brown 1970).

8.3.4 Hydrogeology

The following section describes the hydrogeological setting within the LSA for the Project (Figure 8.3-6) used in the baseline. The baseline setting is defined from available published work and recent seasonal surveys and investigations. Figure 8.3-7 presents the Kennady Lake area and the various drillhole locations used in these surveys. For additional information regarding hydrogeology, the reader is referred to Annex G (Hydrogeology Baseline).

8.3.4.1 Methods

Baseline conditions provide a reference for identifying effects, and for qualitative and quantitative assessments of such effects. Groundwater conditions in the Project area were described in terms of geological setting, physical and chemical characterization, assessment of groundwater quality and conceptual and numerical modelling, and included the following:

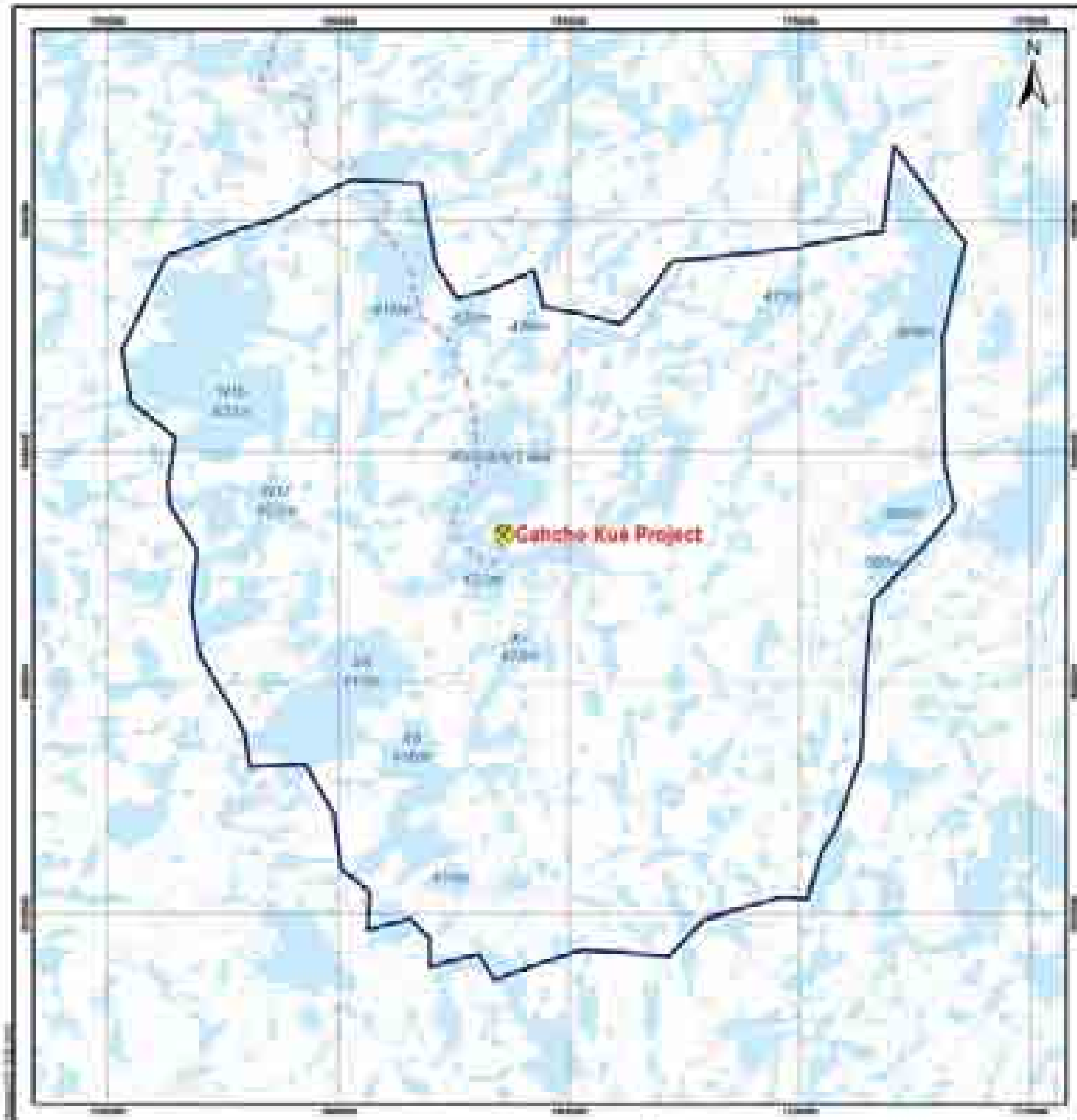
- collection and review of the pertinent information on the Project site, surrounding areas and region;
- completion of field programs in 2004 and 2005 including site reconnaissance, hydrogeological drilling and testing, and collection of groundwater samples;
- implementation of standard quality assurance and quality control procedures in the collection and analysis of field data and samples;
- performing laboratory analyses of collected groundwater samples;
- data processing and interpretation of collected information to define the conceptual hydrogeological condition, and to construct numerical flow models;
- development of a local groundwater flow model; and
- reporting.

8.3.4.2 Results

8.3.4.2.1 Groundwater Flow Regimes

The hydrogeology of the Project area is controlled by the permafrost characteristics, distribution, and spatial and temporal dynamics within the LSA. It is divided into two primary groundwater regimes:

- shallow groundwater regime; and
- deep groundwater regime.



LEGEND
Gahcho Kué Project
Winter Access Road
Watercourse
Contour (20m interval)
Waterbody
Local Study Area

NOTES
Base data source: The Atlas of Canada
Elevations shown are approximate (+/- 1m).
Lake elevations were derived from National Topographic Base Data (NTDB) 1:50,000 data and LiDAR data provided by the client.

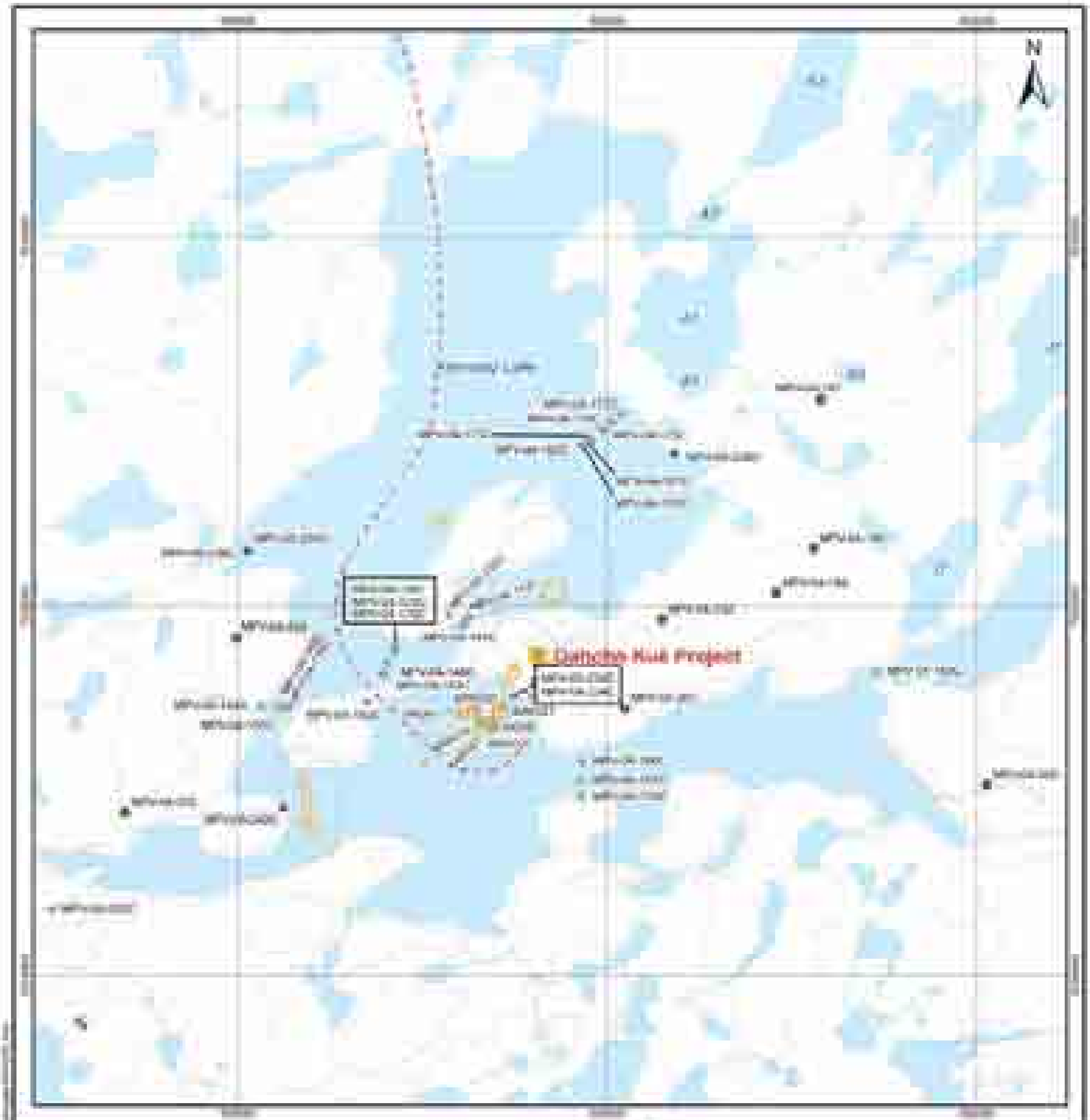
GAHCHO KUÉ PROJECT

Hydrogeology Local Study Area

PROJECTION	DATUM
Canadian Lambert Conf. Conic	NAD83

B-Hydrogeo-023-GIS.mxd		December 16, 2010
JOB NO. 09-1365-1004	REVISION NO. 1	
OFFICE GOLD-CAL	DRAWN SK	CHECK JF

Figure 8.3-6



LEGEND

- Gahcho Kué Project
- Winter Access Road
- Contour (10m interval)
- Watercourse
- Waterbody
- Shallow Groundwater Sampling Location
- Till Sampling Drillhole Location

Borehole
- 1996
- 2004
- 2005
- Kimberlite Outline
- Pit Outline

NOTES

1) Base Data Source: National Topographic Base Data (NTDB) 1:50,000
2) Borehole Data Sources:
-Hydrological Consultants Inc. December 2005. Draft Predicted Hydrologic Effects of Developing Gahcho Kué Diamond Project. Prepared for SRK Ltd. HCI-1759.
-Bruce Geotechnical Consultants. 1996. AK5034: Diamondiferous Kimberlite Pipe Geotechnical Studies, Permafrost and Ground Ice Conditions. A report prepared for Canamera Geological Ltd.

GAHCHO KUÉ PROJECT

Borehole Locations

PROJECTION: UTM Zone 12	DATUM: NAD83		
FILE NO: B-Hydrogeo-006-GIS			October 22, 2010
JOB NO: 09-1365-1004	REVISION NO: 4		
OFFICE: GOLD-CAL	DRAWN: JH	CHECK: DC	**Figure 8.3-7**

The shallow groundwater regime consists of the active layer above the permanent permafrost. This is an ephemeral system in that in winter time it is primarily frozen and is only active in the summer months. The deep groundwater regime is laterally continuous and found in bedrock below the permafrost at approximately 300 metres below ground surface (mbgs). It is anticipated that there is generally little to no hydraulic connection between the two flow regimes because of the thick, low permeability permafrost.

Groundwater in the shallow groundwater system is underlain by permanently frozen unconsolidated sediments (i.e., till, sand, and organic soils) or by frozen bedrock with low hydraulic conductivity. Groundwater in the active layer is controlled by surface topography and flows towards local lows, represented by lakes and the surface water drainage network. This conceptual framework applies to the on-land areas underlain by massive and continuous permafrost.

Taliks are found in unfrozen ground encountered within the discontinuous permafrost zone. Closed taliks exist beneath smaller lakes that possess sufficient depth such that they do not freeze to the bottom in winter, but not sufficient size for the talik below to extend through to the deep groundwater flow regime. Closed taliks can be also be encountered within isolated areas of glaciolacustrine plains, fluvial-glaciofluvial valleys, and intermittent creek channels treed with spruce, tall willow and high polar birch.

Open taliks penetrate the permafrost completely, connecting shallow and deep groundwater (van Everdingen 1998). Open taliks may be found below large rivers and lakes and may be noncryotic (a hydrothermal talik; i.e., at temperatures above 0°C) or cryotic (a hydrochemical talik; i.e., at temperatures below 0°C due to elevated TDS concentrations). An open talik exists under Kennady Lake and other large lakes in the region measuring several hundred metres in size.

Recharge to the deep groundwater flow regime is predominantly limited to areas of open taliks beneath large, surface water bodies. Generally, deep groundwater will flow from higher elevation lakes to lower elevation lakes. To a lesser degree, groundwater beneath the permafrost is influenced by density differences due to the upward diffusion of deep-seated brines (density-driven flow).

8.3.4.2.2 Groundwater Usage

Groundwater sources from both the active layer and from the deep groundwater below the permafrost are not used for drinking water in continuous permafrost regions. Due to the presence of deep permafrost, the seasonal nature of the active layer, and the availability of good quality drinking water from surface water sources near the project site, it is unlikely that groundwater will be used as a drinking water source in the future.

8.3.4.2.3 Hydrostratigraphy

The conceptual hydrogeological model comprises six hydrostratigraphic units consisting of till, shallow exfoliated rock, deep competent rock, kimberlite, kimberlite contact zone, and enhanced permeability zones associated with sub-vertical faults (Figure 8.3-8 and 8.3-9). These units are described below.

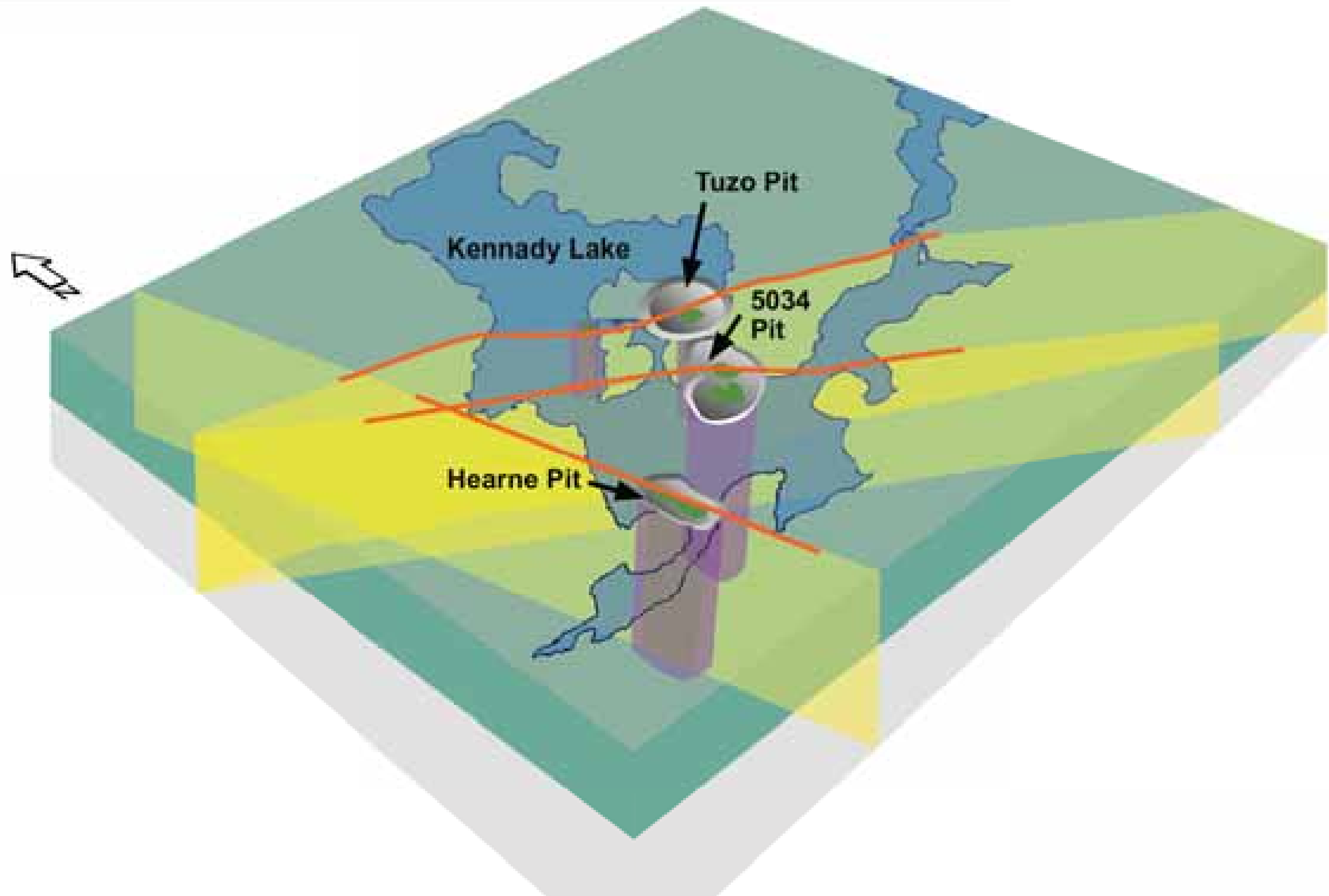
Relatively competent bedrock is assumed to comprise the majority of the rock domain, and the hydraulic conductivity of competent rock is assumed to decrease with depth. Areas of greater fracturing associated with post-glacial rebound, faulting or along the kimberlite contact are assumed to have greater hydraulic conductivity than the less disturbed rock mass.

In developing of the conceptual hydrogeological model for the project, a reasonably conservative approach was undertaken, so that it is expected that the actual groundwater inflows to the open pits and associated impacts to the environment will be less than those predicted by the numerical hydrogeological model. Where uncertainty in parameter values exists, reasonable upper bound values of hydraulic conductivities have been selected.

Till

The till unit is located directly beneath Kennady Lake. Several lake bottom sediment samples collected below Kennady Lake contained unconsolidated sand, pebbles, cobbles, and boulders with few fines (Annex G). The mean thickness of the lake bottom sediments intersected by drillholes within Kennady Lake was 7 m. No in-situ hydraulic conductivity testing has been carried out in this unit beneath the lake; however, based on the material description, the hydraulic conductivity of this material is expected to be greater than the bedrock below, and therefore will not restrict groundwater flow from Kennady Lake.

L:\2009\1365\09-1365-1004\21000\Report B\Core\Draw figures Gahcho Kue Profile 09-1365-1004 C Bieber J Farah\B-Hydrogeo-004-CAD HydroStratigraphy.cdr

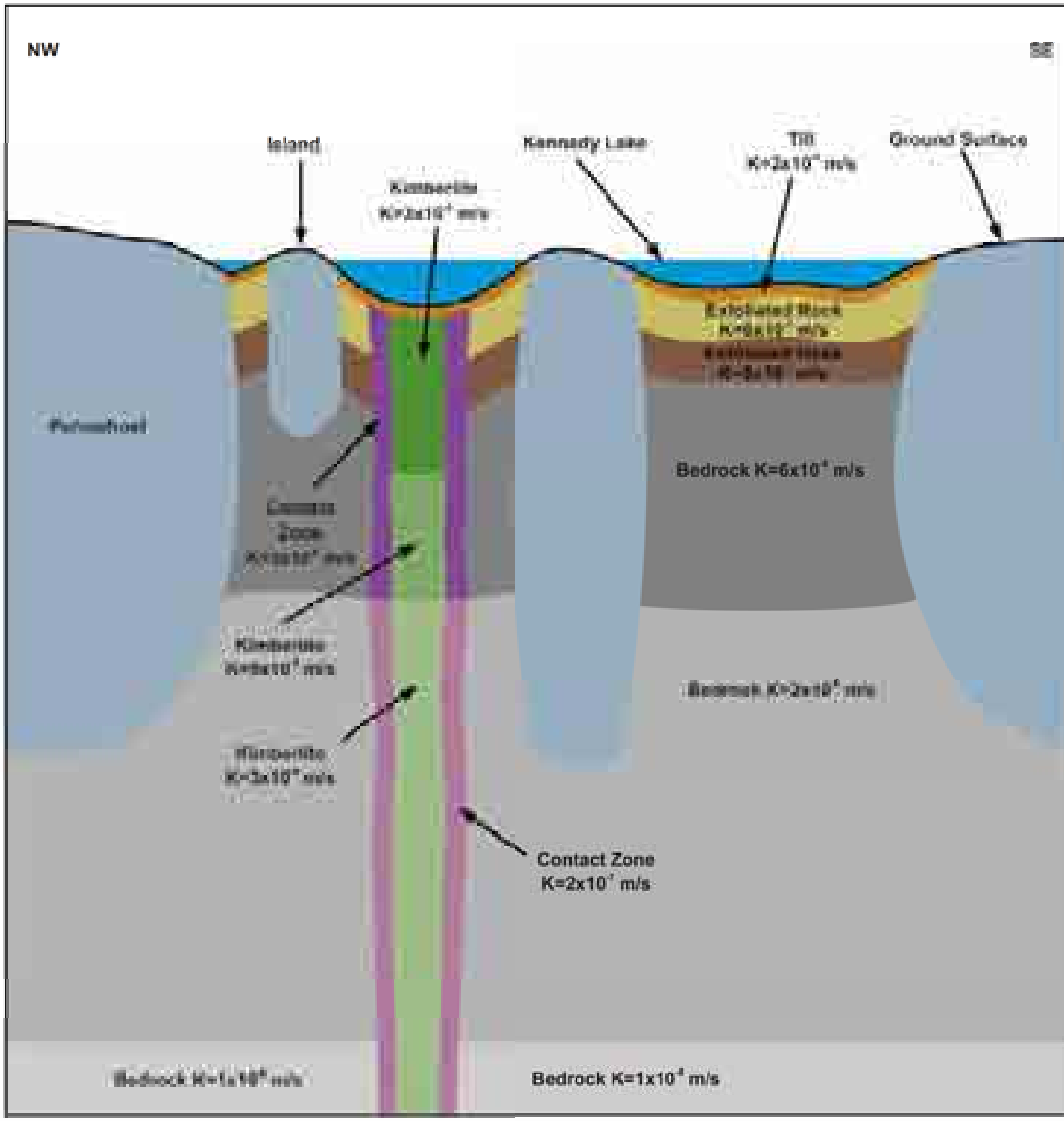


LEGEND

- Surface Expression of Potential Enhanced Permeability Zone
- Contact Zone
- Deep Bedrock
- Kimberlite Pipe
- Lake
- Permafrost
- Potential Enhanced Permeability Zone

Schematic Only

GACHO KUÉ PROJECT	
Hydrostratigraphy of the Local Study Area	
PROJECTION: N/A	DATUM: N/A
SCALE: NOT TO SCALE	DE BEERS CANADA
FILE No: B-Hydrogeo-004-CAD	DATE: October 21, 2010
JOB No: 09-1365-1004	REVISION No: 0
OFFICE: GOLD - CAL	DRAWN: DLM
CHECK: DC	**Figure 8.3-8**



LEGEND

Ground Surface

Till

NOTE

ability zones not shown

#1 for locations

GACHO KUÉ PROJECT

Hydrostratigraphy of the Local Study Area – Cross-Section View

N/A	N/A
NOT TO SCALE	
SOW-11.6-019-CAD	September 28, 2010
JOB No. 09-1365-1004	REVISION No. 0
OFFICE: GOLD - CAL	DRAWN: DLM
CHECK: DC	Figure 8.3-9

Exfoliated Bedrock

The uppermost zone of bedrock typically has numerous horizontal fractures as a result of exfoliation due to rebound following deglaciation. This zone is estimated to be about 60 m thick, and can be further divided into two sub-zones. The exfoliated bedrock forms a relatively permeable unit within the taliks, but, below the land surface, it is entirely within the permafrost zone. Exfoliation planes are near horizontal; therefore, the vertical hydraulic conductivity of this unit is expected to be less than the horizontal hydraulic conductivity, and flow in this unit is expected to be primarily horizontal. The arithmetic mean of single-well response testing in this unit is considered to be most representative of the hydraulic conductivity on the scale of the open pits. Over 100 single-well response tests have been conducted in this unit. The arithmetic mean of these tests above 30 mbgs is about 6×10^{-6} metres per second (m/s), while between 30 mbgs and 60 mbgs, the arithmetic mean is about 5×10^{-7} m/s (Table 8.3-13).

Table 8.3-13 Summary of Hydrostratigraphy in EIS Model

Hydrostratigraphic Unit	Depth (mbgs)	Average Hydraulic Conductivity[a] (m/s)	Number of Tests
Exfoliated bedrock	0 to 30	6×10^{-6}	70
	30 to 60	5×10^{-7}	48
Bedrock	60 to 200	6×10^{-8}	70
	200 to 500	2×10^{-8}	24
Kimberlite pipe	0 to 100	3×10^{-6}	31
	100 to 200	9×10^{-8}	14
Contact between kimberlite pipes and bedrock	60 to 200	3×10^{-6}	26
	200 to 400	2×10^{-7}	11
Potential Enhanced Permeability Zones	60 to 400	1×10^{-6} to 3×10^{-6}	27

[a] For exfoliated rock and enhanced permeability zones, average hydraulic conductivity was calculated using the arithmetic mean of hydraulic conductivity values calculated from testing. For all other units, averages were calculated using the geometric mean. Values calculated based on the geometric mean were multiplied by a scaling factor of 3.

mbgl = metres below ground level; m/s = metres per second.

Massive Bedrock

The massive bedrock unit is dominated by granitoids and granitic gneiss, but is not uniform; ultramafic rocks are also present. The bedrock below 60 mbgs, is generally less permeable than the overlying sediments, and the hydraulic conductivity is expected to decrease further with greater depths (Stober and Bucher 2007). Nearly 100 single-well response tests have been conducted in the bedrock below 60 mbgs with the deepest tests extending to nearly 500 mbgl. The geometric mean of single well response tests carried out from 60 mbgs to 200 mbgs is about 2×10^{-8} m/s, while the geometric mean of testing below

200 m-bgl is about 5 x 10^{-9} m/s. All of these tests were of short duration and conducted within single wells.

Research has shown that these types of tests generally underestimate the hydraulic conductivity at the scale of excavations with similar dimensions to that of the open pits at the Project (Illman and Tartakovsky 2006; Niemann and Rovey 2008). The reason for this is that single-well tests investigate hydraulic conductivity over a small scale volume of rock near to the well screen or packer isolated interval of the borehole. The resulting values of hydraulic conductivity from these tests are more often representative of the lower-permeability rock composed of poorly connected and small aperture discontinuities (e.g., fractures). Testing of a larger volume of rock generally will include better connected and larger aperture discontinuities; hence, a higher permeability. It has been found that hydraulic conductivity values determined from single-well response tests generally underestimate the large-scale hydraulic conductivity by a factor of 2 to 5 times, depending on the relative scale of the disturbance to the hydrogeologic regime. Single-well response tests result in a relatively small disturbance to the hydrogeologic regime compared to the disturbance caused by the excavation of the open pit,

In the conceptual model, the hydraulic conductivity of the massive bedrock was increased by a factor of 3 to account for scaling affects related to the relative difference between the volume of rock tested in a single-well response test and the volume of the excavation at the open pits within the Project site. Accordingly, the geometric mean values of hydraulic conductivity determined from the single-well response tests were increased by a factor of 3 times in the conceptual hydrogeologic model (Table 8.3-13). Although hydraulic conductivity testing is limited to less than 500 m depth, the hydraulic conductivity of the bedrock is expected to decrease further with depth, as observed at other sites (Stober and Bucher 2007). Based on published reductions in hydraulic conductivity with depth (Stober and Bucher 2007); the hydraulic conductivity of the bedrock below 500 m is expected to decrease to less than 1 x 10^{-8} m/s.

Kimberlitic Pipe Zone

Nearly 50 single well response tests have been carried out in eight boreholes drilled into the 5034 pipe to a maximum depth of nearly 300 mbgl. The geometric mean of hydraulic conductivity tests in the kimberlite to 100 m depth is about 9 x 10^{-7} m/s, while the geometric mean of testing from 100 mbgl to 200 mbgl was about 3 x 10^{-8} m/s. The results of three single well response tests carried out in the 5034 pipe in borehole MPV-05-239C below 200 mbgs suggest that the hydraulic conductivity of the kimberlite decreases further at greater depths with the highest hydraulic conductivity measured below 200 m-bgl being 1 x 10^{-9} m/s.

Similar to the massive bedrock, the geometric mean of the hydraulic conductivity of the kimberlite was increased by a factor of 3 to account for scaling effects.

Contact Zone(s)

A distinct contact zone with enhanced permeability was encountered between the 5034 kimberlite pipe and the bedrock in five boreholes: BAK020, BAK015, MPV-04-234, MPV-05-239C, and MPV-05-240C. This zone is estimated to be between 50 m and 100 m wide. The geometric mean of hydraulic conductivity tests within this zone to 200 m-bgl is about 1×10^{-6} m/s. The geometric mean of comparable tests completed below 200 m-bgl is about 7×10^{-8} m/s. Although the enhanced permeability indicated from testing in boreholes MPV-04-234 and MPV-05-239C could also be due to increased fracturing or larger fracture aperture associated with a linear structural feature, these results are also included in calculations of average hydraulic conductivity of the contact zone, as these structures would likely overlap.

The contact zones between other geologic formations were also tested. The contact zones between the granite and a dolerite dyke in MPV-04-127C and between the granite and ultramafic rocks in MPV-04-144C did not identify any increased hydraulic conductivity.

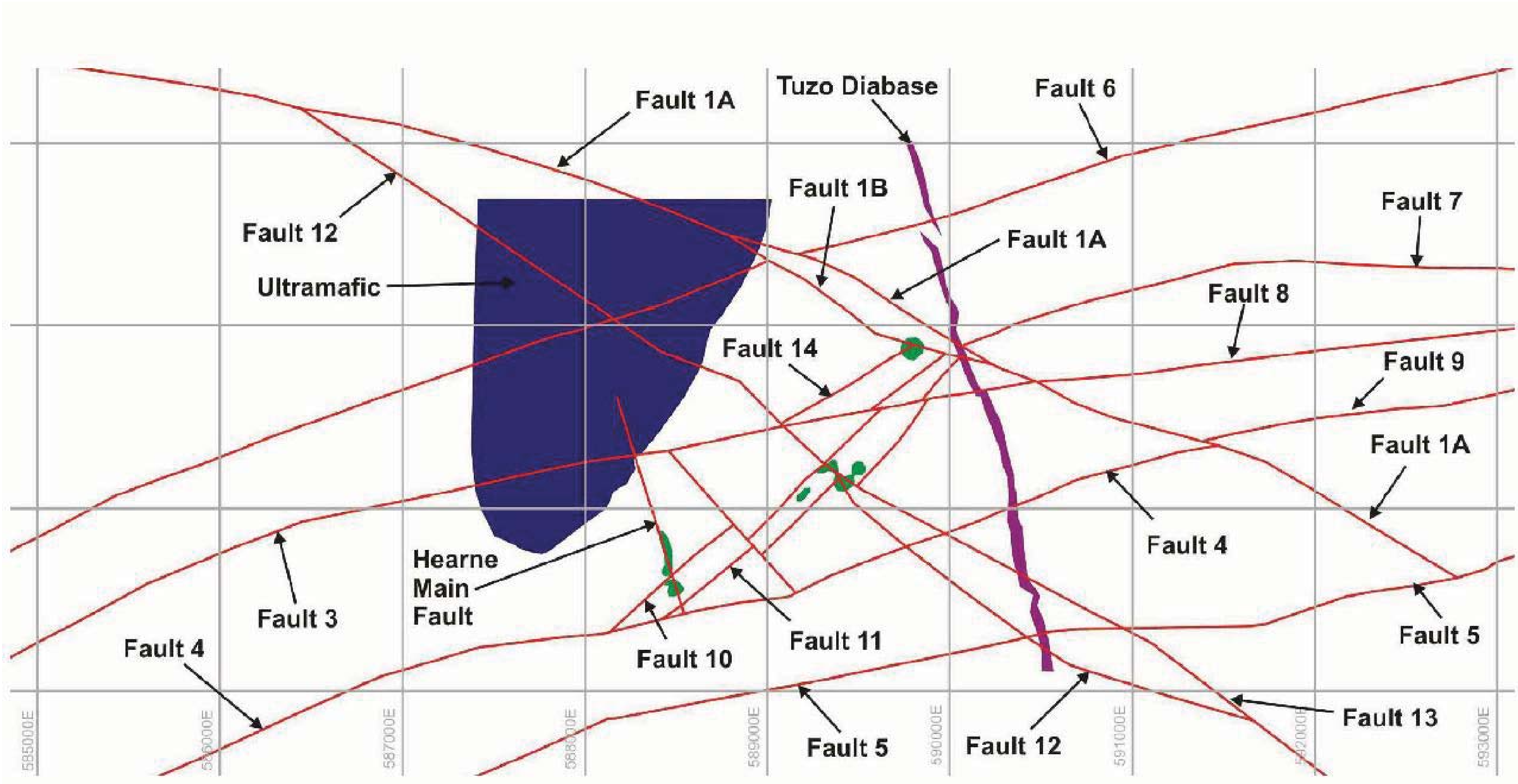
Enhanced Permeability Zones

Enhanced permeability zones or zones of greater fracturing or larger apertures related to structures such as faults have been found to be present at operating diamond mines in crystalline rock of the Canadian Shield. These zones have been found at Diavik, Ekati and at Snap Lake; none of which were identified during extensive field investigations at these sites prior to mining. At Diavik, in addition to the 100 m wide enhanced permeability zone referred to as Dewey's Fault, similar but thinner zones have been found: one zone parallel to Dewey's Fault and the other two perpendicular.

Higher permeability zones due to greater fracturing or larger fracture aperture associated with structural features may be present at the Project site. As discussed above, analysis of air photos, gravity and aeromagnetic data was used by SRK (2004) to identify possible enhanced permeability zones associated with faults. Three of these zones (Figure 8.3-8), one passing through each of the three pipes, are considered to be of potential importance for governing groundwater inflow quality and quantity to the three planned open pits. These zones correspond to Fault 1A/1B, Fault 12 and the Hearne Main Fault identified on Figure 8.3-10. The results of single-well response testing across these potential enhanced permeability zones have been somewhat inconclusive. Attempts to test some of these features were unsuccessful. Where the features may have been intersected it could not be determined if the high permeability calculated from the tests were related to these structures or to a highly permeable contact zone around the kimberlite. Nevertheless, because the zones associated with faults have been identified at three mines with similar host rocks, it was considered prudent to include these potential enhanced permeability zones in the conceptual hydrogeologic model developed for the Project. Therefore, the three zones identified in Figure 8.3-8 were assumed to have enhanced permeability.

Tests in three boreholes MPV-04-234, MPV-05-238C, MPV-05-239C may have measured the hydraulic conductivity of the potential enhanced permeability zone passing through the 5034 pipe. Because of the assumed enhanced permeability of these zones compared to the surrounding rock, the dominant groundwater flow pattern induced during mining will be near parallel to the features; therefore, the arithmetic mean of single-well response testing within these features provides the best approximation of the bulk hydraulic conductivity.

The arithmetic mean of the hydraulic conductivity values calculated below 60 mbgs in these wells is 3×10^{-6} m/s. The continuous and relatively high flows of water observed during purging of the three boreholes prior to groundwater sampling corroborates the high hydraulic conductivity values measured in these boreholes.



Source:
Figure 3.5, SRK (SRK Consulting (Canada) Inc.). 2004. Gahcho Kué Diamond Project - Mining Geotechnics. Prepared for De Beers Canada Ltd. November 2004.

GAHCHO KUÉ PROJECT			
Gahcho Kué Project Structural Geology Model			
PROJECTION: N/A		DATUM: N/A	
SCALE: NOT TO SCALE			
FILE No: B-Hydrogeo-001-CAD.dwg			DATE: October 25, 2010
JOB No: 09-1365-1004	REVISION No: 0		Figure 8.3-10
OFFICE: GOLD - CGY	DRAWN: RFM	CHECK: DC	

A test in borehole MPV-04-144C may have measured the hydraulic conductivity of the potential enhanced permeability zone passing through the Hearne Main Fault. Hydraulic conductivities over a zone of intense shearing at 107 to 110 mbgs, which was thought to correspond to the geophysical lineation identified by SRK (2004), were no greater than those in the competent rock. However, several pyrite bearing fractures intersected at 130 to 150 mbgs, coincided with higher hydraulic conductivity values. The arithmetic mean of the three tests carried out from 130 to 150 mbgs is 1×10^{-6} m/s. No testing that has been carried out to date that would have intersected the enhanced permeability zone assumed to pass through the Tuzo pipe (Fault 1A and 1B).

Although the results of testing across potential enhanced permeability zones have been somewhat inconclusive, zones of enhanced permeability can be composed of sparsely spaced highly permeable discontinuities within a lower permeability pseudo-matrix. Depending on the orientation of a borehole drilled within such a zone, none or many permeable fractures may be intersected. Identification of enhanced permeability zones can be difficult with geotechnical logging and single-well response testing alone. Enhanced permeability zones associated with structural features have been identified at other diamond mines in the north only after mining began, and it is possible that additional enhanced permeability zones may be identified within the Project area once mining begins. Because of this difficulty in identifying such features prior to mining, and the apparent prevalence at diamond mines in the Arctic, the numerical hydrogeological model that was developed to predict mine inflows assumes that such enhanced permeable zones are present.

8.3.4.3 Groundwater Quality

8.3.4.3.1 Shallow Groundwater Flow System

The shallow groundwater system is only active in the summer season, and receives water mainly from summer precipitation, with possibly a minor contribution from snowmelt. Groundwater samples in the active layer had total dissolved solids (TDS) concentrations ranging from 44 to 544 milligrams per litre (mg/L), which is classified as fresh water (less than 1,000 mg/L TDS).

The chemistry of shallow groundwater is expected to be similar over most of the LSA. The shallow groundwater system is disconnected from the deep groundwater regime below the permafrost. Shallow groundwater can discharge to the surface drainage system. No evidence of saline seeps was reported from surface water quality, soil or vegetation studies completed for the Project.

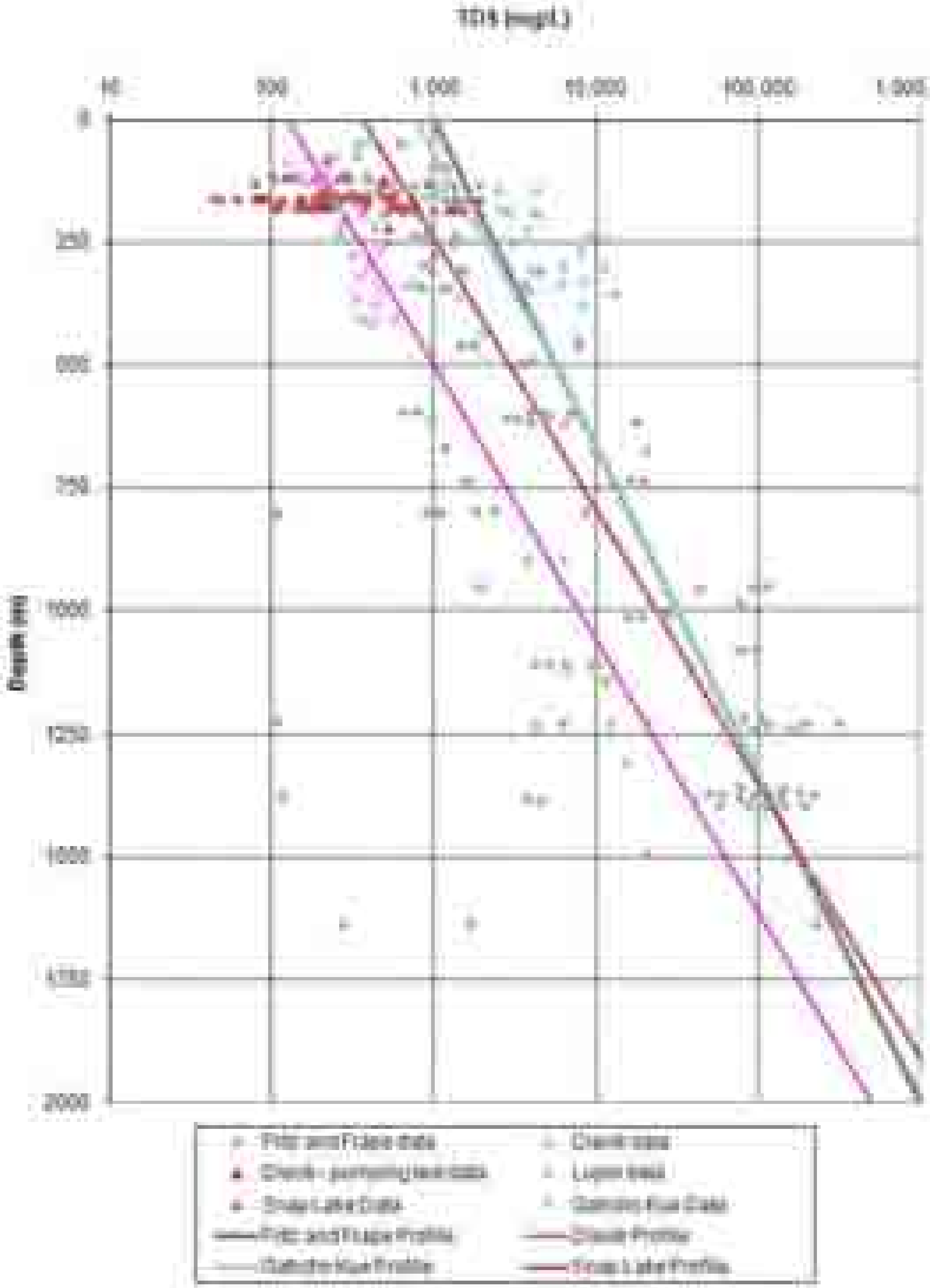
8.3.4.3.2 Deep Groundwater Flow System

Permafrost in the LSA extends to a depth of about 300 m below surface in areas outside the influence of lakes or taliks, which can be considered as a typical permafrost thickness corresponding to permafrost formation in the Project area's climate condition (Brown 1970). In the region beneath continuous permafrost, groundwater mineralization with depth in the Canadian Shield is expected to approximate the regional relationship developed by Fritz and Frape (1987) and shown in Figure 8.3-11. Up to 50% by weight of the dissolved solids in saline samples could be attributed to chloride.

The chemistry of some of the groundwater samples collected at the site were affected by sampling difficulties resulting in dilution of the samples by drilling fluids. Five of the nearly forty groundwater samples were considered to be notably contaminated and, therefore, were removed from Figure 11.6-11. These groundwater samples were collected in boreholes MPV-04-118C, MPV-04-127C, and MPV-04-135C.The remainder of the groundwater quality data in the LSA has considerable variability for samples collected at similar depths. This variability may be due to local variations in the vertical and horizontal components of the convective flux due to variations in the hydraulic and density gradients, and hydraulic conductivity. In addition, local variations in the diffusive flux from the deep-seated saline groundwater may be present due to variations in the relative interconnection of pore space in the rock mass. Difficulties encountered during groundwater sampling that resulted in mixing of groundwater samples with drilling fluids which, depending on the groundwater quality and chemical composition of these fluids, could over- or under-estimate the actual TDS and may also contribute to this variability. Despite this variability, the TDS of groundwater samples collected for the Project is generally consistent with the TDS of groundwater observed at other sites in the Canadian Shield (Figure 8.3-11), and the data set is considered sufficient for characterization of the groundwater chemistry for the Project.

The Fritz and Frape profile (1987) shown in Figure 8.3-11 was developed using chemical analyses of deep saline water collected by various investigators from several sites in the Canadian Shield. The Diavik profile was derived from site-specific data from Diavik, supplemented by information from the Lupin mine site located about 200 km north of Diavik (Kuchling et al. 2000). The Diavik Site is located about 300 km northeast of Yellowknife, and about 150 km northwest of the Project site. Data for the Snap Lake Project, which is located about 85 km northwest of the Project, consist of site information augmented with deep groundwater data from the other data sources discussed previously.

Figure 8.3-11 Total Dissolved Solids in Groundwater versus Depth



TDS = total dissolved solids; mg/L = milligrams per Litre; m = metre

The Project TDS versus depth profile was developed based on a best fit to the TDS of groundwater samples at the site to the maximum depth of site-specific data (450 mbgs). Below this depth, the profile was assumed to follow the Fritz and Frape profile (Fritz and Frape 1987), which is the most conservative profile of TDS with depth for data collected in the Canadian Shield.

In general, groundwater below the permafrost is dominated by chloride and calcium, with sodium, magnesium and sulphate levels increasing in step with increasing TDS levels. This trend is similar to the typical pattern observed in the deep waters from the Canadian Shield.

8.3.4.4 Groundwater Flow

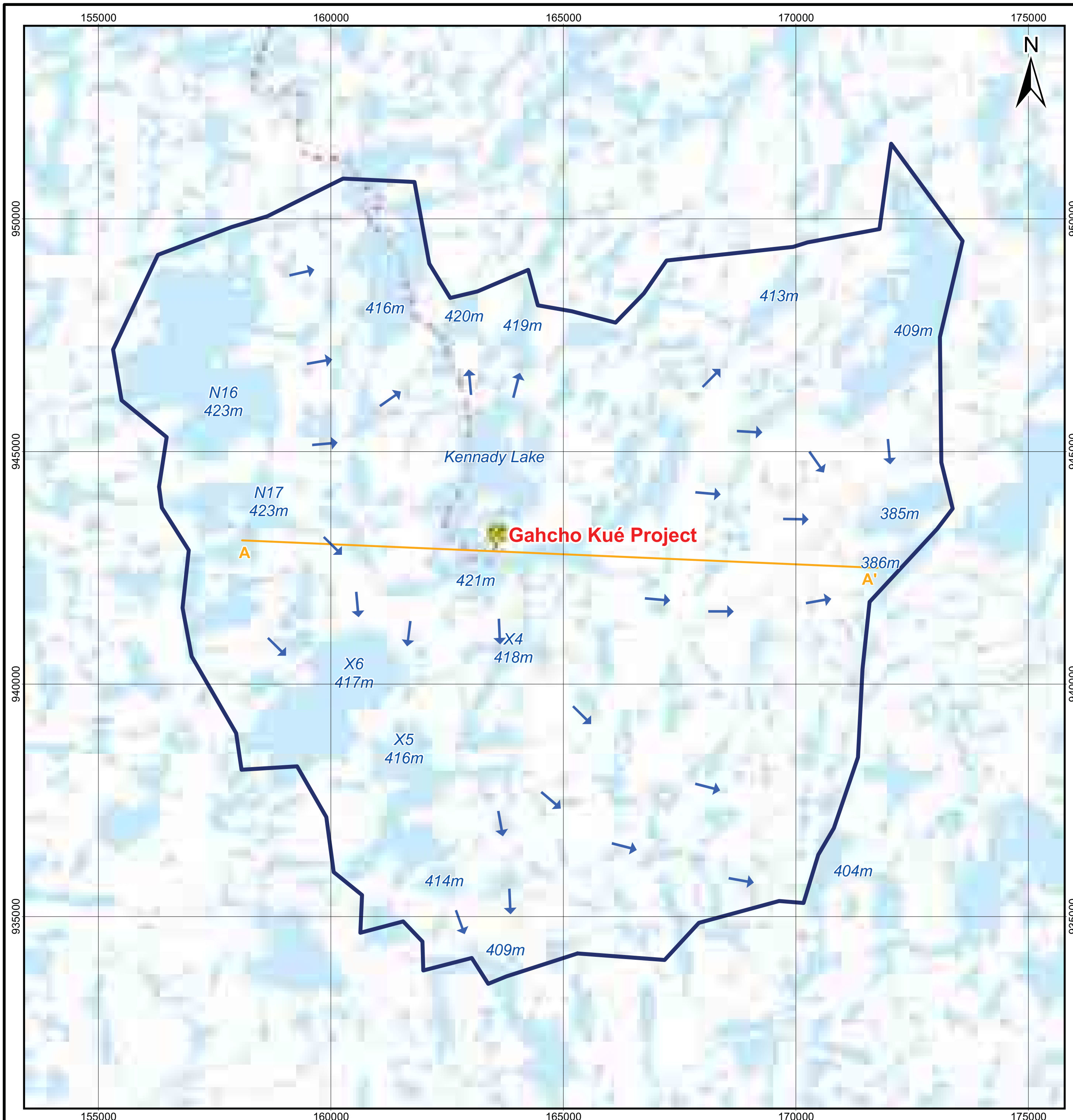
8.3.4.4.1 Shallow Groundwater Flow

In the shallow seasonally active groundwater regime, hydraulic gradients closely follow land topography. On this basis, the slope of the local terrain suggests hydraulic gradients in the active zone may range from 0.001 to 0.1 metre per metre (m/m). Based on surficial geology and vegetation mapping results, most of the elevated terrains appear to be well drained, and the groundwater table was not encountered within auger holes drilled in elevated areas during the 2004 field inspection. The auger holes never penetrated deeper than 0.4 to 0.6 m below grade due to auger refusal. In the fluvial channels, groundwater can be expected at shallower depths (less than 1 m), and in the peat bogs the groundwater table usually coincided with the ground surface. In terms of travel distance, groundwater in the till is likely to move in the range of centimetres per day, but locally faster groundwater movement may also occur. Groundwater flow in the shallow system is controlled by local topography, and, as a result, the total travel distance would usually extend only to the nearest pond, lake, or stream.

8.3.4.4.2 Deep Groundwater Flow

Open taliks play a pivotal role in controlling the deep groundwater flow, as the overlying lakes provide the driving head for the flow system beneath the zone of continuous permafrost. Generally, groundwater will flow from higher elevation lakes to lower elevation lakes.

Lakes expected to have open taliks extending to the deep groundwater flow system and their respective elevations are identified on Figures 8.3-12. Flow directions in the deep groundwater flow regime were inferred from the elevations of these lakes and are also presented on Figure 8.3-12 and Figure 8.3-13. The elevations of these lakes indicate that the groundwater flow direction in the deep groundwater flow regime in the area of the LSA is generally to the south and east.



LEGEND

- Gahcho Kué Project
- Contour (20m interval)
- Watercourse
- Winter Access Road
- Waterbody
- Conceptual Cross Section
- Inferred Groundwater Flow Direction Beneath Permafrost
- Local Study Area

NOTES
Base data source: The Atlas of Canada
Elevations shown are approximate (+/- 1m).
Lakes labelled with elevations are assumed to have open taliks. Lake elevations were derived from National Topographic Base Data (NTDB) 1:50,000 data and LiDAR data provided by the client.

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GAHCHO KUÉ PROJECT

Conceptual Model of Groundwater Flow in the Kennady Lake Area - Plan View - Pre-Mining

PROJECTION:	DATUM:
Canadian Lambert Conf. Conic	NAD83

Scale: 1:120,000
2 1 0 2
Kilometres

FILE No:	DATE:
SON-11.6-002-GIS	December 16, 2010

JOB NO:	REVISION NO:	
09-1365-1004	1	
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Figure 8.3-12

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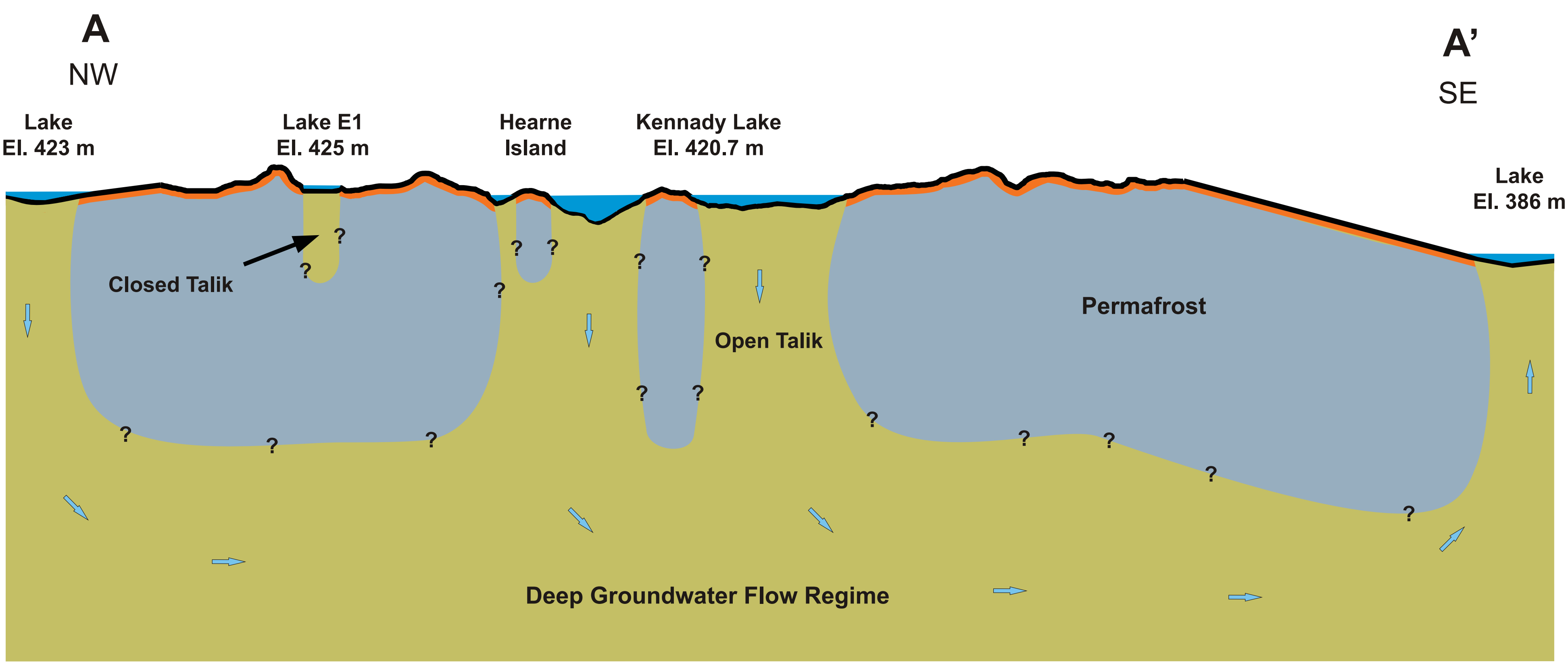


LEGEND

- Active Layer (Shallow Groundwater Flow Regime)
- Ground Surface
- Inferred Groundwater Flow Direction
- Deep Groundwater Flow Regime
- Permafrost

Schematic Only
Approximate vertical exaggeration of 1:8

GACHO KUÉ PROJECT

Conceptual Model of Groundwater Flow – Cross-Section View Pre-Mining

PROJECTION: N/A	DATUM: N/A	
SCALE: NOT TO SCALE		
FILE No: SON-11.6-011-CAD		DATE: September 29, 2010
JOB No: 09-1365-1004	REVISION No: 0	Figure 8.3-13
OFFICE: GOLD - CAL	DRAWN: DLM	CHECK: DC

These groundwater flow directions were inferred assuming that open taliks exist beneath lakes identified on Figure 8.3-12. On a regional scale, it was also assumed that the hydraulic conductivity of the bedrock beneath the permafrost is relatively homogeneous and isotropic.

8.3.5 Surface Water Quantity

This following section describes the hydrological conditions for Kennady Lake and the Kennady Lake watershed. For additional baseline details, the reader is referred to Annex H (Climate and Hydrology Baseline) and Addendum HH.

8.3.5.1 Methods

The description of hydrology focuses on the streamflow at lake outlets in the Kennady Lake watershed. Hydrometric data, stream geomorphology data, and ice and winter flow information were collected for baseline reporting. The baseline report examines local and regional data to develop the following estimates:

- long-term mean values of discharge and annual water yield;
- ranges of natural variability;
- dry and wet year values;
- peak discharges; and
- low flows.

A water balance model was developed to derive long-term mean characteristics and variability for key waterbodies within the Kennady Lake watershed because long-term regional hydrometric stations are sparse, regional data are not applicable to small, local watersheds with variable storage and lake outlet geometry, and there are only short periods of record for hydrometric stations at the Project.

8.3.5.2 Results

Kennady Lake is a headwater lake, receiving runoff from smaller tributary watersheds. Each such tributary watershed typically contains a series of small lakes with interconnecting channels, through which tributary runoff is conveyed before it reaches Kennady Lake. The watershed and watershed boundaries for Kennady Lake are shown in Figure 8.3-1 and characteristics of component watersheds are summarized in Table 8.3-14.

Table 8.3-14 Kennady Lake Watershed Area Summary

Watershed	Land Surface Area (km^2)	Lake Surface Area (km^2)	Total Area (km^2)	Lake Surface Fraction
A	1.59	0.645	2.24	0.288
B	1.10	0.174	1.27	0.137
C	0.323	0.018	0.341	0.053
D	3.47	1.03	4.50	0.228
E	1.15	0.244	1.39	0.175
F	0.260	0.039	0.300	0.131
G	0.765	0.090	0.855	0.105
H	0.730	0.102	0.832	0.122
I	0.594	0.152	0.746	0.204
J	1.12	0.525	1.65	0.318
Kennady Lake[(a)]	21.2	11.3	32.5	0.348

[(a)] Areas at Kennady Lake outlet include upstream watersheds A to J and Ka to Ke.

km^2 = square kilometres.

Stream Geomorphology

Lakes generally comprise more than 35% of the landscape within the Kennady Lake watershed, and are typically connected by short outlet channels that are steep relative to overall land slopes. Channels are typically only slightly entrenched, have high bankfull width-to-depth ratios (W/D greater than 12) and are moderately sinuous (i.e., curving). Sinuosity is greater than 1.2. Most lake outlet channels in the Kennady Lake watershed could be described as C1 or C2 channels by the Rosgen Level II classification system (Rosgen 1994), though some have side channels and very high width-to-depth ratios, and could be classified as D1 or D2 channels.

The beds of larger channels are typically armoured with bedrock or boulder layers that do not erode. Channels may include flat and steep reaches as governed by the local topography and bedrock outcrops. Channel banks typically consist of vegetated mats of organic material up to 300 mm thick, below which are found organics and fine soils within a matrix of boulders similar to the bed materials. Mid-channel islands were observed to also consist of a veneer of vegetated organic mat resting on a boulder substrate.

Erosion resistance of channel/banks is also likely enhanced by frozen conditions during spring snowmelt peak discharges, as has been observed in other northern areas (Scott 1978). However, during unfrozen conditions after spring runoff, these banks may be sensitive to changes in flow regime.

Channels at the outlets of small, headwater lakes may be poorly defined and flow through organics, mostly without the cobble and boulder bed typical of the medium to larger channels described for the other watersheds. Although some cobbles and boulders may be present along the channel, the bed and banks are largely composed of easily erodible organics and fine-grained soils, which could be sensitive to changes in flow regime.

A summary of the lake outlet channel characteristics for Area 8 is provided in Table 8.3-15.

Table 8.3-15 Lake Outlet Channel Data Downstream of Kennady Lake

Outlet Channel	Watershed Area (km^2)	Length (m)	Elevation Drop (m)	Slope	Channel Type
Kennady Lake Outlet (Stream K5)	32.5	100	0.140	0.001	well-defined with boulder bed, shallow and wide, with sub- and side channels present

km^2 = square kilometres; m = metres.

8.3.5.2.1 Ice and Winter Flows

Winter Conditions

Data and observations of ice conditions and winter flows in the Kennady Lake watershed are summarized in Table 8.3-16. Ice thicknesses for the surveyed lakes appear similar for both years, with an average of about 1.7 m in 2004 and 1.8 m in 2005. Ice surface levels were also consistently about 15 cm higher than the water levels, indicating a floating ice cover with some snow load. For Kennady Lake, the January 2005 water level was only 0.004 m below the late September 2004 water level of 7.161 m (local datum), indicating that fall water levels remained stable to freeze-up, likely due to inflows approximately equalling outflows for that period.

All lake outlets that were examined were consistently observed to be completely frozen with zero flow during the winter. This appears to be the typical winter condition for all lakes in the Kennady Lake watershed.

Table 8.3-16 Lake Ice, Winter Water Levels, and Outlet Flow Conditions in the Kennady Lake Watershed, 2004 and 2005

Lake	Date	Ice Thickness (m)	Ice Level[(a)] (m)	Water Level[(a)] (m)	Outlet Condition
D7	May 2004	1.75	9.585	9.425	frozen, no flow
	Apr 2005	1.71	no data	9.607	frozen, no flow
D1	May 2004	1.64	8.252	8.092	frozen, no flow
	Apr 2005	1.79	no data	8.150	frozen, no flow
E1	May 2004	1.68	8.752	8.582	frozen, no flow
	Apr 2005	no data	no data	ice to bottom	frozen, no flow
Area 8	May 2004	1.65	7.283	7.143	frozen, no flow
	Jan 2005	1.74	7.287	7.157	frozen, no flow
	Apr 2005	1.96	no data	no data	frozen, no flow

(a) Local datum.

m = metres.

Spring Melt Conditions

During the first week or two of the runoff period, regular observations of water levels and discharge measurements were made at intervals of one to two days. Dates relating to the start of runoff for the monitoring stations for 2004 and 2005 are presented in Table 8.3-17.

Table 8.3-17 Runoff Start-up Dates in the Kennady Lake Watershed, 2004 and 2005

Location	Year	Start of Runoff	First Discharge Measurement	Runoff Peak
Lake D7	2004	June 3	June 5	June 11
	2005	June 2	June 4	June 6
Lake D1	2004	June 2	June 5	June 5
	2005	June 3	June 4	June 4
Lake E1	2004	June 2	June 3	June 5
	2005	June 2	June 4	June 5
Kennady Lake	2004	June 1	June 5	June 15
	2005	June 3	June 5	June 10

Freeze-up Conditions

On the basis of the observed winter conditions, observed start and end of season lake levels, the likely influence of watershed area, upstream lakes, and typical regional temperatures, the following estimates were made for freeze-up of the outlets:

- Lake E1 typically discharges to the end of September;
- Lakes D1 and D7 typically continue to discharge to about the middle of October; and

- Kennady Lake typically discharges to about the end of October.

8.3.5.2.2 Mean Water Balance

A mean annual water balance for a typical watershed was developed based on the mean values of the various parameters, on a hydrological year basis. The example provided in Table 8.3-18, although describing a lake in the L watershed, provides a basic characterization for mean conditions that is applicable to the Kennady Lake watershed.

Table 8.3-18 Representative (Lake L1) Watershed Mean Annual Water Balance for Natural Conditions

Component	Magnitude (mm)	Comment
Total precipitation	331.6	mean annual value
Rainfall	162.0	mean annual value
Snowfall as SWE	169.6	mean annual value
Spring SWE	117.7	mean annual value, accounting for 30% loss due to sublimation (51.9 mm)
Net precipitation input	279.7	rainfall + spring SWE
Surface runoff (at Lake L1 outlet)	141.1	mean annual value
Lake evaporation at 285 mm	93.8[a]	32.9% of watershed L is lake surface
Evapotranspiration at 66.8 mm	44.8[b]	67.1% of watershed L is land surface
Net watershed output	279.7	surface runoff + lake evaporation + evapotranspiration

(a) Total evaporation loss from lake surfaces = (285 mm) x (0.329) = 93.8 mm.

(b) Total evapotranspiration loss from land surfaces = (66.8 mm) x (0.671) = 44.8 mm.

SWE = snow water equivalent; mm = millimetres; % = percent.

The total evaporative loss from lake and land surfaces (lake evaporation and land evapotranspiration) equals 138.6 mm or 50% of the net pre-snowmelt precipitation input. When combined with sublimation of snow (51.9 mm), the total loss equals 190.5 mm or 57% of the total precipitation.

The surface runoff amount represents 43% of the total precipitation, or 50% of the net precipitation, which is the precipitation remaining after the snow sublimation loss is deducted.

8.3.5.2.3 Kennady Lake Outlet Flow Regimes

Frequency analysis of the hydrology model results (floods and droughts) for the outlet of Kennady Lake (Stream K5) was carried out for use in fisheries and water quality baseline reports and to provide a basis for environmental impact assessment and engineering design. The following parameters were examined:

- maximum, mean, and minimum daily outflow volumes for each calendar month;
- annual 7-day and 14-day mean flood discharges; and
- annual 30-day, 60-day, and 90-day low flow discharges for the period of July, August, and September.

Results for Kennady Lake outflow are presented in Table 8.3-19 (mean daily outflow volumes) and Table 8.3-20 (long-duration floods and low flow discharges).

Table 8.3-19 Derived Mean Daily Outflow Volumes at the Outlet of Kennady Lake (Stream K5)

Condition	Return Period (years)	Mean Daily Outflow Volume (m^3)					
		May	June	July	August	September	October
Wet	100	36,000	121,000	86,500	59,600	68,600	13,500
	50	21,400	114,000	76,800	52,000	53,900	11,700
	20	10,400	104,000	68,300	44,100	39,800	8,860
	10	5,790	97,600	61,900	38,100	29,200	6,640
	5	2,930	85,900	53,400	32,000	22,500	5,160
Median	2	708	65,900	39,300	22,800	13,200	3,070
Dry	5	0	47,000	28,400	16,500	8,350	1,820
	10	0	36,900	23,100	13,900	6,880	1,430
	20	0	28,500	19,000	12,100	6,010	1,190
	50	0	19,200	14,700	10,400	5,280	985
	100	0	12,900	12,000	9,420	4,910	878

m^3 = cubic metres.

Table 8.3-20 Derived Representative Discharges at the Outlet of Kennady Lake (Stream K5)

Condition	Return Period (years)	Peak Daily Q (m^3/s)	7-Day Average Peak Q (m^3/d)	14-Day Average Peak Q (m^3/d)	30-Day (July to September) Low Flow Q (m^3/d)	60-Day (July to September) Low Flow Q (m^3/d)	90-Day (July to September) Low Flow Q (m^3/d)
Wet	100	2.51	192,000	167,000	48,900	52,500	59,000
	50	2.43	186,000	162,000	41,400	46,200	53,700
	20	2.28	176,000	153,000	32,400	38,200	46,600
	10	2.14	166,000	145,000	26,200	32,300	41,000
	5	1.96	153,000	133,000	20,300	26,500	35,100
Median	2	1.56	123,000	108,000	12,800	18,300	26,000
Dry	5	1.07	85,500	77,200	8,070	12,500	18,500
	10	0.80	65,100	60,000	6,560	10,900	16,100
	20	0.57	47,600	45,200	5,750	10,100	14,700
	50	0.32	27,900	28,400	5,210	9,550	13,700
	100	0.15	14,900	17,300	5,000	9,340	13,200

m^3/s = cubic metres per second; m^3/d = cubic metres per day; Q = discharge.

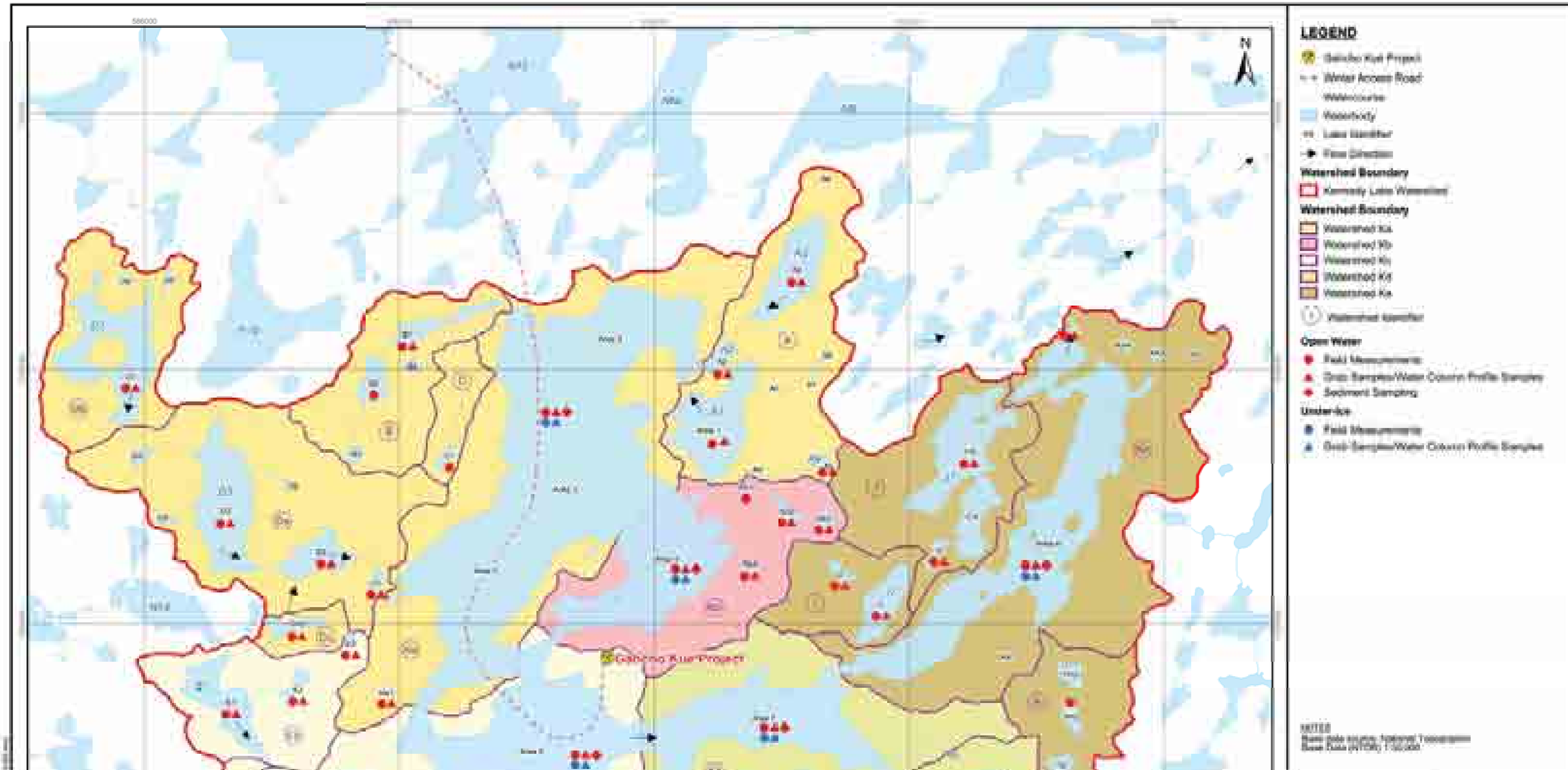
8.3.6 Surface Water and Sediment Quality

The following section provides an overview of the baseline surface water quality and sediment quality for Kennady Lake and its watershed. The baseline setting is defined from published work by others and several seasons of investigations by several consultants and consulting teams. For additional information regarding surface water quality, the reader is referred to Annex I (Water Quality Baseline) and Addendum II.

8.3.6.1 Methods

The baseline sampling programs involved the collection of water and sediment samples from Kennady Lake, and small lakes in the Kennady Lake watershed. Several baseline field programs have been conducted in the Kennady Lake watershed since 1996. The location and timing for each sampled lake is denoted for each type of water or sediment sample collected, and represented in Figure 8.3-14 using different symbols:

- in situ measurements are denoted with a circle;
- grab water samples and water samples collected as part of a vertical profile are denoted with a triangle; and
- grab sediment samples are denoted with a diamond.



GAHCHO KUÉ PROJECT

Surface Water Quality Sampling Locations in the Kennady Lake Watershed

Figure 8.3-14

The colour of the symbol denotes sampling during under-ice (blue) and open water (red) conditions.

All data from the baseline study reports were classified as in situ (spot or profile measurements), grab samples, or vertical profile sampling. Summary statistics for water and sediment quality, including the median, minimum, and maximum values, as well as the range of sample sizes, were prepared for each chemical constituent analyzed and are presented in tabular format. Water quality summaries were prepared for both under-ice and open water conditions.

All data were summarized into the following three categories, based on the proportion of values below their respective MDLs, and analyzed separately:

- data series where values below the MDL consisted of approximately one-third to one-quarter (or less) of the data series;
- data series where values below the MDL ranged from approximately one-third to two-thirds of the data series; and
- data series where values below the MDL comprised approximately two-thirds to three-quarters (or more) of the data series.

When the data series occurred in the first category, all values below the MDL were assigned a value of one-half of the most sensitive MDL and descriptive statistics (e.g., minimum, median, and maximum) were calculated. By using a value of half of the most sensitive MDL in this case, a representative statistical analysis of the natural conditions could be accomplished.

For data in the second category, descriptive statistics were calculated on values at or above the MDL only. If a value of half the most sensitive MDL was used in this case, the data series may have become skewed.

For data series in the final category, only minimum and maximum values were provided. By using a value of half the most sensitive MDL in this case, descriptive statistics may have provided a median below the most sensitive MDL.

Minimum and maximum detection limits were presented in addition to the statistical descriptors of the data range for each parameter to assist in understanding the statistical descriptors presented. The baseline data represents data collected over more than 10 years. Improvements or changes in analytical methods and procedures over the period of baseline data collection have resulted in inconsistent detection limits within the data. Generally, lower detection limits have been associated with more recent baseline field programs.

All results for the water sampling programs were compared to both the most recent Canadian Council of Ministers of the Environment (CCME) Canadian Water Quality Guidelines (CWQG) for the protection of aquatic life (CCME 2006, 2007) and Health Canada Guidelines for Canadian Drinking Water Quality (CDWQG) (Health Canada 2006, 2007). The results of the sediment sampling programs were compared to the CCME Interim Sediment Quality Guidelines (ISQG) for the protection of aquatic life (CCME 2002).

The CWQG and ISQG are intended to protect all forms of aquatic life, including the most sensitive species, for the long-term (CCME 2006). They are based on toxicity tests of the effects on sensitive aquatic species and tend to be conservative in nature.

8.3.6.2 Results

8.3.6.2.1 Kennady Lake

Physical Limnology and Vertical Structure

Under-ice Conditions

During under-ice conditions, all basins in Kennady Lake were inversely stratified. Cooler waters approaching 0°C occurred immediately below the ice with temperatures gradually increasing with increased depth. Maximum temperatures (around 4°C) generally occurred at depths greater than 6 m (Figure 8.3-15a).

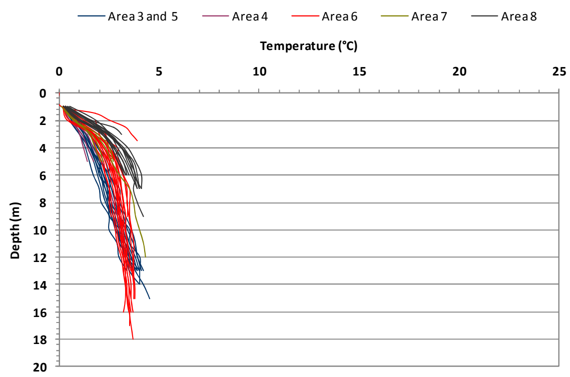
At the ice-water interface, measured conductivity in all areas of Kennady Lake ranged from 9 to 11 microSiemens per centimetre (µS/cm) (Figure 8.3-15b). Conductivity measured during under-ice conditions generally increased slightly with increasing depth in Kennady Lake.

Concentrations of dissolved oxygen (DO) ranged from 13 to 22 milligrams per litre (mg/L) in the upper 2 m of the water column and decreased rapidly with depth to near anoxia (i.e., DO concentrations less than 2 mg/L) at depths greater than 12 m during late winter (April to May) (Figure 8.3-15c). In general, DO concentrations were below the CWQG for cold water aquatic life (9.5 mg/L for early life stages and 6.5 mg/L for other life stages) at depths generally greater than 8 m in the deeper basins of Kennady Lake.

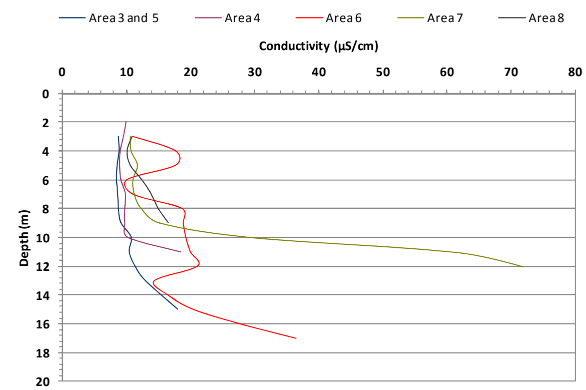
Water column profile measurements for pH in under-ice conditions were limited to water surface measurements (Figure 8.3-15d). Measured field pH values ranged between 6 and 7.

Figure 8.3-15 Physico-chemical Water Quality Profile Data in Kennady Lake During Under-ice Conditions

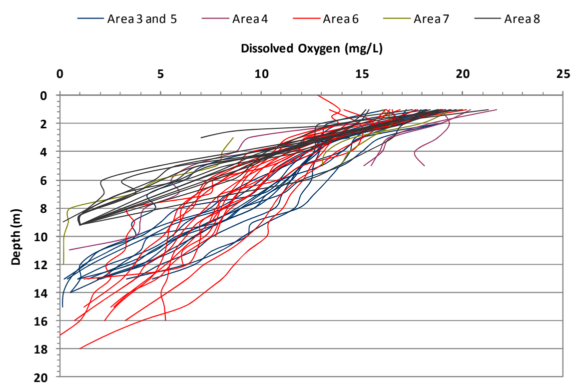
a.) Water Temperature



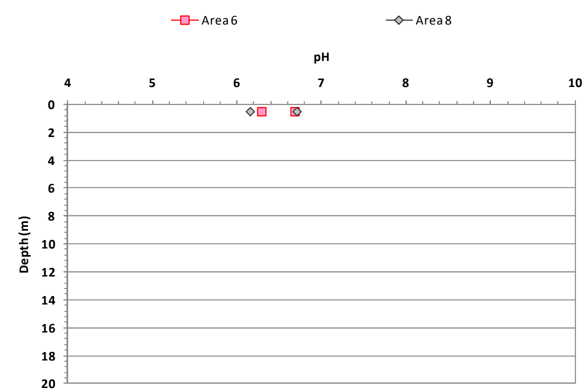
b.) Conductivity



c.) Dissolved Oxygen



d.) pH



Note: Only single surface ice-covered pH readings collected.

m = metres, °C = degrees Celsius, µS/cm = microSiemens per Centimetre, mg/L = milligrams per litre.
Individual field results not presented in field profile figures.

Open Water Conditions

Temperature profiles were vertically homogeneous during most open water sampling events, indicating that the water column in Kennady Lake was typically well mixed by temperature-related, density-driven overturn in spring and fall as well as wind-driven circulation during summer months (Figure 8.3-16a). Temperatures varied during open water conditions from 3°C to 17°C. Well-developed seasonal thermoclines (steep temperature gradients) were observed between depths of 10 and 14 m in Area 6 during sampling events in late July 1999, early August 2004 and July 2010. The temperature gradients for the 1999 and 2004 thermoclines were about 5.5°C per metre, but the July 2010 thermocline was less defined.

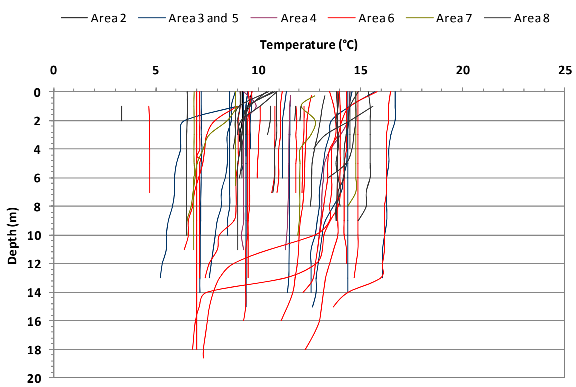
Measured conductivity during open water conditions was very low, ranging between 8 and 14 μS/cm (Figure 8.3-16b). There was very little variability throughout the water column indicating that total dissolved solids (TDS) were equally distributed throughout the lake, and that Areas 2 through 8 of Kennady Lake were well mixed during open water conditions.

Dissolved oxygen concentrations were generally uniform throughout the water column of Areas 2 to 8 of Kennady Lake during open water conditions, ranging from 9 to 16.5 mg/L (Figure 8.3-16c). Decreases in DO at depths greater than 12 m were observed in Area 6, associated with the measured temperature thermoclines. The DO concentrations measured during most sampling events were above the lowest acceptable dissolved oxygen concentrations for the protection of early life stages (9.5 mg/L) and other life stages (6.5 mg/L) of cold water aquatic life in the CWQG. There were no DO concentrations recorded below 6.5 mg/L with the exception of one result which may have been due to the probe reading pore water in the sediments.

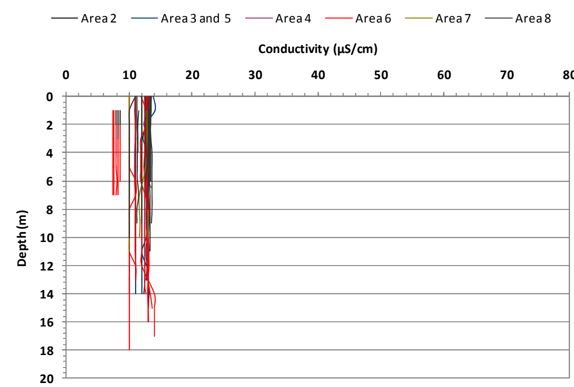
Open water pH field results ranged from 6.4 to 8.3 (Figure 8.3-16d). Field pH profiles in Kennady Lake were fairly uniform throughout the water column for each field program. Observed changes in pH between field programs are likely due to seasonal variation in addition to calibration changes in the field instrument. Several vertical profiles measured during fall field programs were below the acceptable pH range of the CWQG (6.5 to 8.5).

Figure 8.3-16 Open Water Kennady Lake Field Data (1998 to 2010)

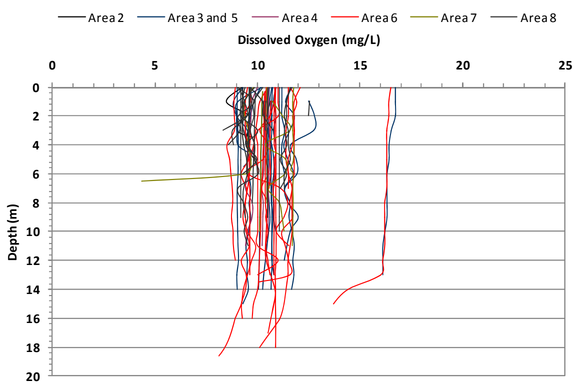
a.) Water Temperature



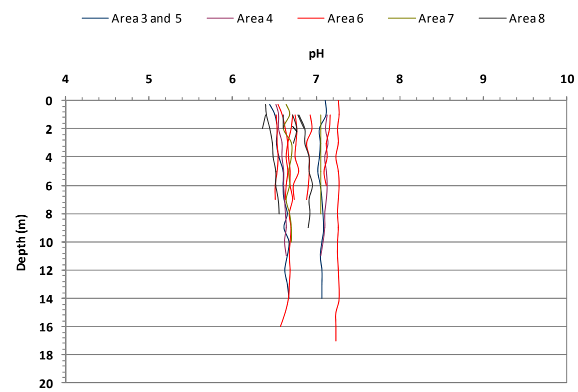
b.) Conductivity



c.) Dissolved Oxygen



d.) pH



Note: Questionable profiles from September 11 -13, 2004 removed.

m = metre, °C = degrees Celsius, µS/cm = microSiemens per centimetre, mg/L = milligrams per litre.

Individual field results not presented in field profile figures.

Water Quality

The water in Areas 2 through 8 of Kennady Lake is soft, having a median hardness of 3.8 mg/L during open water conditions and 6 mg/L during under-ice conditions (Table 8.3-21). The median alkalinity during both open water and under-ice conditions, which is also 4 and 6 mg/L respectively, is an indication of the low buffering capacity of water from Kennady Lake.

The concentrations of TDS were low during open water and under-ice conditions, (medians of 5.4 and 7 mg/L, respectively), indicating a very small amount of dissolved substances in the water (Table 8.3-21). Bicarbonate was the dominant ion surveyed during both water conditions, whereas sulphate and chloride were at or below the detection limit during most sampling events. Calcium was the major cation measured in all areas of Kennady Lake.

Total suspended solids (TSS) were generally measured at or below detection limits during under-ice conditions (78% of samples were below detection limits during under-ice conditions; Table 8.3-21), indicating that water in Kennady Lake is very clear and contains very little suspended solids. The highest measurement of TSS (27 mg/L) was reported during open water conditions. Only 67% of samples were below detection limits during open water conditions.

The concentrations of inorganic nitrogen compounds, such as ammonia, nitrate, and nitrite, generally were below detection during open water conditions (Table 8.3-21). Total Kjeldahl nitrogen (TKN) was measured above detection levels only during open water conditions, where it was generally found at low concentrations (median of 0.3 mg/L).

Total phosphorus (TP) was more variable during under-ice conditions than during open water conditions. Due to the number of results below detection, a median TP concentration could not be calculated. Samples collected during ice-cover had a minimum concentration of <1 micrograms per litre (µg/L) and a maximum concentration of 10 µg/L. Open water concentrations had a maximum value of 6 µg/L. The observed concentrations of nutrients indicate that Kennady Lake can be classed as an oligotrophic lake, is phosphorus-limited, and has low biological productivity.

Table 8.3-21 Summary of Water Quality in Areas 2 through 8 in Kennady Lake, 1995 to 2010

Parameter Name	Unit	Method Detection Limit			Kennady Lake: Under-Ice Conditions (1996 - 2004)						Guidelines				Kennady Lake: Open Water (1995 - 2010)						Guidelines			
											Aquatic Life - Chronic [a]		Human Health - Chronic [b]								Aquatic Life - Chronic [a]		Human Health - Chronic [b]	
		Min	Max	Number of Method Detection Limits	n	Min	Med	Max	Count Below Detection	% Below Detection	Value	Guideline Exceedance Count	Value	Guideline Exceedance Count	n	Min	Med	Max	Count Below Detection	% Below Detection	Value	Guideline Exceedance Count	Value	Guideline Exceedance Count
Field measured																								
pH	pH units	-	-	-	4	**6.2**[c]	6.5	6.7	0	0	6.5 - 8.5	2	5.0 - 9.0	0	261	**6.8**	6.8	7.3	0	0	6.5 - 8.5	85	5.0 - 9.0	13
Temperature	°C	-	-	-	567	0	2.7	4.5	0	0	-	0	-	0	561	3.3	12	18	0	0	-	0	-	0
Specific Conductivity	µS/cm	-	-	-	51	8.4	11	72	0	0	-	0	-	0	488	7.4	12	18	0	0	-	0	-	0
Dissolved Oxygen	mg/L	-	-	-	548	**0**[c]	9.6	22	0	0	6.5	160	-	0	528	**1.4**[c]	11	17	0	0	6.5	2	-	0
Conventional Parameters																								
Colour	TCU	1	-	1	0	-	-	-	0		-	0	-	0	22	0.5	10	30	4	18.2	-	0	-	0
Specific Conductance	µS/cm	-	-	0	116	12	18	27	0	0	-	0	-	0	45	10	13	23	0	0	-	0	-	0
Dissolved Organic Carbon	mg/L	1	-	1	35	2.7	3.6	5.1	0	0	-	0	-	0	28	0.5	3	6	1	3.6	-	0	-	0
Hardness	mg/L	6	-	1	129	4.3	6	10	0	0	-	0	-	0	83	1.3	3.8	5	22	26.5	-	0	-	0
pH	pH units	-	-	0	125	**5**[c]	6.4	6.8	0	0	6.5 - 8.5	78	5.0 - 9.0	0	47	**5.6**[c]	6.5	7.2	0	0	6.5 - 8.5	23	5.0 - 9.0	0
Total Alkalinity	mg/L	1	5	2	160	0.5	6	9	17	10.6	-	0	-	0	79	0.5	3.6	27	12	15.2	-	0	-	0
Total Dissolved Solids	mg/L	2	20	3	78	3	7	27	21	26.9	-	0	-	0	78	1	5.4	32	20	25.6	-	0	-	0
Total Organic Carbon	mg/L	1	3.1	2	88	1.6	3.7	8.8	1	1.1	-	0	-	0	38	0.5	3.1	4	2	5.3	-	0	-	0
Total Suspended Solids	mg/L	0.1	5	5	138	<1	-	18	107	77.5	-	0	-	0	52	<0.1	-	27	35	67.3	-	0	-	0
Major Ions																								
Bicarbonate	mg/L	1	5	2	88	2.5	9	10	2	2.3	-	0	-	0	40	0.5	4	33	12	30	-	0	-	0
Calcium	mg/L	-	-	0	150	0.65	1.4	2.5	0	0	-	0	-	0	58	0.1	1	1.8	0	0	-	0	-	0
Carbonate	mg/L	0.5	5	3	88	<5	-	<5	88	100	-	0	-	0	40	<0.5	-	<5	40	100	-	0	-	0
Chloride	mg/L	0.5	1	2	159	<0.5	-	6.3	107	67.3	230	0	-	0	78	0.25	0.6	1.7	21	26.9	230	0	-	0
Magnesium	mg/L	0.5	-	1	150	0.27	0.6	1	0	0	-	0	-	0	58	0.25	0.42	1.1	7	12.1	-	0	-	0
Potassium	mg/L	0.5	2	2	136	0.25	0.5	1	8	5.9	-	0	-	0	58	0.25	0.38	0.56	15	25.9	-	0	-	0
Sodium	mg/L	0.5	2	3	136	0.33	0.8	1.2	14	10.3	-	0	-	0	58	0.45	0.58	2.9	22	37.9	-	0	-	0
Sulphate	mg/L	0.5	1	2	157	0.5	1	11	28	17.8	-	0	-	0	76	0.46	1	2.1	38	50	-	0	-	0
Sulphide	µg/L	2	-	1	0	-	-	-	0		2.4	0	-	0	6	<2	-	<2	6	100	2.5	0	-	0
Nutrients																								
Nitrate + Nitrite	mg-N/L	0.003	0.006	2	80	0.006	0.029	0.34	27	33.8	2.93	0	10	0	15	<0.003	-	0.078	14	93.3	2.93	0	10	0
Nitrogen - Ammonia	mg-N/L	0.005	0.1	3	159	0.0025	0.014	0.062	42	26.4	49	0	-	0	76	0.005	0.007	0.063	44	57.9	16	0	-	0
Nitrogen - Kjeldahl	mg-N/L	0.2	-	1	0	-	-	-	0	-	-	0	-	0	28	0.1	0.3	1.3	3	10.7	-	0	-	0
Phosphorus, total	µg/L	1	300	7	112	<1	-	10	80	71.4	50	0	-	0	68	<20	-	6	62	91.2	50	0	-	0
Phosphorus, dissolved	mg/L	0.002	0.3	3	48	<0.002	-	0.009	34	70.8	-	0	-	0	49	<0.005	-	0.19	37	75.5	-	0	-	0
General Organics																								
Total Phenolics	µg/L	2	-	1	0	-	-	-	0	-	5	0	-	0	6	<2	-	<2	6	100	5	0	-	0
Total Recoverable Hydrocarbons	mg/L	0.1	2	2	0	-	-	-	0	-	-	0	-	0	28	<0.1	-	0.2	26	92.9	-	0	-	0
Total Metals																								
Aluminum	µg/L	5	20	2	165	3.2	6.7	51	0	0	100	0	100	0	87	2.5	10	**730**[c, d]	21	24.1	100	2	100	2
Antimony	µg/L	0.02	1	5	165	0.015	0.08	0.72	55	33.3	-	0	5.5	0	87	<0.02	-	**15**[d]	60	69	-	0	5.5	1
Arsenic	µg/L	0.1	1	3	165	0.05	0.13	0.3	5	3	5	0	10	0	87	0.06	0.11	1.5	38	43.7	5	0	10	0

Table 8.3-21 Summary Water Quality in Areas 2 through 8 in Kennady Lake, 1995 to 2010 (continued)

Parameter Name	Unit	Method Detection Limit			Kennady Lake: Under-Ice Conditions (1996 - 2004)										Kennady Lake: Open Water (1995 - 2010)									
											Guidelines										Guidelines			
											Aquatic Life - Chronic (a)		Human Health - Chronic (b)								Aquatic Life - Chronic (a)		Human Health - Chronic (b)	
		Min	Max	Number of Method Detection Limits	n	Min	Med	Max	Count Below Detection	% Below Detection	Value	Guideline Exceedance Count	Value	Guideline Exceedance Count	n	Min	Med	Max	Count Below Detection	% Below Detection	Value	Guideline Exceedance Count	Value	Guideline Exceedance Count
Barium	µg/L	1	10	3	165	0.25	2.6	8.1	3	1.8	-	0	1000	0	87	1.5	1.9	11	30	34.5	-	0	1000	0
Beryllium	µg/L	0.01	5	5	165	<0.2	-	<5	165	100	-	0	4	0	87	<0.01	-	<5	87	100	-	0	4	0
Boron	µg/L	1	100	5	165	0.5	2	7	5	3	-	0	5000	0	87	1	2	9	40	46	-	0	5000	0
Cadmium	µg/L	0.002	0.2	6	165	<0.02	-	**0.05**(c)	157	95.2	0.0029	8	5	0	89	<0.002	-	**0.005**(c)	88	98.9	0.002	1	5	0
Calcium	µg/L	1000	-	1	165	170	1310	2400	0	0	-	0	-	0	87	100	940	2530	1	1.1	-	0	-	0
Chromium	µg/L	0.06	15	6	165	<0.06	-	0.78	113	68.5	1	0	50	0	87	<0.06	-	**1.5**(c)	83	95.4	1	2	50	0
Cobalt	µg/L	0.1	1	3	165	<0.1	-	1.2	141	85.5	-	0	-	0	87	<0.1	-	0.4	71	81.6	-	0	-	0
Copper	µg/L	0.6	10	4	165	0.3	0.6	**311**(c)	49	29.7	2	19	1300	0	87	0.28	0.4	**8**(c)	49	56.3	2	1	1300	0
Iron	µg/L	5	50	4	165	2.5	10	**433**(c, d)	44	26.7	300	2	300	2	87	10	27	195	37	42.5	300	0	300	0
Lead	µg/L	0.05	1	4	165	<0.05	-	0.6	152	92.1	1	0	10	0	87	<0.05	-	0.7	66	75.9	1	0	10	0
Lithium	µg/L	0.1	20	4	165	0.2	0.9	1.4	77	46.7	-	0	-	0	56	<0.1	-	6	41	73.2	-	0	-	0
Magnesium	µg/L	500	-	1	165	240	560	1020	0	0	-	0	-	0	87	250	410	1000	8	9.2	-	0	-	0
Manganese	µg/L	5	-	1	165	0.5	2.5	**378**(d)	2	1.2	-	0	50	25	87	2	3.9	36	9	10.3	-	0	50	0
Mercury	µg/L	0.0006	500	8	162	<0.01	-	0.02	155	95.7	0.026	0	1	0	75	<0.0006	-	**0.07**(c)	68	90.7	0.026	3	1	0
Molybdenum	µg/L	0.04	5	6	165	<0.04	-	0.09	162	98.2	73	0	-	0	87	<0.05	-	<5	87	100	73	0	-	0
Nickel	µg/L	0.06	8	5	165	0.03	0.27	2.2	4	2.4	25	0	340	0	87	0.18	0.25	10	20	23	25	0	340	0
Potassium	µg/L	500	2000	2	165	210	459	1000	20	12.1	-	0	-	0	87	349	380	740	32	36.8	-	0	-	0
Selenium	µg/L	0.01	10	7	165	<0.1	-	0.2	161	97.6	1	0	10	0	87	<0.01	-	**3**(c)	84	96.6	1	3	10	0
Silver	µg/L	0.0005	0.2	6	165	<0.01	-	**0.88**(c)	154	93.3	0.1	9	-	0	89	<0.0005	-	0.0036	83	93.3	0.1	0	-	0
Sodium	µg/L	500	2000	2	165	280	606	1000	20	12.1	-	0	-	0	87	440	490	700	44	50.6	-	0	-	0
Strontium	µg/L	-	-	0	165	3.5	8.6	69	0	0	-	0	-	0	65	5	6.3	20	0	0	-	0	-	0
Sulphur	µg/L	10000	-	1	0	-	-	-	0	-	-	0	-	0	9	300	300	500	6	66.7	-	0	-	0
Thallium	µg/L	0.002	100	5	77	<0.03	-	0.05	75	97.4	0.8	0	0.13	0	78	<0.002	-	0.1	77	98.7	0.8	0	0.13	0
Titanium	µg/L	0.1	100	5	77	<0.1	-	1	73	94.8	-	0	-	0	56	<0.1	-	4	55	98.2	-	0	-	0
Uranium	µg/L	0.01	0.5	4	165	<0.01	-	0.2	149	90.3	-	0	-	0	73	<0.01	-	0.25	63	86.3	-	0	-	0
Vanadium	µg/L	0.05	30	6	165	<0.05	-	0.12	164	99.4	-	0	-	0	87	<0.05	-	0.6	77	88.5	-	0	-	0
Zinc	µg/L	0.8	8	5	165	0.8	2.8	14	68	41.2	30	0	5100	0	87	0.1	1.3	**63**(c)	56	64.4	30	3	5100	0
Dissolved Metals(e)																								
Aluminum	µg/L	5	10	2	158	2.6	5	15	0	0	-	0	-	0	49	2.5	5	170	10	20.4	-	0	-	0
Antimony	µg/L	0.03	0.1	3	158	0.015	0.09	0.81	45	28.5	-	0	-	0	49	<0.05	-	0.09	43	87.8	-	0	-	0
Arsenic	µg/L	0.1	0.1	1	158	0.05	0.13	0.21	1	0.6	-	0	-	0	49	0.1	0.12	0.2	17	34.7	-	0	-	0
Barium	µg/L	3	10	2	158	1.1	2.5	7.1	0	0	-	0	-	0	49	1.8	2.1	5	27	55.1	-	0	-	0
Beryllium	µg/L	0.01	5	5	158	<0.2	-	<0.5	158	100	-	0	-	0	49	<0.01	-	<5	49	100	-	0	-	0
Boron	µg/L	1	100	4	158	0.5	2	7	2	1.3	-	0	-	0	49	<4	-	4	35	71.4	-	0	-	0
Cadmium	µg/L	0.005	0.2	4	158	<0.02	-	0.05	150	94.9	-	0	-	0	49	<0.005	-	0.07	48	98	-	0	-	0
Chromium	µg/L	0.06	15	5	158	0.06	0.12	4.2	103	65.2	-	0	-	0	49	<0.1	-	1.8	42	85.7	-	0	-	0
Cobalt	µg/L	0.05	1	3	158	<0.1	-	0.7	140	88.6	-	0	-	0	49	<0.05	-	0.7	41	83.7	-	0	-	0
Copper	µg/L	0.6	10	4	158	0.3	0.7	72	19	12	-	0	-	0	49	0.32	0.4	5.9	29	59.2	-	0	-	0
Iron	µg/L	5	30	4	158	5	9	131	95	60.1	-	0	-	0	49	<10	-	120	36	73.5	-	0	-	0
Lead	µg/L	0.05	1	2	158	<0.05	-	0.23	153	96.8	-	0	-	0	49	<0.05	-	0.47	34	69.4	-	0	-	0

Table 8.3-21 Summary Water Quality in Areas 2 through 8 in Kennady Lake, 1995 to 2010 (continued)

Parameter Name	Unit	Method Detection Limit			Kennady Lake: Under-Ice Conditions (1996 - 2004)										Kennady Lake: Open Water (1995 - 2010)									
											Guidelines										Guidelines			
											Aquatic Life - Chronic [a]		Human Health - Chronic [b]								Aquatic Life - Chronic [a]		Human Health - Chronic [b]	
		Min	Max	Number of Method Detection Limits	n	Min	Med	Max	Count Below Detection	% Below Detection	Value	Guideline Exceedance Count	Value	Guideline Exceedance Count	n	Min	Med	Max	Count Below Detection	% Below Detection	Value	Guideline Exceedance Count	Value	Guideline Exceedance Count
Lithium	µg/L	0.1	15	3	158	0.2	0.9	1.4	73	46.2	-	0	-	0	27	<1	-	1	21	77.8	-	0	-	0
Manganese	µg/L	1	5	2	158	0.09	1	300	0	0	-	0	-	0	49	0.15	0.5	5	13	26.5	-	0	-	0
Mercury	µg/L	0.002	1	6	158	<0.01	-	0.02	156	98.7	-	0	-	0	49	<0.002	-	0.005	46	93.9	-	0	-	0
Molybdenum	µg/L	0.04	1	5	144	<0.04	-	0.3	142	98.6	-	0	-	0	49	<0.05	-	0.5	48	98	-	0	-	0
Nickel	µg/L	0.1	1	2	144	0.015	0.3	2.5	0	0	-	0	-	0	49	0.05	0.26	2.9	9	18.4	-	0	-	0
Selenium	µg/L	0.04	2	7	144	<0.1	-	0.1	141	97.9	-	0	-	0	49	<0.04	-	<2	49	100	-	0	-	0
Silver	µg/L	0.005	0.1	5	144	<0.01	-	0.89	136	94.4	-	0	-	0	49	<0.005	-	<0.1	49	100	-	0	-	0
Strontium	µg/L	-	-	0	144	4.2	8.4	13	0	0	-	0	-	0	27	6.1	7	11	0	0	-	0	-	0
Sulphur	µg/L	10,000	10,000	1	0	-	-	-	0	-	-	0	-	0	6	<10,000	-	<10,000	6	100	-	0	-	0
Thallium	µg/L	0.002	100	5	56	<0.03	-	0.14	53	94.6	-	0	-	0	49	<0.002	-	0.07	44	89.8	-	0	-	0
Titanium	µg/L	0.1	100	4	56	<0.1	-	0.2	53	94.6	-	0	-	0	27	<0.5	-	<100	27	100	-	0	-	0
Uranium	µg/L	0.01	0.5	3	144	<0.01	-	0.02	132	91.7	-	0	-	0	49	<0.01	-	0.01	42	85.7	-	0	-	0
Vanadium	µg/L	0.05	30	5	143	<0.05	-	<1	143	100	-	0	-	0	49	<0.2	-	<30	49	100	-	0	-	0
Zinc	µg/L	0.8	5	4	143	0.4	1.9	12	18	12.6	-	0	-	0	49	0.4	3	17	14	28.6	-	0	-	0

Note: Presented guidelines were calculated using median values for data when applicable.
Individual guidelines were calculated for each sample, to determine the number of results above guidelines when applicable.
Bold values indicate a guideline exceedance.

[a] Canadian Environmental Quality Guidelines (CCME 1999 with updates to 2010). Winnipeg, MB.

[b] The human health guideline is based on the CCME drinking water guideline, Health Canada (2008).

[c] Concentration higher than the relevant chronic aquatic life guideline or beyond the recommended pH or DO concentration range.

[d] Concentration higher than the relevant human health guideline or beyond the recommended pH range.

[e] Some maximum dissolved metals concentrations are higher than the maximum total metal concentration in the statistical summary.

NA = not applicable, "-" = not available; °C = degrees Celsius, µS/cm = microSiemens per centimetre, mg/L = milligrams per litre, mV = millivolts, mg-N/L = milligrams nitrogen per litre, µg/L = micrograms per litre, TCU = True colour units; % = percent, n = number of samples, < = less than; min = minimum; med = median; max = maximum.

Levels of total organic carbon (TOC) and dissolved organic carbon (DOC) were low during both open water and under-ice conditions (Table 8.3-21). The water colour was observed at levels above the CDWQG of 15 true colour units (TCU) for four sampling events during the open water season. Oil and grease, phenol, and petroleum hydrocarbons were generally not detected.

The concentrations of total and dissolved metals were low, several metals near or below detection limits (e.g., cadmium, lead, mercury, molybdenum, selenium and thallium) (Table 8.3-21). More variability was observed during open water conditions; however, median concentrations for most metals were similar during both under-ice and open water conditions. Exceedances of applicable guidelines were observed for total aluminum, antimony, cadmium, chromium, copper, iron, manganese, mercury, selenium, silver, and zinc. The median concentrations of dissolved metals were similar to the total fraction.

Sediment Quality

Kennady Lake sediments collected for sediment quality analyses were mainly composed of sand, with some silt and clay (Table 8.3-22). The TOC ranged from 7% to 15% of the sediment composition. Inorganic carbon constituted 1.7% or less of the sediment whereas calcium carbonate content ranged between 0.1 and 0.6%.

In Kennady Lake, phosphorus was the dominant nutrient bound to the sediment, although the observed concentrations were variable (ranging from 1,390 to 2,450 micrograms per gram [µg/g]). In comparison, available phosphorus concentrations ranged from 7 to 37 µg/g, (Table 8.3-22). Nitrate concentrations were low (maximum of 0.7 µg/g), with several sediment samples yielding concentrations below the detection limit of 0.5 µg/g.

The total petroleum hydrocarbon (TPH) content in Kennady Lake sediments was detected and variable, ranging from 7 to 2,450 µg/g (Table 8.3-22). Hydrocarbons found in the sediment may be from natural sources, such as those by-products associated with the decomposition of organic matter.

The predominant metals in the sediment included aluminum, iron, and magnesium (Table 8.3-22). Concentrations of metals in the sediment were generally within the applicable aquatic life guidelines; however, arsenic exceeded the ISQG in most sediment samples, and copper was measured above the ISQG in all samples. Guideline exceedances also were observed for cadmium and zinc.

Table 8.3-22 Sediment Quality Summary for Kennady Lake, 1995 to 2010

Parameter	Unit	Method Detection Limit		Kennady Lake							Guideline
											Sediment Quality Guidelines (ISQG)
		Min	Max	Count	Min	Med	Max	Count Below Detection	% Below Detection	Number of Times a Guideline is Exceeded	CCME (2002)
Texture and Carbon Content											
Sand	%	1	1	1	70	-	70	0	0	0	-
Silt	%	1	1	1	28	-	28	0	0	0	-
Clay	%	1	1	1	2	-	2	0	0	0	-
Calcium Carbonate	%	0.005	0.005	5	0.115	0.155	0.52	2	40	0	-
Inorganic Carbon, Total	%	0.01	0.02	10	<0.01	0.44	1.72	2	20	0	-
Organic Carbon, Total	%	0.01	0.2	10	7.14	11.6	15	0	0	0	-
Carbon, Total	%	0.01	0.2	10	7.8	12.2	15	0	0	0	-
Nutrients and Organics											
Nitrate	µg/g	0.5	0.5	5	<0.5	0.65	0.7	3	60	0	-
Phosphorus, Available	µg/g	1	2	5	7	23	37	0	0	0	-
Phosphorus, Total	µg/g	5	5	5	1,390	1,630	2,450	0	0	0	-
Total Petroleum Hydrocarbons	µg/g	8	400	10	880	1,640	2,290	5	50	0	-
Total Metals											
Aluminum	µg/g	5	5	5	12,300	18,600	22,100	0	0	0	-
Arsenic	µg/g	0.5	1	10	3	**6.85**	**8.7**	0	0	6	5.9
Barium	µg/g	1	10	10	66	69.5	91	0	0	0	-
Cadmium	µg/g	0.1	0.2	10	0.3	0.4	**0.7**	0	0	1	0.6
Calcium	µg/g	5	5	5	2,700	3,590	4,380	0	0	0	-
Chromium	µg/g	0.5	1	10	27.8	30.9	**41**	0	0	2	37.3
Cobalt	µg/g	0.5	1	10	8	15.8	22	0	0	0	-
Copper	µg/g	0.1	5	10	**47**	**63.7**	**110**	0	0	10	35.7
Iron	µg/g	5	5	5	29,600	67,600	69,500	0	0	0	-
Lead	µg/g	0.5	1	10	2.6	5.45	9	0	0	0	35
Magnesium	µg/g	1	1	5	3,300	4,360	5,060	0	0	0	-
Manganese	µg/g	0.5	0.5	5	234	324	525	0	0	0	-

Table 8.3-22 Sediment Quality Summary for Kennady Lake, 1995 to 2005 (continued)

Parameter	Unit	Method Detection Limit		Kennady Lake							Guideline
		Min	Max	Count	Min	Med	Max	Count Below Detection	% Below Detection	Number of Times a Guideline is Exceeded	Sediment Quality Guidelines (ISQG) CCME (2002)
Mercury	µg/g	0.05	0.5	10	<0.05	-	0.09	7	70	0	0.17
Molybdenum	µg/g	0.4	0.5	10	2.6	4.15	6.1	0	0	0	-
Nickel	µg/g	0.5	1	10	26	32	48	0	0	0	-
Potassium	µg/g	2	5	10	12	978	2,000	0	0	0	-
Selenium	µg/g	0.5	0.5	10	0.5	0.8	1.3	4	40	0	-
Sodium	µg/g	1	1	5	119	133	150	0	0	0	-
Thallium	µg/g	0.3	0.5	10	<0.3	-	0.4	9	90	0	-
Vanadium	µg/g	0.2	1	10	33	36.7	46.5	0	0	0	-
Zinc	µg/g	0.5	10	10	65	99.5	**157**	0	0	2	123

Source: Canadian Environmental Quality Guidelines (CCME 1999 with updates to 2010). Winnipeg, MB.

Note: **Bolded** numbers indicate where a guideline is exceeded.

ISQG = Interim Sediment Quality Guidelines; CCME = Canadian Council of Ministers of the Environment; min = minimum; med = median; max = maximum; % = percent; µg/g = micrograms per gram (dry weight basis); - = not applicable.

8.3.6.2.2 Lakes in the Kennady Lake Watershed

Physical Limnology and Vertical Structure

Vertical profile data for physical parameters, such as temperature and DO, were collected during July and August 2002, 2004, 2007, and 2010 for lakes in the A, B, D, E, F, G, and I watersheds. In-situ measurements were not measured for lakes in the Kennady Lake watershed during under-ice conditions.

Temperature profiles measured during open water conditions in the deeper small lakes, Lakes A1, A3, I1 and J1b, had similar temperature ranges in open water conditions as the areas of Kennady Lake. The small lakes had near-surface temperatures ranging from 11°C to 18°C and were generally well-mixed (Figure 8.3-17a). A thermocline was observed in a water column profile measurement in Lake A3; the thermocline was located between approximately 10 or 12 m, where the temperature decreased from 12°C to 8°C.

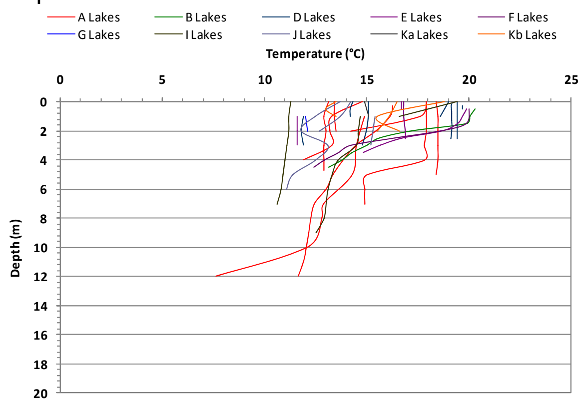
Measured conductivity during open water conditions was very low, ranging between 5 and 26 μS/cm (Figure 8.3-17b). There was very little variability throughout the water column indicating that TDS were equally distributed throughout the lakes, i.e., the small lakes were well mixed during open water conditions.

Vertical profiles of DO and conductivity had only slight variability between surface and near bottom of the small lakes, indicating that the lakes were well mixed (Figure 8.3-17c). Concentrations of DO were higher than the minimum CWQG values during most measurements, with the exception of one profile collected for Lake A3 in July 2007. Dissolved oxygen concentrations of less than 1 mg/L where measured at the near bottom depths (i.e., 6 and 7 m, respectively).

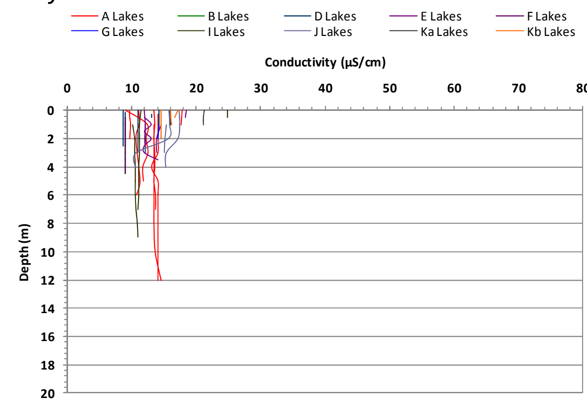
Surface pH readings for the lakes in the Kennady Lake watershed varied between 5.8 and 9.4 pH units (Figure 8.3-17d), ranging from slightly acidic to slightly alkaline. Many pH measurements were below the acceptable range of the CWQG and CDWQG during early spring, whereas measurements were above this range during certain summer observations.

Figure 8.3-17 Physico-chemical Water Quality Profile Data for Lakes in the Kennady Lake Watershed (2002 to 2010)

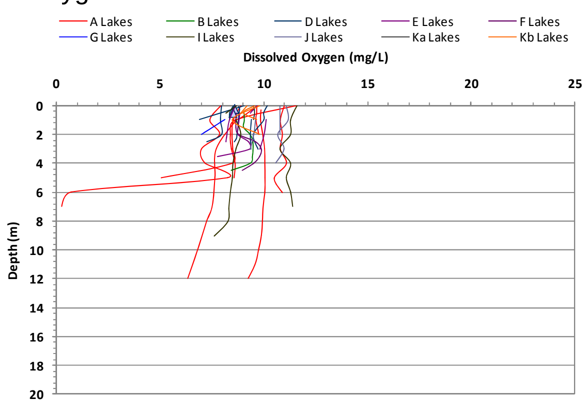
a.) Water Temperature



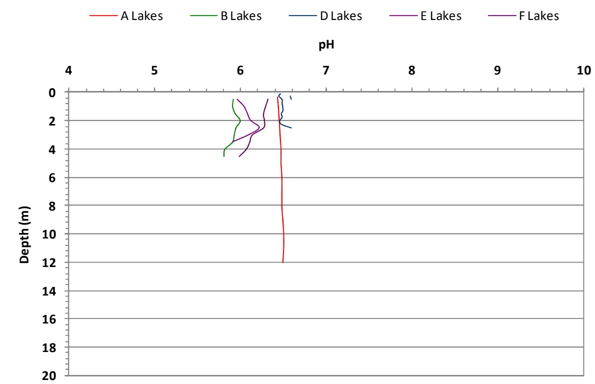
b.) Conductivity



c.) Dissolved Oxygen



d.) pH



m = metre, °C = degrees Celsius, µS/cm = microSiemens per Centimetre, mg/L = milligrams per litre.

Individual field results not presented in field profile figures.

Water Quality

Since the small lakes in the Kennady Lake watershed contribute to the loading of substances into the individual areas of Kennady Lake, the water quality similarities and differences are discussed for all surveyed lakes. The available data for all lakes in the Kennady Lake watershed are presented in Table 8.3-23. Lake E2 had a different chemistry than the other lakes in the Kennady Lake watershed and the data for this lake are presented separately in Table 8.3-23.

Hardness and alkalinity were low in most of the small lakes (Table 8.3-23), with several measurements below the detection limit. There was very little difference in concentrations among the lakes, with marginally higher concentrations of both parameters measured in Lake E2. These hardness and alkalinity results indicate that water in most of the lakes in the Kennady Lake watershed is soft and has a low buffering capacity.

Concentrations of TDS were generally low (Table 8.3-23); however, there was some variability in the amount of dissolved substances found in the different lakes, ranging from less than 5 to 64 mg/L. Lake E2 had higher TDS concentrations than most other lakes (minimum of 55 mg/L). Bicarbonate was the dominant anion in most lakes, and sulphate was below 4.2 mg/L in all lakes surveyed. Sodium was the major cation measured in most lakes, with the highest concentrations measured in Lake E2.

The TSS concentrations were generally measured slightly above the detection limit or were not detected (Table 8.3-23). The highest TSS concentrations were measured in Lake E2. The lakes in the Kennady Lake watersheds were very clear and contained low concentrations of suspended particulate matter.

The concentration of dissolved inorganic nitrogen fractions, such as ammonia nitrate, and nitrite were below the detection limit (Table 8.3-23). TKN was measured at low concentrations, with highest concentrations reported in Lake E2. Total phosphorus was not detected in over half the measurements. The measured concentrations of nutrients indicate that the lakes in the Kennady Lake watershed have an oligotrophic status, are phosphorus-limited, and are indicative of low biological productivity.

Table 8.3-23 Water Quality Summary for Lakes in the Kennady Lake Watershed, 1995 to 2010

Parameter Name	Unit	Method Detection Limit			Lakes in the Kennady Lake Watershed Excluding Lake E2 and Kennady Lake (1995 - 2010)						Lake E2 (2004)						Guidelines Exceedances for All Results within the Kennady Lake Basin including Lake E2			
																	Aquatic Life - Chronic [(a)]		Human Health - Chronic [(b)]	
		Min	Max	Number of Method Detection Limits	n	Min	Med	Max	Count Below Detection	% Below Detection	n	Min	Med	Max	Count Below Detection	% Below Detection	Value	Guideline Exceedance Count	Value	Guideline Exceedance Count
Field measured																				
pH	NA	-	-	-	97	**5.5**[(c)]	6.5	**9.4**[(c, d)]	0	0	4	**6.2**[(c)]	6.6	6.9	0	0	6.5 - 8.5	59	5.0 - 9.0	4
Temperature	°C	-	-	-	176	4.8	13	20	0	0	4	10	15	22	0	0	-	0	-	0
Specific Conductance	µS/cm	-	-	-	174	4.3	12	26	0	0	4	<1	36	48	0	0	-	0	-	0
Dissolved Oxygen	mg/L	-	-	-	174	4.5[(c)]	9.6	13	0	0	4	8.2	9.3	13	0	0	6.5	3	-	0
Conventional Parameters[(e)]																				
Colour	TCU	-	-	0	23	5	20	85	0	0	2	125	-	175	0	0	-	0	-	0
Specific Conductance	µS/cm	-	-	0	36	9	16	31	0	0	3	37	40	44	0	0	-	0	-	0
Dissolved Organic Carbon	mg/L	-	-	0	29	3.3	6	20	0	0	2	20	-	36	0	0	-	0	-	0
Hardness	mg/L	6	-	1	39	3.8	6	9.7	23	59	3	9.1	12	14	0	0	-	0	-	0
pH	NA	-	-	0	36	5.3[(c)]	6.6	7.2	0	0	3	**6.4**[(c)]	6.9	7.2	0	0	6.5 - 8.5	13	5.0 - 9.0	0
Total Alkalinity	mg/L	1	5	2	45	0.5	10	35	7	15.6	3	2.5	13	14	1	33.3	-	0	-	0
Total Dissolved Solids	mg/L	10	20	2	39	5	19	64	10	25.6	2	57	-	84	0	0	-	0	-	0
Total Organic Carbon	mg/L	-	-	0	29	3	5.8	19	0	0	2	19	-	30	0	0	-	0	-	0
Total Suspended Solids	mg/L	1	2	2	29	1	2	5	19	65.5	2	3	-	55	0	0	-	0	-	0
Major Ions																				
Bicarbonate	mg/L	1	5	2	44	0.5	12	43	4	9.1	3	6	15	17	0	0	-	0	-	0
Calcium	mg/L	-	-	0	36	0.66	0.98	2.3	0	0	3	2.7	3.3	4.3	0	0	-	0	-	0
Carbonate	mg/L	0.5	5	3	44	<0.5	-	<5	44	100	3	<1	-	<5	3	100	-	0	-	0
Chloride	mg/L	0.1	1	3	45	0.1	0.2	1	23	51.1	3	0.4	0.5	1	0	0	230	0	-	0
Magnesium	mg/L	0.5	0.5	1	36	0.25	0.44	1.1	3	8.3	3	1.2	1.5	2.2	0	0	-	0	-	0
Potassium	mg/L	0.5	0.5	1	36	0.24	0.42	0.83	3	8.3	3	0.77	1.2	1.2	0	0	-	0	-	0
Sodium	mg/L	1	1	1	36	0.39	1	3.9	3	8.3	3	2.7	3	4.4	0	0	-	0	-	0
Sulphate	mg/L	0.5	1	2	45	0.00029	0.9	2	15	33.3	3	0.0057	2.6	4.2	0	0	-	0	-	0
Sulphide	µg/L	2	-	1	6	2	-	2	4	66.7	0	-	-	-	0		2.4	0	-	0
Nutrients																				
Nitrate + Nitrite	mg-N/L	0.003	0.006	2	12	<0.003	-	0.022	11	91.7	1	-	<0.006	-	1	100	2.93	0	10	0
Nitrogen - Ammonia	mg-N/L	0.05	0.1	2	39	<0.05	-	0.01	38	97.4	2	<0.1	-	<0.1	2	100	21	0	-	0
Nitrogen - Kjeldahl	mg-N/L	0.2	-	1	20	0.2	0.3	1.1	9	45	2	1.1	-	2.7	0	0	-	0	-	0
Phosphorus, total	µg/L	20	300	4	39	<20	-	**100**[(c)]	30	76.9	2	37	-	**83**[(c)]	0	0	50	3	-	0
Phosphorus, dissolved	mg/L	0.005	0.3	2	30	<0.005	-	0.016	23	76.7	2	-	0.006	-	1	50	-	0	-	0
General Organics																				
Total Phenolics	µg/L	2	-	1	6	<2	-	2	5	83.3	0	-	-	-	0		5	0	-	0
Total Recoverable Hydrocarbons	mg/L	0.1	2	2	29	<0.1	-	208	20	69	2	-	0.2	-	1	50	-	0	-	0
Total Metals[(e)]																				
Aluminum	µg/L	20	20	1	45	10	51	**240**[(c, d)]	16	35.6	3	**207**[(c, d)]	459	**1130**[(c, d)]	0	0	100	8	100	8
Antimony	µg/L	0.02	1	5	45	<0.02	-	2.1	37	82.2	3	-	0.5	-	2	66.7	-	0	5.5	0
Arsenic	µg/L	0.4	1	2	45	<0.4	-	0.5	33	73.3	3	0.7	0.9	1.1	0	0	5	0	10	0

Table 8.3-23 Water Quality Summary for Lakes in the Kennady Lake Watershed, 1995 to 2010 (continued)

Parameter Name	Unit	Method Detection Limit			Lakes in the Kennady Lake Watershed Excluding Lake E2 and Kennady Lake (1995 - 2010)						Lake E2 (2004)						Guidelines Exceedances for All Results within the Kennady Lake Basin including Lake E2			
																	Aquatic Life - Chronic [a]		Human Health - Chronic [b]	
		Min	Max	Number of Method Detection Limits	n	Min	Med	Max	Count Below Detection	% Below Detection	n	Min	Med	Max	Count Below Detection	% Below Detection	Value	Guideline Exceedance Count	Value	Guideline Exceedance Count
Barium	µg/L	5	-	1	45	1.7	3.3	7.4	23	51.1	3	9	13	22	0	0	-	0	1000	0
Beryllium	µg/L	0.01	1	4	45	<0.01	-	<1	45	100	3	<0.5	-	<1	3	100	-	0	4	0
Boron	µg/L	8	20	3	45	<8	-	2	42	93.3	3	<10	-	<20	3	100	-	0	5000	0
Cadmium	µg/L	0.002	0.2	4	45	<0.002	-	**0.008**[c]	40	88.9	3	<0.2	-	<0.2	3	100	0.0031	2	5	0
Calcium	µg/L	1000	-	1	41	580	1130	2,240	14	34.1	2	3,300	-	3,500	0	0	-	0	-	0
Chromium	µg/L	0.1	5	5	45	<0.1	-	4[c]	39	86.7	3	0.45	1.7	**2.7**[c]	1	33.3	1	6	50	0
Cobalt	µg/L	0.1	0.5	2	45	0.02	0.1	0.7	28	62.2	3	0.8	1	2	0	0	-	0	-	0
Copper	µg/L	1	5	2	45	0.56	1.1	**12**[c]	29	64.4	3	**5**[c]	5	**12**[c]	0	0	2	8	1300	0
Iron	µg/L	50	-	1	41	17	132	**540**[c, d]	3	7.3	2	**626**[c, d]	-	**1,280**[c, d]	0	0	300	7	300	7
Lead	µg/L	0.05	0.5	3	45	<0.05	-	0.4	36	80	3	0.05	0.1	0.8	1	33.3	1	0	10	0
Lithium	µg/L	1	20	2	16	0.6	0.95	1.4	10	62.5	0	-	-	-	0	-	-	0	-	0
Magnesium	µg/L	500	-	1	41	310	560	6,200	16	39	2	1420	-	2,280	0	0	-	0	-	0
Manganese	µg/L	-	-	0	41	1.1	3.3	16	0	0	2	18	-	20	0	0	-	0	50	0
Mercury	µg/L	0.0006	500	7	41	<0.0006	-	0.01	36	87.8	2	<1	-	<500	2	100	0.026	0	1	0
Molybdenum	µg/L	0.05	5	4	45	<0.05	-	0.3	38	84.4	3	0.25	0.5	0.9	1	33.3	73	0	-	0
Nickel	µg/L	0.6	8	2	45	0.22	0.85	13	19	42.2	3	1.4	5.2	5.5	0	0	25	0	340	0
Potassium	µg/L	500	500	1	41	250	490	850	20	48.8	2	830	-	1310	0	0	-	0	-	0
Selenium	µg/L	0.04	10	6	45	<0.04	-	<10	45	100	3	<0.4	-	<10	3	100	1	0	10	0
Silver	µg/L	0.01	0.4	4	45	<0.01	-	**0.5**[c]	38	84.4	3	<0.2	-	<0.4	3	100	0.1	1	-	0
Sodium	µg/L	500	2000	2	41	390	568	1,190	23	56.1	2	-	2,100	-	1	50	-	0	-	0
Strontium	µg/L	-	-	0	22	4.2	7.2	14	0	0	1	-	26	-	0	0	-	0	-	0
Sulphur	µg/L	10,000	-	1	15	300	500	800	6	40	0	-	-	-	0	-	-	0	-	0
Thallium	µg/L	0.002	0.1	3	43	<0.002	-	0.003	40	93	3	<0.05	-	<0.1	3	100	0.8	0	0.13	0
Titanium	µg/L	0.5	10	4	20	<0.5	-	4	15	75	1	-	44	-	0	0	-	0	-	0
Uranium	µg/L	0.05	0.1	2	45	<0.05	-	0.024	38	84.4	3	0.09	0.1	0.3	0	0	-	0	-	0
Vanadium	µg/L	0.1	5	4	45	0.08	0.27	0.4	28	62.2	3	1.4	2.5	5.6	0	0	-	0	-	0
Zinc	µg/L	2	4	2	45	0.9	7	**55**[c]	16	35.6	3	13	15	15	0	0	30	4	5100	0
Dissolved Metals																				
Aluminum	µg/L	10	-	1	30	5	23	125	4	13.3	2	134	-	165	0	0	-	0	-	0
Antimony	µg/L	0.02	0.1	3	30	<0.02	-	0.04	25	83.3	2	<0.1	-	<0.1	2	100	-	0	-	0
Arsenic	µg/L	0.1	-	1	30	0.05	0.12	0.5	10	33.3	2	-	0.9	-	1	50	-	0	-	0
Barium	µg/L	3	-	1	30	1.6	3	4	18	60	2	8	-	8	0	0	-	0	-	0
Beryllium	µg/L	0.01	0.5	3	30	<0.01	-	0.1	29	96.7	2	<0.1	-	<0.1	2	100	-	0	-	0
Boron	µg/L	4	20	2	30	<4	-	2	29	96.7	2	<4	-	<4	2	100	-	0	-	0
Cadmium	µg/L	0.005	0.05	2	30	<0.005	-	0.12	27	90	2	<0.05	-	<0.05	2	100	-	0	-	0
Chromium	µg/L	0.1	0.5	3	30	<0.1	-	0.7	27	90	2	1	-	1.7	0	0	-	0	-	0
Cobalt	µg/L	0.05	-	1	30	0.025	0.085	1.5	9	30	2	0.3	-	0.63	0	0	-	0	-	0
Copper	µg/L	1	2	2	30	<1	-	1.2	23	76.7	2	4	-	4	0	0	-	0	-	0
Iron	µg/L	20	-	1	30	3	67	280	4	13.3	2	405	-	437	0	0	-	0	-	0

Table 8.3-23 Water Quality Summary for Lakes in the Kennady Lake Watershed, 1995 to 2010 (continued)

Parameter Name	Unit	Method Detection Limit			Lakes in the Kennady Lake Watershed Excluding Lake E2 and Kennady Lake (1995 - 2010)						Lake E2 (2004)						Guidelines Exceedances for All Results within the Kennady Lake Basin including Lake E2			
																	Aquatic Life - Chronic [a]		Human Health - Chronic [b]	
		Min	Max	Number of Method Detection Limits	n	Min	Med	Max	Count Below Detection	% Below Detection	n	Min	Med	Max	Count Below Detection	% Below Detection	Value	Guideline Exceedance Count	Value	Guideline Exceedance Count
Lead	µg/L	0.05	-	1	30	<0.05	-	0.09	23	76.7	2	<0.05	-	<0.05	2	100	-	0	-	0
Lithium	µg/L	1	-	1	7	0.5	1	1.3	1	14.3	0	-	-	-	0	-	-	0	-	0
Manganese	µg/L	-	-	0	30	0.9	3	14	0	0	2	4.8	-	12	0	0	-	0	-	0
Mercury	µg/L	0.01	1	3	30	<0.01	-	0.009	24	80	2	<1	-	<1	2	100	-	0	-	0
Molybdenum	µg/L	0.05	0.3	2	30	<0.05	-	0.14	28	93.3	2	0.5	-	0.6	0	0	-	0	-	0
Nickel	µg/L	-	-	0	30	0.2	0.4	2	0	0	2	1.9	-	2.5	0	0	-	0	-	0
Selenium	µg/L	0.04	2	4	30	<0.04	-	<2	30	100	2	<2	-	<2	2	100	-	0	-	0
Silver	µg/L	0.005	0.1	3	30	<0.005	-	<0.1	30	100	2	<0.05	-	<0.05	2	100	-	0	-	0
Strontium	µg/L	-	-	0	7	4	5.7	7.4	0	0	0	-	-	-	0	-	-	0	-	0
Sulphur	µg/L	10,000	10,000	1	6	<10,000	-	<10,000	6	100	0	-	-	-	0	-	-	0	-	0
Thallium	µg/L	0.002	0.05	3	30	<0.002	-	0.15	23	76.7	2	-	0.08	-	1	50	-	0	-	0
Titanium	µg/L	0.5	10	2	7	<0.5	-	<10	7	100	0	-	-	-	0	-	-	0	-	0
Uranium	µg/L	0.01	0.05	2	30	<0.01	-	0.023	24	80	2	0.08	-	0.08	0	0	-	0	-	0
Vanadium	µg/L	0.2	1	3	30	<0.2	-	<1	30	100	1	-	1.1	-	0	0	-	0	-	0
Zinc	µg/L	2	2	1	30	0.5	2	12	8	26.7	1	-	2	-	0	0	-	0	-	0

Note: Presented guidelines were calculated using median values for data when applicable.
Individual guidelines were calculated for each sample, to determine the number of results above guidelines when applicable.
Bold values indicate a guideline exceedance.

(a) Canadian Environmental Quality Guidelines (CCME 1999 with updates to 2010). Winnipeg, MB.

(b) The human health guideline is based on the CCME drinking water guideline, Health Canada (2008).

(c) Concentration higher than the relevant chronic aquatic life guideline or beyond the recommended pH or DO concentration range.

(d) Concentration higher than the relevant human health guideline or beyond the recommended pH range.

(e) Some maximum dissolved parameter concentrations are higher than the maximum total parameter concentrations in the statistical summary.

NA = not applicable, "-" = not available; °C = degrees Celsius, µS/cm = microSiemens per centimetre, mg/L = milligrams per litre, mV = millivolts, mg-N/L = milligrams nitrogen per litre, µg/L = micrograms per litre, TCU = True colour units; % = percent, n = number of samples, < = less than; min = minimum; med = median; max = maximum.

Measured concentrations of TOC and DOC were under 20 mg/L in all lakes, with the exception of Lake E2 (Table 8.3-23). The TOC and DOC measured in Lake E2 varied between 19 and 36 mg/L. The water colour often exceeded the CDWQG guideline (median of 23 TCU), with readings from Lake E2 being much higher than in other lakes (ranging from 125 to 175 TCU). Total recoverable hydrocarbons, and total phenolics were generally not detected (Table 8.3-23); however, a total phenolic concentration of 208 mg/L was detected in one sample. The elevated concentrations of these parameters were not observed during other sampling events and may be attributed to a natural increase in hydrocarbons from the decay of vegetation borne through runoff.

The concentrations of many metals were low, with several metals measured near or below the detection limit (Table 8.3-23). There was little variability in metals concentrations measured between lakes. For metals reported above the detection limit, Lake E2 tended to have higher concentrations than other lakes in the Kennady Lake watershed. Exceedances of applicable guidelines were observed for total aluminum, chromium, copper, iron, selenium, and zinc.

Sediment Quality

Baseline sediment sampling was not conducted for the small lakes in the Kennady Lake watershed, and historical data were not available. The composition of the sediment in these lakes is undetermined.

8.3.7 Lower Trophic Levels

The following section describes the baseline information for the lower trophic level communities (e.g., plankton, benthic invertebrate communities) for the proposed Project. For additional information regarding lower trophic levels, the reader is referred to the limnology and lower trophic level sections of Annex J (Fisheries and Aquatic Resources Baseline) and Addendum JJ.

8.3.7.1 Methods

Lower trophic level studies in Kennady Lake and its watershed were initiated in 1996 and continued through 2007. Data were collected for the following lower trophic communities and supporting variables:

- Phytoplankton and zooplankton communities were sampled in Kennady Lake.
- Zooplankton communities were sampled in 14 small lakes within the Kennady Lake watershed.
- Benthic invertebrate communities were sampled in Kennady Lake.

- Sediment samples were collected from Kennady Lake for toxicity analysis.

8.3.7.2 Results

8.3.7.2.1 Plankton Communities

Phytoplankton and Chlorophyll *a*

Total phytoplankton biomass was considerably lower in 2004 than in 2007 (Figure 8.3-18). There was no consistent spatial pattern in phytoplankton biomass among areas sampled in Kennady Lake.

Phytoplankton communities in Kennady Lake consist of representatives of six major taxonomic groups: cyanobacteria (blue-green algae); Chlorophyta (green algae); Chrysophyta (golden algae); Cryptophyta (biflagellates with chloroplasts); Bacillariophyceae (diatoms); and Pyrrophyta (dinoflagellates). Phytoplankton community composition based on abundance was similar among the five basins within Kennady Lake, but differed between the two years with available data (Figure 8.3-19). Cyanobacteria and Chlorophyta were the dominant taxonomic groups in 2004, whereas cyanobacteria and Chrysophyta were dominant in 2007. Although cyanobacteria were consistently the most abundant taxonomic group in all areas of Kennady Lake in 2004, this group accounted for only a small proportion of the total phytoplankton biomass (Figure 8.3-20). In contrast, cyanobacteria accounted for 20 to 60% of total phytoplankton biomass in 2007. Chrysophyta typically dominated the phytoplankton community biomass in Areas 3 to 7 in 2004 and Area 8 in 2007, which is indicative of oligo- to oligomesotrophic conditions.

There was little variation in chlorophyll *a* concentration among areas in Kennady Lake, in both 2004 and 2007. Most concentrations were approximately 1 µg/L, within a range characteristic of oligotrophic lakes. Concentrations were consistent with those in lakes of similar trophic status in the Slave Geological Province, with lakes between southern Yukon Territory and the Tuktoyaktuk Peninsula, NWT, and with lakes between Yellowknife and Contwoyto Lake, NWT (Pienitz et al. 1997a, 1997b).

Zooplankton

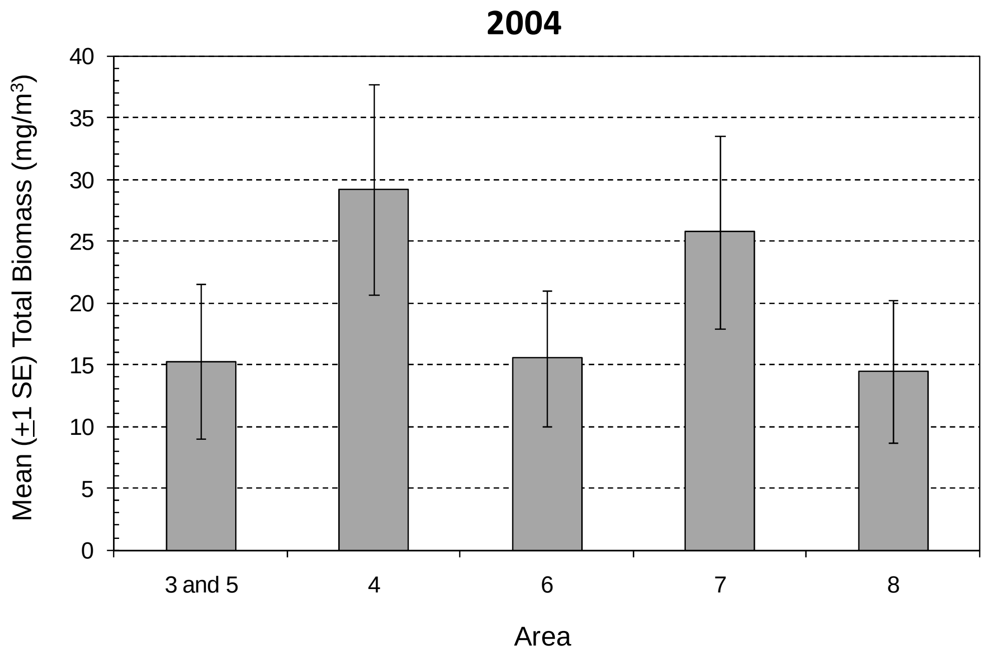
Total zooplankton biomass was highly variable between 2004 and 2007, with an up to ten-fold range between years in Area 4 (Figure 8.3-21). There was no consistent spatial pattern in zooplankton biomass among areas sampled in Kennady Lake.

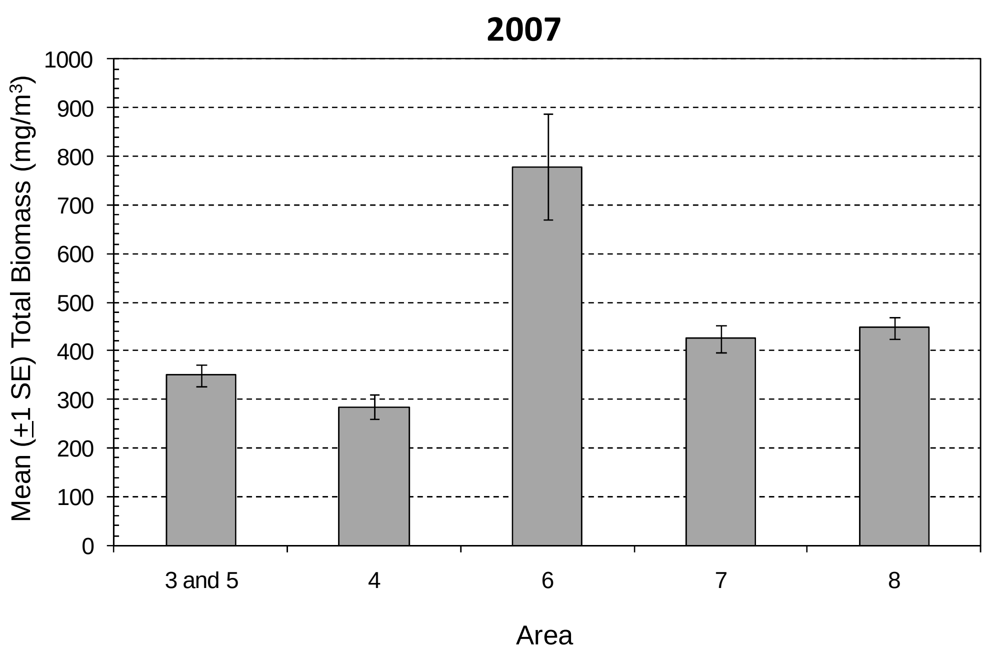
The zooplankton community of Kennady Lake consisted of representatives of four major taxonomic groups: Rotifera, Cladocera, Calanoida (calanoid copepods), and Cyclopoida (cyclopoid copepods).

Zooplankton community composition based on abundance was similar in the five areas within Kennady Lake in 2004. However, the relative abundance of copepod nauplii was slightly higher in Area 8 (Figure 8.3-22). In 2007, the Area 8 community was more strongly dominated by Rotifera compared to other areas; copepod nauplii were not enumerated in 2007 samples. Community composition based on biomass was more variable among areas in 2004, with Cladocera accounting for a lower proportion and calanoids accounting for a greater proportion of total community biomass in Area 4 compared to the other four areas sampled (Figure 8.3-23). In 2007, calanoid copepods were more strongly dominant in areas 6 and 8 compared to other areas.

Zooplankton abundance was also determined during previous small lake surveys. In August 2002 and August 2003, copepods were the most abundant zooplankton in all small lakes sampled (Jacques Whitford 2003a, 2004), consistent with the 2007 results for Kennady Lake. The combined abundance of calanoid and cyclopoid copepods ranged from 1,400 to over 18,000 individuals per cubic metre (ind/m^3) (Table 8.3-24). Cladocerans were occasionally absent from zooplankton samples from these lakes, and had more variable densities among lakes compared to copepods. They were abundant in some of small lakes sampled, with densities as high as 3,600 ind/m^3.

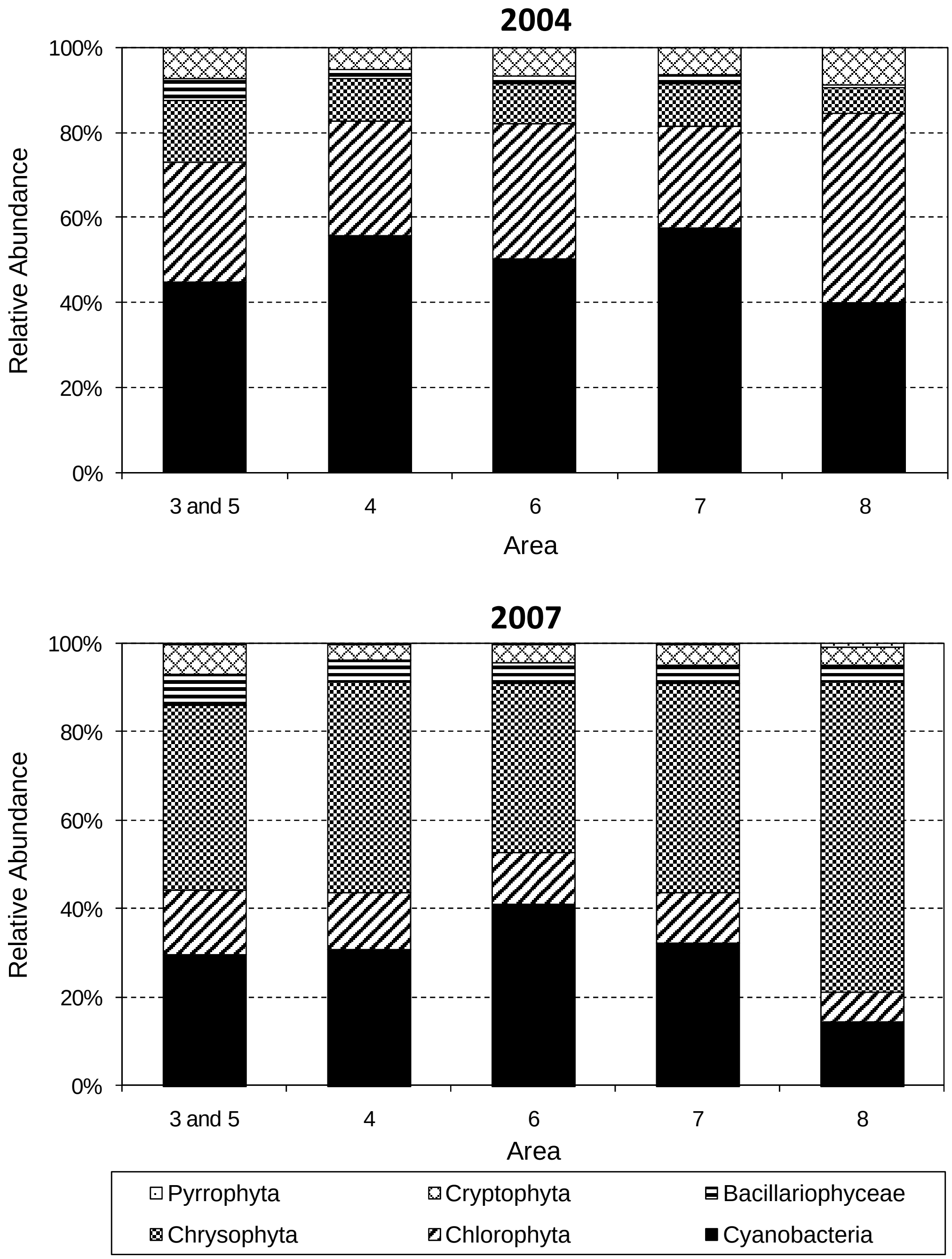
Figure 8.3-18 Total Phytoplankton Biomass in Kennady Lake, August 2004 and August 2007





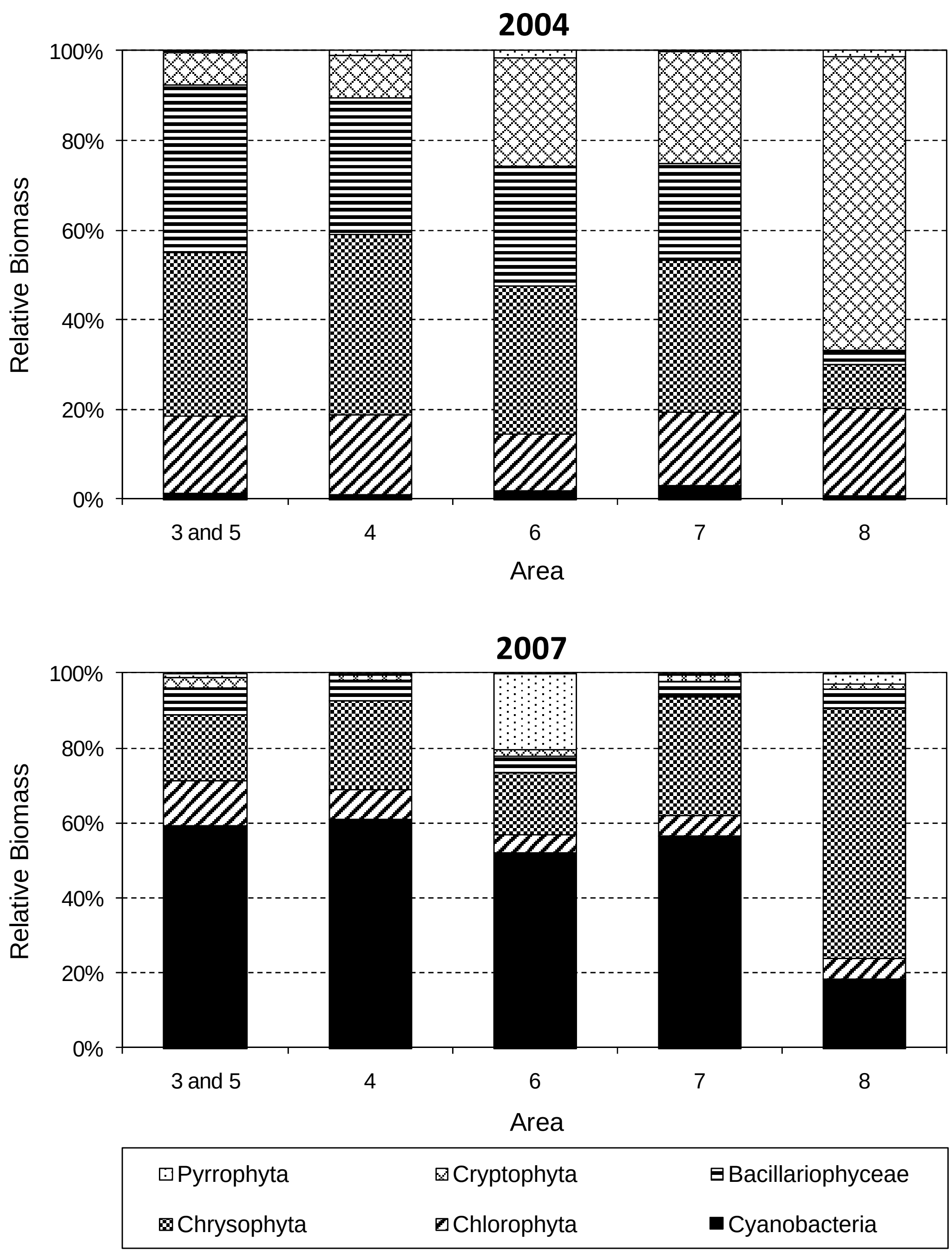
± = plus or minus; SE = standard error; mg/m^3 = milligrams per cubic metre.

Figure 8.3-19 Relative Abundances of Major Phytoplankton Taxa in Kennady Lake, August 2004 and August 2007



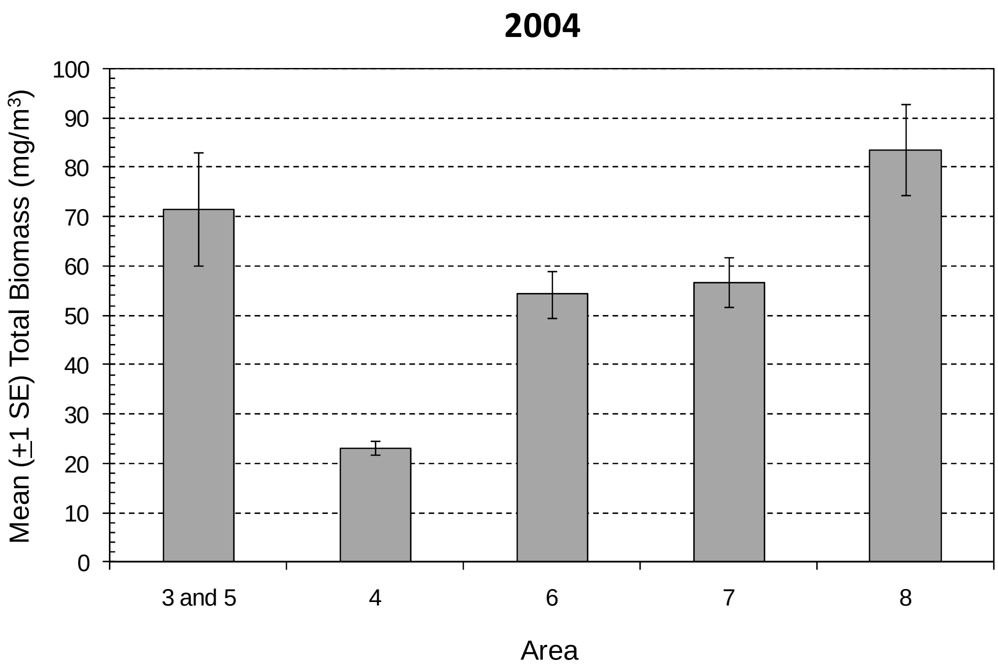
% = percent.

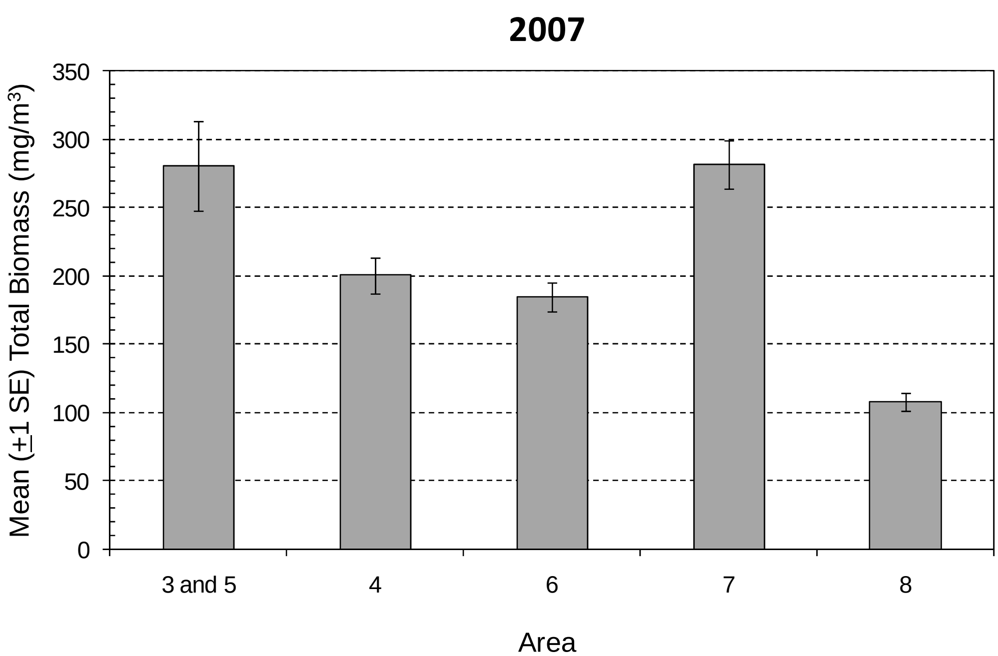
Figure 8.3-20 Relative Biomass of Major Phytoplankton Taxa in Kennady Lake, August 2004 and August 2007



% = percent.

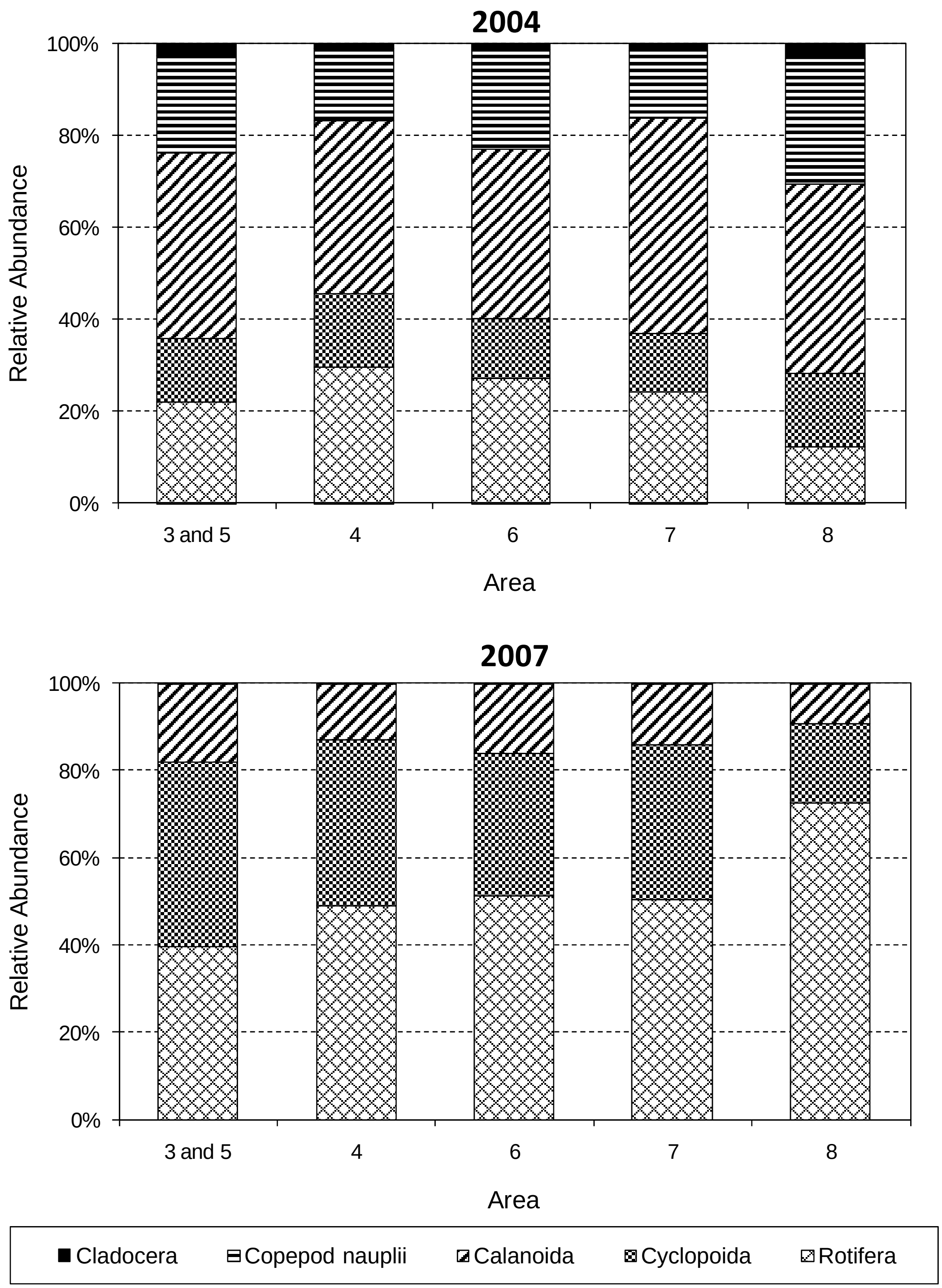
Figure 8.3-21 Total Zooplankton Biomass in Kennady Lake, August 2004 and August 2007





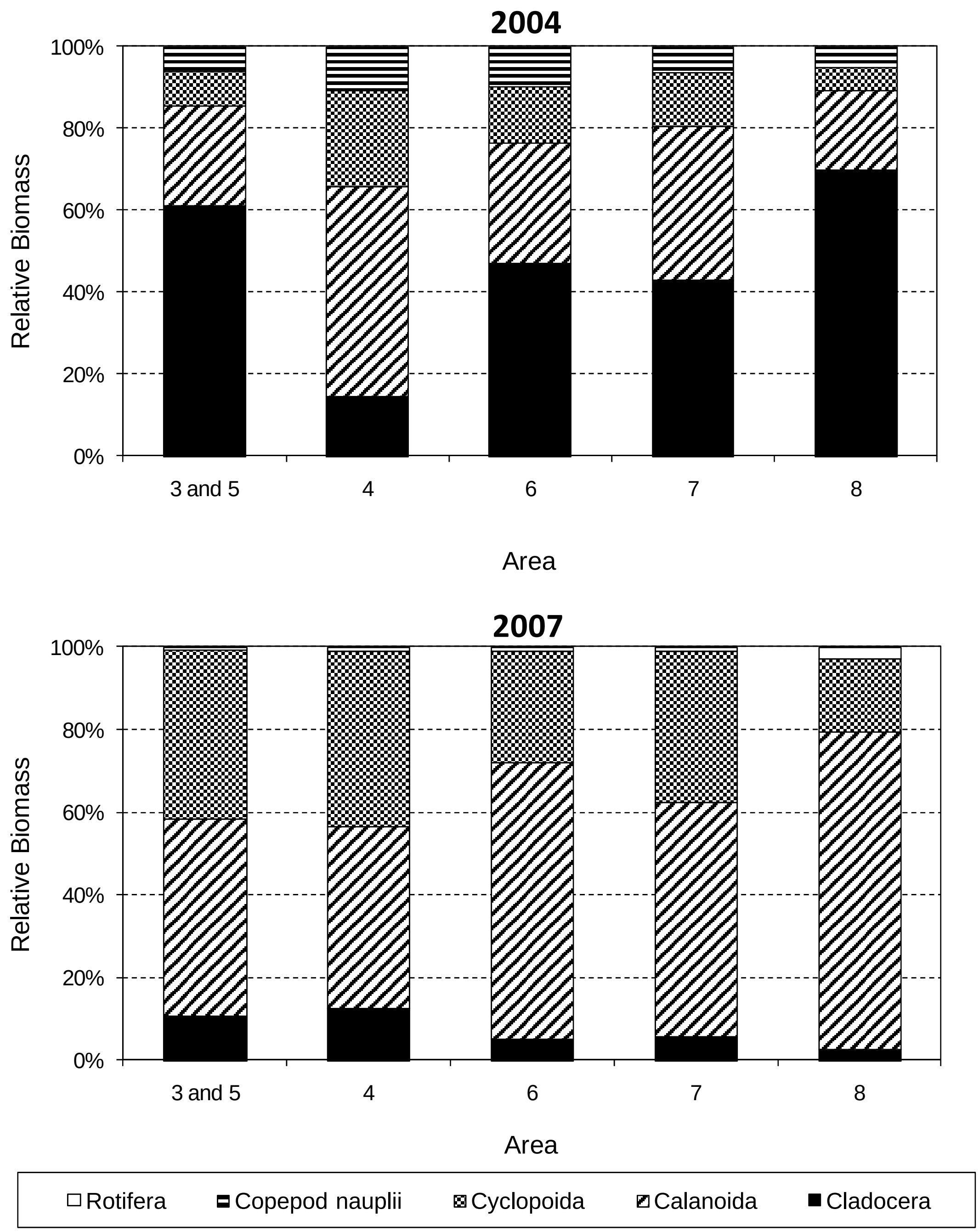
± = plus or minus; SE = standard error; mg/m^3 = milligrams per cubic metre.

Figure 8.3-22 Relative Abundances of Major Zooplankton Taxa in Kennady Lake, August 2004 and August 2007



% = percent.

Figure 8.3-23 Relative Biomass of Major Zooplankton Taxa in Kennady Lake, August 2004 and August 2007



% = percent.

Table 8.3-24 Zooplankton Abundance in Small Lakes in the Kennady Lake Watershed, August 2002 and August 2003

Lake	Copepoda			Cladocera (ind/m^3)
	Calanoida (ind/m^3)	Cyclopoida (ind/m^3)	Total Copepoda (ind/m^3)	
A1	4,205	1,113	5,318	1,268
A2	3,977	490	4,467	61
A9	4,873	4,268	9,141	3,631
D1	5,733	5,574	11,307	597
E3	13,103	364	13,467	2,548
I1	9,595	8,983	18,578	832
I2	857	551	1,408	0
J1a	3,182	61	3,243	245
J1b	5,650	61	5,711	1,632
J2	6,608	245	6,853	0
Ka1	8,174	318	8,492	425
Kb2	2,907	7,277	10,184	66
Kb3	918	734	1,652	61
Kb4	5,803	389	6,192	0

ind/m^3 = individuals per cubic metre.

8.3.7.2.2 Benthic Invertebrate Community

Benthic invertebrate densities in Kennady Lake were generally low in August and September, 2004 (Figures 8.3-24 and 8.3-25). Shallow littoral areas supported a denser benthic invertebrate community than deeper mid-lake areas. The shallow sites (4 to 6 m depth) sampled also had more diverse communities than the deep sites (8 to 18 m depth), as indicated by higher richness values at shallow sites. Dominant invertebrates in Kennady Lake included roundworms (*Nematoda*), aquatic worms (*Oligochaeta*), fingernail clams (Pelecypoda), and midges (*Chironomidae*). Compared to deep sites, relative abundances of midges were higher and relative abundances of roundworms and fingernail clams were lower at shallow sites. Part of the differences observed in benthic community characteristics between shallow and deep sites in 2004 may have been caused by the different sampling times at shallow (mid-September) and deep (early August) sites.

Benthic invertebrate densities in Kennady Lake also were low in fall (late August/early September) 2007 in shallow areas (3 to 6 m) (Figure 8.3-26). Exceptions included sites 4 and 5 in Area 8, where densities were moderate. Richness was similar to the range reported for shallow sites in September 2004. The dominant taxa in 2007 also were similar to those at shallow sites in 2004, with midges, nematodes, fingernail clams and aquatic worms being the more abundant taxa.

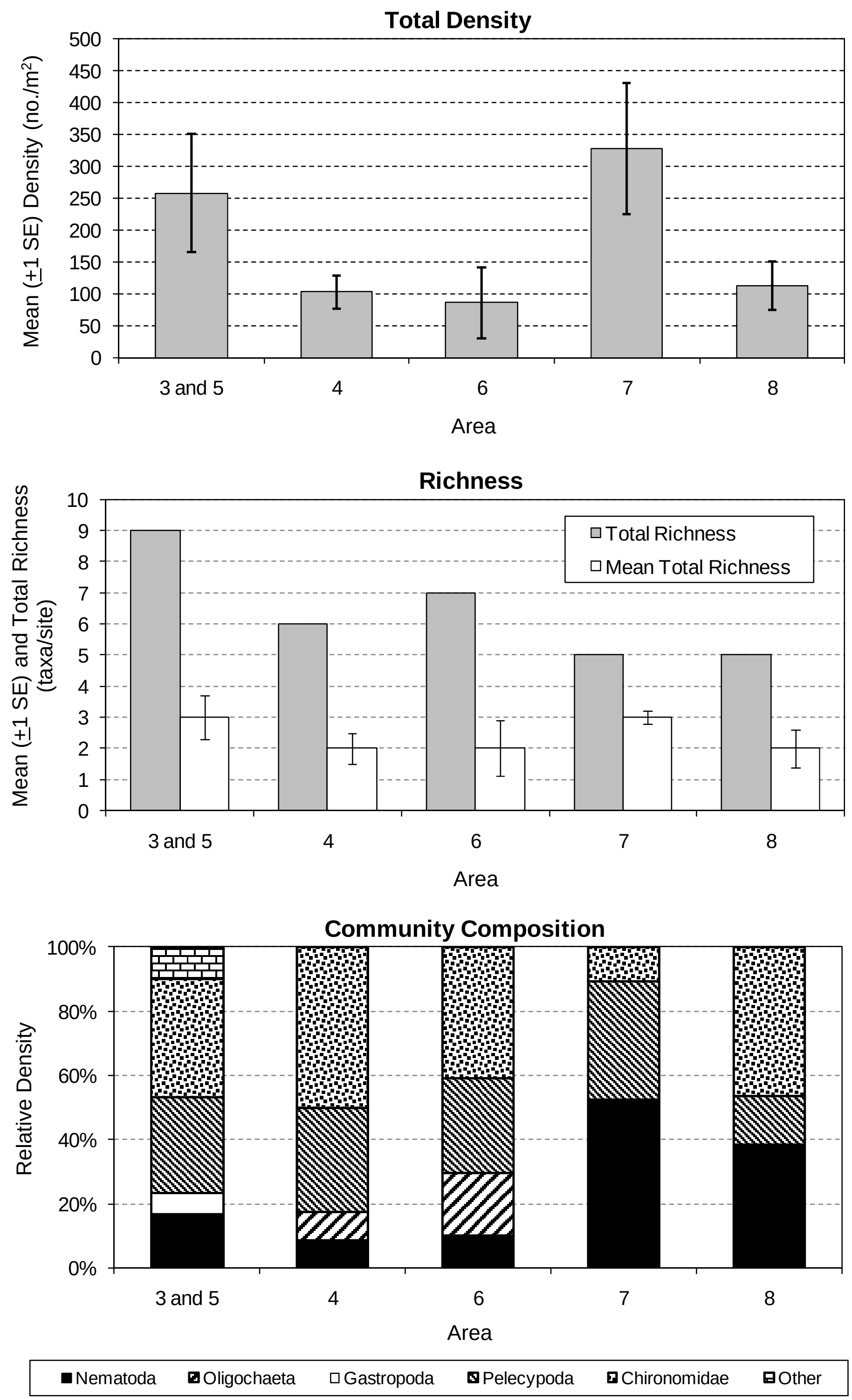
In 2007, the east section of Kennady Lake (Area 8) had the highest mean density and richness (Figure 8.3-26), potentially indicating greater benthic invertebrate productivity due to better quality habitat. Relative to other portions of Kennady Lake, the east section of Area 8 tended to have shallower waters, more abundant fine sediments at depths greater than 2 m, and higher amounts of aquatic vegetation.

Both total density and richness of Kennady Lake benthic communities were lowest in 2004 (Table 8.3-25). Among-year differences in richness and density may partly reflect varying water depth at sampling locations, mesh size differences of the sampling equipment used in different years, and varying levels of identification of invertebrates in some of the major groups. Sample collections were made with a smaller mesh size in 1996 relative to that used in subsequent years. Aquatic worms and water mites were identified to lower levels in 1996 and 2001 than in 2004.

Although some year-to-year differences were apparent in both density and richness of the benthic community in Kennady Lake, available density data indicate that Kennady Lake communities are typically characterized by generally low density (Table 8.3-25). Benthic invertebrate communities from the four studies were similar in terms of richness, with values in the range characteristic of low to moderate richness.

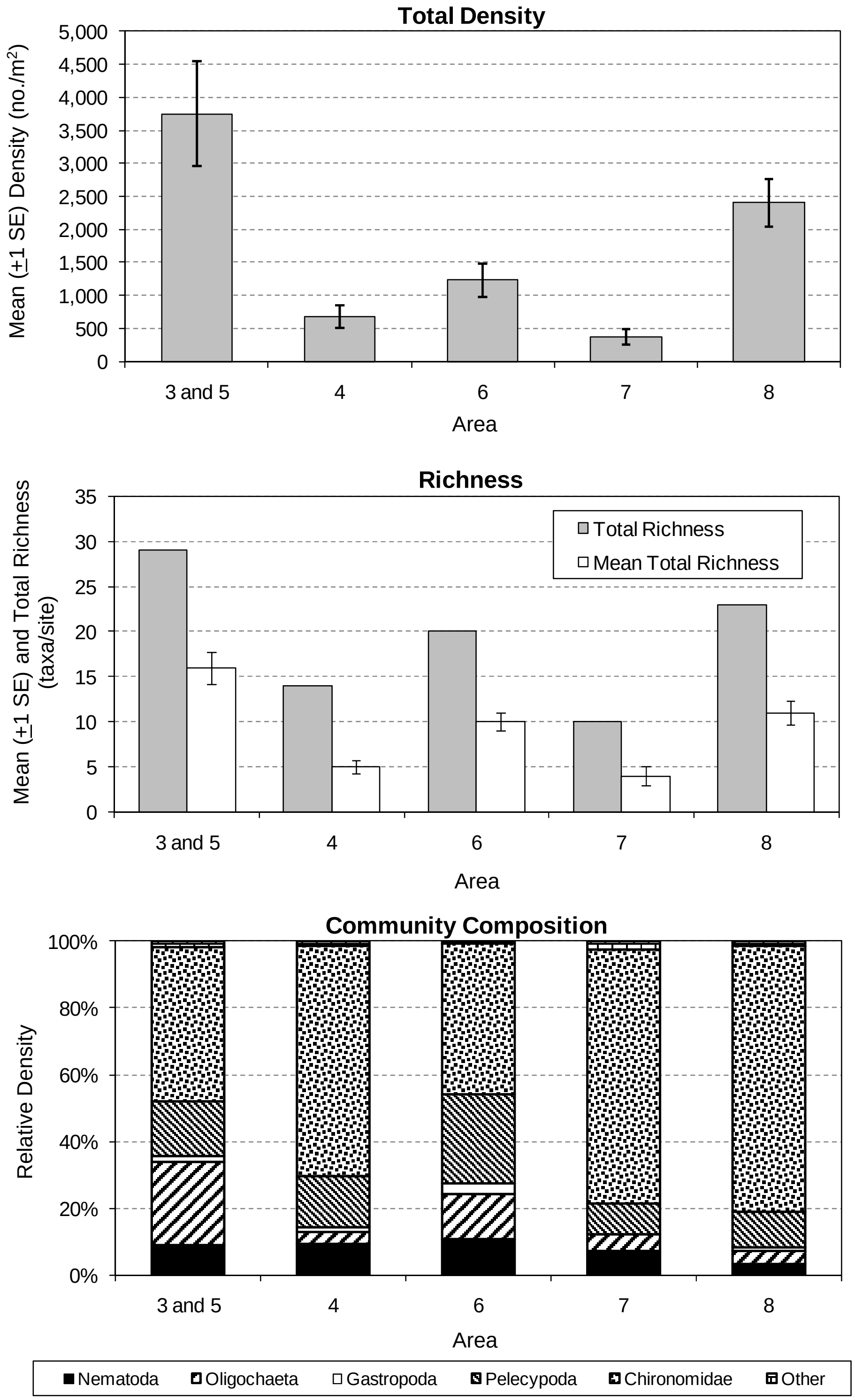
Numerically dominant invertebrate groups in Kennady Lake were similar in all years with available data, and included roundworms, fingernail clams, midges, and aquatic worms. Differences in proportions of major taxa among years were most likely due to variation in sampling locations, sampling depths, and mesh size used to process samples in the field and laboratory.

Figure 8.3-24 Total Abundance, Richness, and Community Composition of Benthic Invertebrates in Kennady Lake at Deep Water Sites, August 2004



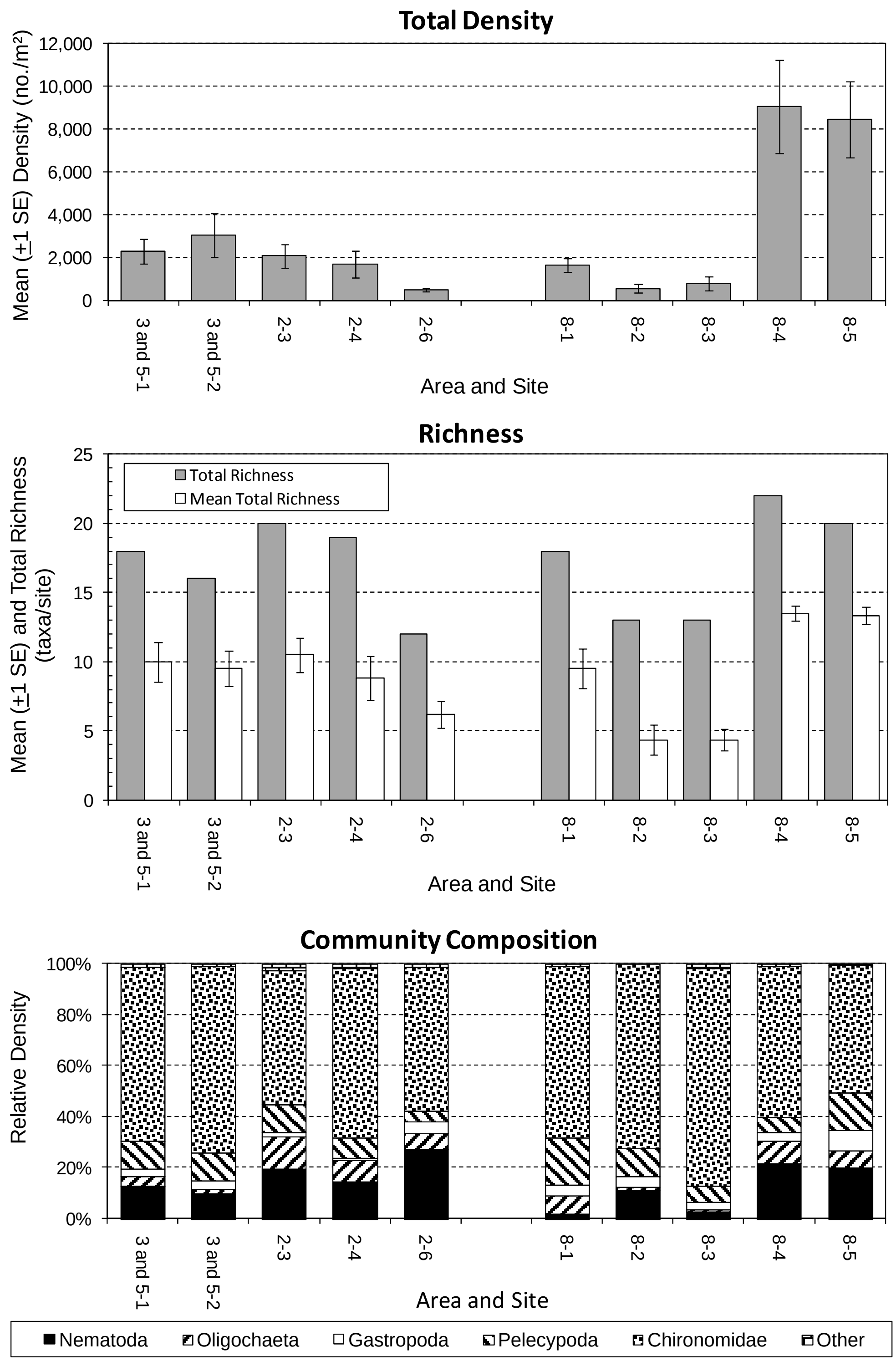
± = plus or minus; SE = standard error; no./m^2 = number of organisms per square metre; % = percent.

Figure 8.3-25 Total Abundance, Richness, and Community Composition of Benthic Invertebrates at Shallow Water Sites in Kennady Lake, September 2004



± = plus or minus; SE = standard error; no./m^2 = number of organisms per square metre; % = percent.

Figure 8.3-26 Total Abundance, Richness, and Community Composition of Benthic Invertebrates in Kennady Lake, Fall 2007



± = plus or minus; SE = standard error; no./m^2 = number of organisms per square metre; % = percent.

Table 8.3-25 Summary of Benthic Invertebrate Density and Richness in Kennady Lake

Study Year	Mean Total Density (no./m² ±1 SE)				Mean Richness (no. of taxa ±1 SE)			
	North Section (Areas 2, 3, 4 and 5)	South Section (Areas 6 and 7)	East Section (Area 8)	Entire Lake	North Section (Areas 2, 3, 4 and 5)	South Section (Areas 6 and 7)	East Section (Area 8)	Entire Lake
1996	2,813 ±820	2,239 ±387	6,035 ±2,097	3,696 ±822	12 ±1.8	10 ±1.5	13 ±1.0	12 ±0.8
2001	2,051 ±365	1,282 ±224	3,162 ±565	2,060 ±186	10 ±0.8	8 ±0.9	11 ±1.0	10 ±0.4
2004	1,199 ±390	504 ±121	1,257 ±419	933 ±187	7 ±1.4	5 ±0.8	7 ±1.7	6 ±0.7
2007	1,911 ±419	-	4,099 ±1,912	-	17 ± 1.4	-	17 ± 1.8	-

± = plus or minus; SE = standard error; no./m² = number of organisms per square metre; no. = number

8.3.7.2.3 Sediment Toxicity

According to Microtox® test results, all sediment samples tested in 2004 and 2005 were non-toxic. In 2004, *Hyalella azteca* survival was significantly reduced compared to lab controls in sediment samples collected from Areas 3 and 5, Area 4 and Area 7 of Kennady Lake. *Hyalella azteca* growth was significantly reduced in the sample collected from Areas 3 and 5 (i.e., analysis by ANOVA using ToxCalc™ 1994 to 1996; $p > 0.05$; see Annex J Fisheries and Aquatic Resources Baseline). Reduced survival in the Area 4 sample may have resulted from a longer sample storage time compared to other samples tested in 2004. *Chironomus tentans* survival and growth were not significantly different between lab controls and lake sediments collected in 2004.

Of the 12 survival and growth tests (six *Hyalella* and six *Chironomus*) run in 2004, results were found to be significantly different from the laboratory controls (i.e., lower than controls) for only four *Hyalella* tests (three survival tests and one growth test) in 2004 and one *Chironomus* test (growth). Overall, these results indicate that bottom sediments in Kennady Lake are generally non-toxic to aquatic life.

8.3.8 Fish

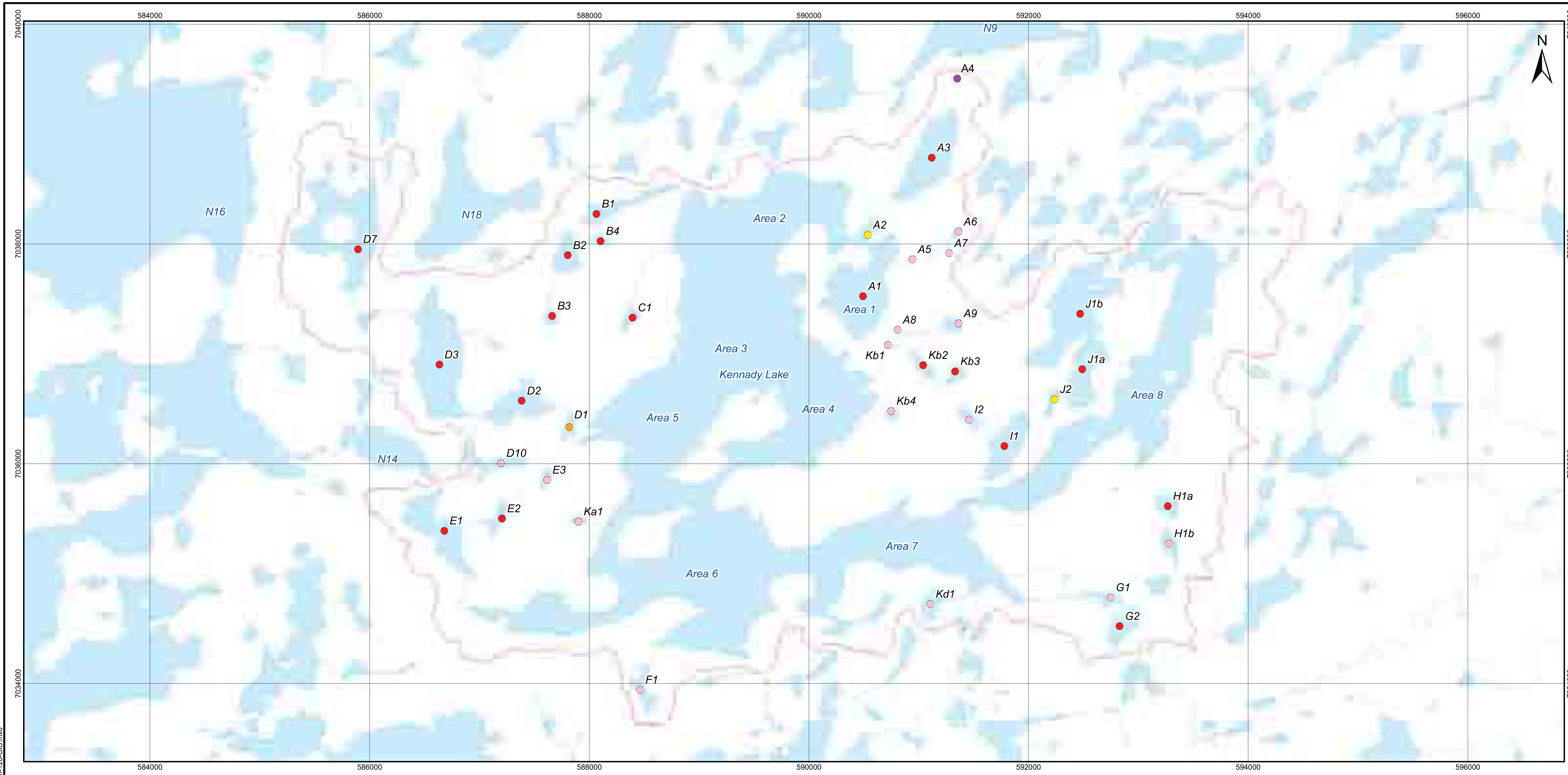
The following section describes the fish and fish habitat baseline information collected for the proposed Project. For additional information regarding fish and fish habitat, the reader is referred to Annex J (Fisheries and Aquatic Resources Baseline) and Addendum JJ.

8.3.8.1 Methods

Aquatics studies in Kennady Lake and the Kennady Lake watershed were conducted between 1996 and 2010.

The following data were collected for fisheries:

- Habitat and bathymetric surveys were conducted in Kennady Lake.
- Gillnetting surveys were conducted to characterize the large-bodied fish community in Kennady Lake.
- Minnow traps, backpack electrofishing and boat electrofishing were used to describe the littoral fish community of Kennady Lake.
- A mark/recapture study was conducted in 2004 to calculate population estimates for the principal large-bodied fish species in Kennady Lake.
- Gillnetting and a hydroacoustic survey were conducted in 2010 to refine the population estimate.
- Spring spawning runs were assessed in Kennady Lake tributaries.
- Lake habitat assessments and fish sampling were conducted to assess the fish-bearing status of small lakes in the Kennady Lake watershed. Small lake habitat sampling locations and fish sampling locations are shown in Figures 8.3-27 and 8.3-28, respectively.
- Limnological surveys were conducted in selected lakes within the Kennady Lake watershed. Limnology sampling locations are shown in Figure 8.3-29.
- Stream habitat assessments were conducted in streams in the Kennady Lake watershed. Stream habitat sampling locations are shown in Figure 8.3-30.
- Stream utilization surveys were conducted in tributaries to Kennady Lake to determine species composition, distribution, and summer abundance of stream-dwelling fish. Stream fish sampling locations are shown in Figure 8.3-31.
- Radio telemetry was used in 2004 and 2005 to monitor movements of fish within Kennady Lake and between Kennady Lake and downstream lakes.
- Fall spawning surveys were conducted in an attempt to identify the principal spawning sites for lake trout and round whitefish in Kennady Lake.
- Fish tissue body burdens of trace metals (a measure of trace metal bioaccumulation in fish) were assessed by collecting muscle and liver samples for metals analysis from lake trout and round whitefish in Kennady Lake and Lake N16.



LEGEND

	Watercourse	**Sampling Year**	
	Waterbody		2010
A1	Lake Identifier		2005
			2004
			2003
			2000
			Kennady Lake Watershed Boundary

NOTES

Base data source: National Topographic Base Data (NTDB) 1:50,000
*Habitat Surveys Conducted in 1996, 1999, 2000, 2001, and/or 2005

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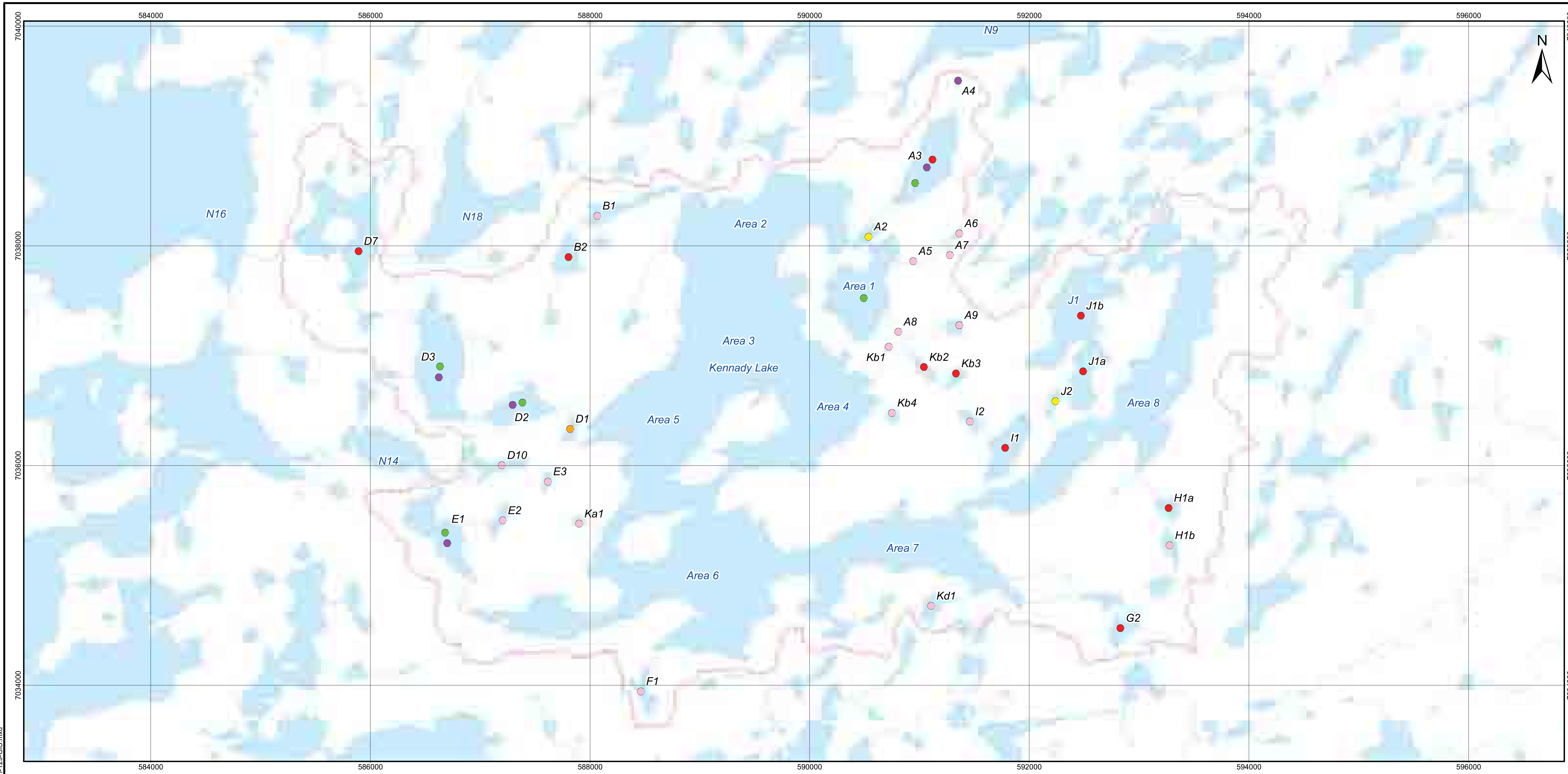
GAHCHO KUÉ PROJECT

Fish Habitat Sampling Locations in Small Lakes in the Kennady Lake Watershed, 2000 to 2010

PROJECTION: UTM Zone 12	DATUM: NAD83		
Scale: 1:35,000 (500 250 0 500 Meters)			
FILE No: E-Fish-126-GIS		DATE: December 16, 2010	
JOB NO: 09-1365-1004	REVISION NO: 1		
OFFICE: GOLD-CAL	DRAWN: SK	CHECK: JF	**Figure 8.3-27**



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LEGEND

Watercourse

Waterbody

A1 Lake Identifier

Sampling Year

- 2010
- 2007
- 2005
- 2004
- 2003
- 2000

Kennady Lake Watershed Boundary

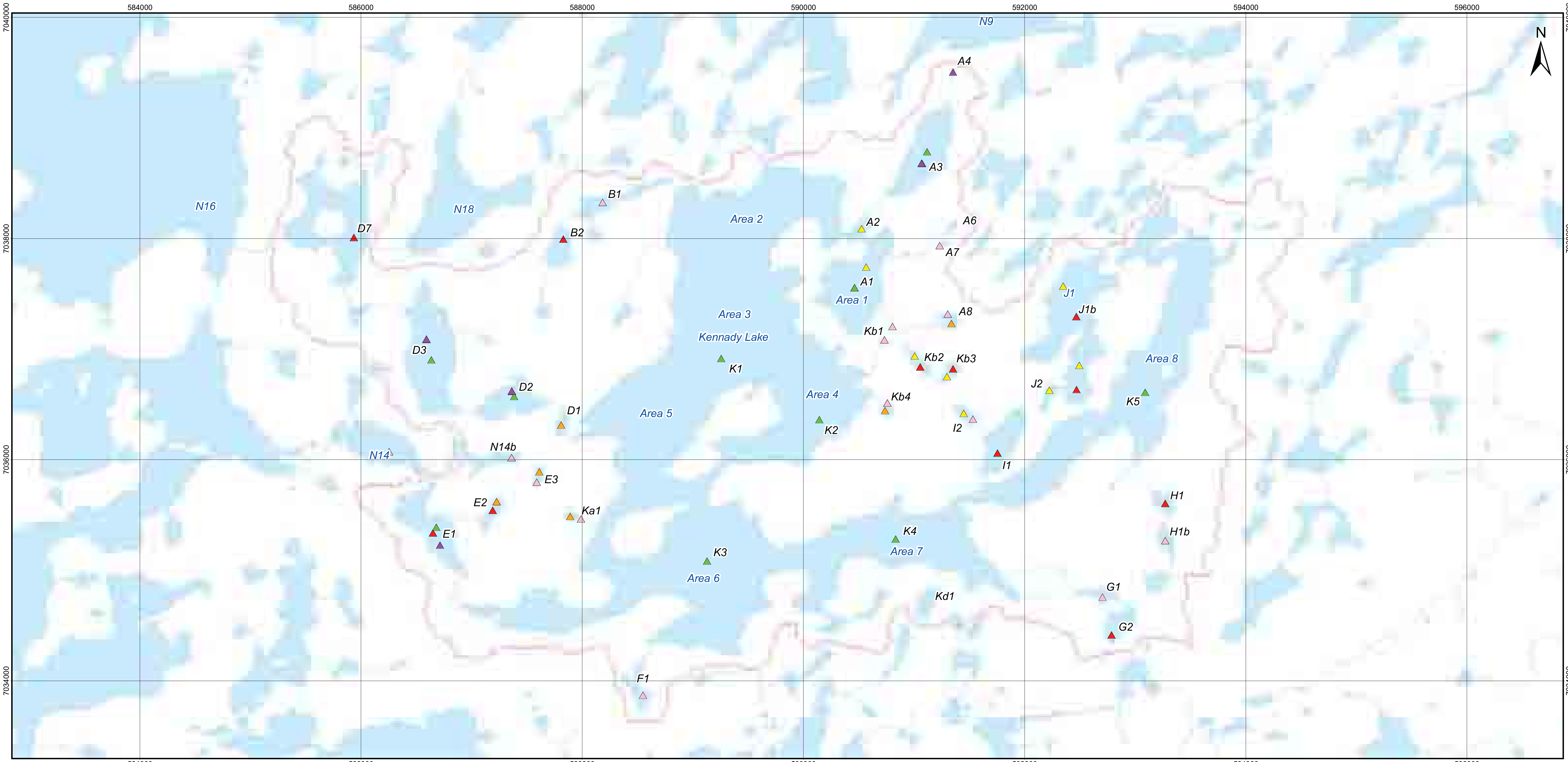
NOTES

Base data source: National Topographic Base Data (NTDB) 1:50,000

GAHCHO KUÉ PROJECT

Small Lake Fish Sampling Locations in the Kennady Lake Watershed, 2000 to 2010

PROJECTION: UTM Zone 12	DATUM: NAD83	DE BEERS
Scale: 1:35,000 500 250 0 500 Meters		
FILE No: E-Fish-129-GIS		DATE: December 16, 2010
JOB NO: 09-1365-1004	REVISION NO: 1	Figure 8.3-28
OFFICE: GOLD-CAL	DRAWN: SK	CHECK: JF



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LEGEND

Watercourse
Waterbody
A1 Lake Identifier

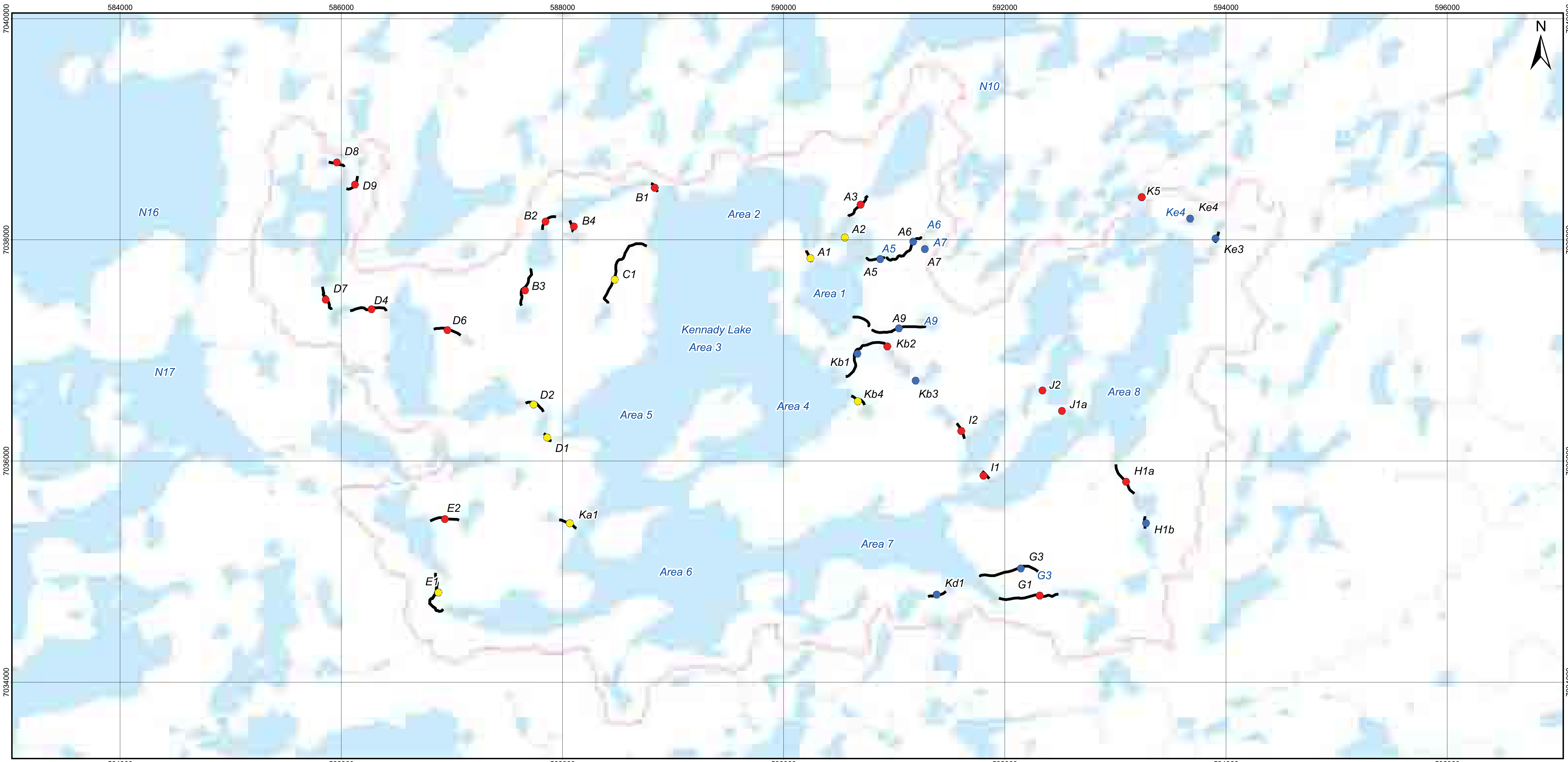
Sampling Year
- 2010
- 2007
- 2005 (Limnology)
- 2004 (Limnology)
- 2003 (Limnology, Zooplankton)
- 2002 (Limnology, Zooplankton)
- Kennady Lake Watershed Boundary

NOTES
Base data source: National Topographic Base Data (NTDB) 1:50,000
*Habitat Surveys Conducted in 1996, 1999, 2000, 2001, and/or 2005

GAHCHO KUÉ PROJECT

Small Lake Limnological Sampling Locations in the Kennady Lake Watershed, 2002 to 2010

PROJECTION: UTM Zone 12	DATUM: NAD83	DE BEERS
Scale: 1:35,000 500 250 0 500 Meters		
FILE No: E-Fish-128-GIS		DATE: December 16, 2010
JOB NO: 09-1365-1004	REVISION NO: 1	Figure 8.3-29
OFFICE: GOLD-CAL	DRAWN: SK	CHECK: JF



LEGEND

Waterbody
Watercourse
A1 Lake Identifier

Sampling Year
2004
2000
1996
Habitat Survey
Kennady Lake Watershed Boundary

NOTES
Base data source: National Topographic Base Data (NTDB) 1:50,000
Habitat Surveys Conducted in 1996, 1999, 2000, 2001, and/or 2004

GAHCHO KUÉ PROJECT

Stream Habitat Sampling Locations in the Kennady Lake Watershed, 1996 to 2010

PROJECTION: UTM Zone 12
DATUM: NAD83

Scale: 1:35,000
500 250 0 500
Meters

FILE No: E-Fish-127-GIS
DATE: December 16, 2010
JOB NO: 09-1365-1004
REVISION NO: 7
OFFICE: GOLD-CAL
DRAWN: SK
CHECK: JF

Figure 8.3-30

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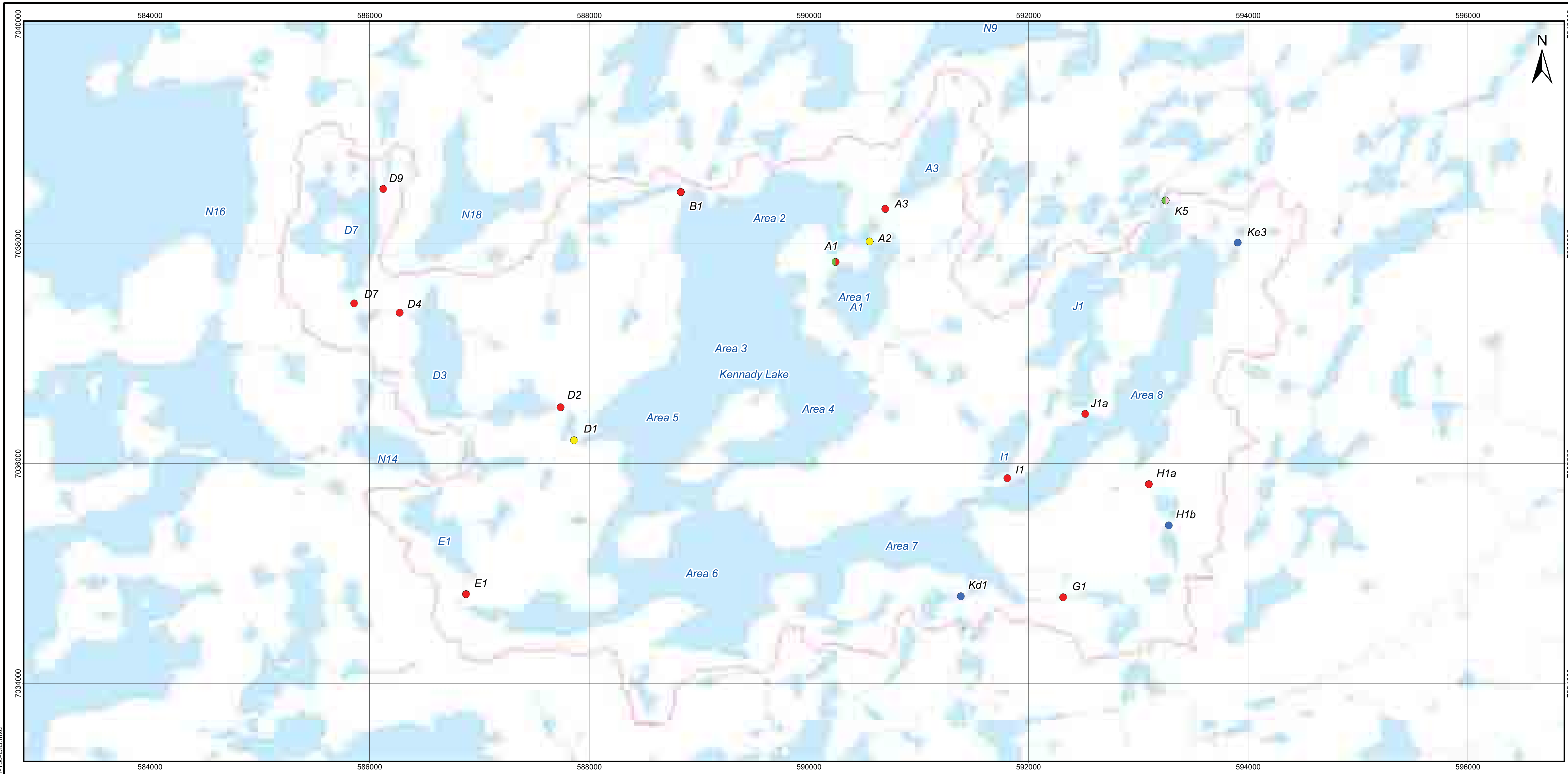

LEGEND

Watercourse	**Sampling Year**
Waterbody	2007
A1 Lake Identifier	2005
	2004
	2000
	1996
	Kennady Lake Watershed Boundary

NOTES
Base data source: National Topographic Base Data (NTDB) 1:50,000

GAHCHO KUÉ PROJECT

Stream Fish Sampling Locations in the Kennady Lake Watershed, 1996 to 2010

PROJECTION: UTM Zone 12	DATUM: NAD83		
Scale: 1:35,000 500 250 0 500 Meters			
FILE No: E-Fish-130-GIS		DATE: December 16, 2010	
JOB NO: 09-1365-1004	REVISION NO: 1	**Figure 8.3-31**	
OFFICE: GOLD-CAL	DRAWN: SK	CHECK: JF	

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8.3.8.2 Results

8.3.8.2.1 Aquatic Habitat

Kennady Lake

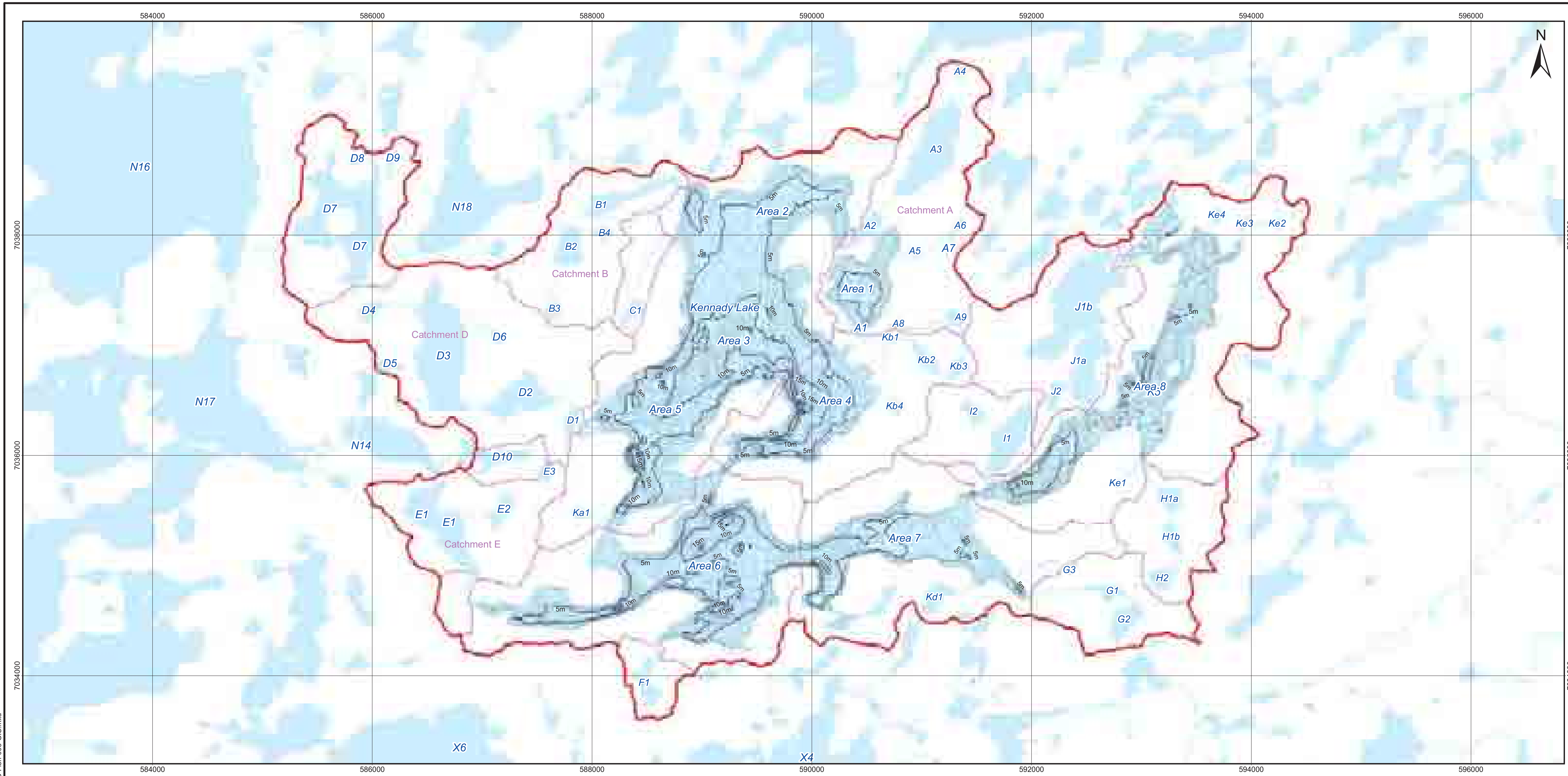
In general, habitat in Kennady Lake can be classified into three types based on depth and dominant substrate type:

- shallow, nearshore habitat within the zone of freezing and ice scour (i.e., less than 2 m deep);
- nearshore habitat deeper than the zone of ice scour but where wave action prevents excessive accumulation of sediments (i.e., greater than 2 m but less than 4 m); and
- deep (greater than 4 m), offshore habitat with substrate usually consisting of a uniform layer of loose, thick organic material and fine sediment.

A bathymetric map of Kennady Lake is presented in Figure 8.3-32.

Annual ice thickness in Kennady Lake is typically up to 2 m and substrates in nearshore areas less than 2 m deep are subjected to ice scour each winter. In Kennady Lake, 60% of all nearshore habitat falls within this ice scour zone, making it effectively unusable by fall spawning fish species such as lake trout and round whitefish for spawning and egg development.

Nearshore habitats (less than 4 m) comprise about 48% (393 ha) of the total area of Kennady Lake (Table 8.3-26). Most of this nearshore habitat (greater than 57%) has a low gradient (less than 10º) extending from the wetted edge to deeper (greater than 4 m) habitat offshore. Clean cobble and boulder substrates are the most common substrate types found in nearshore habitats and are generally found along exposed shorelines where wind and wave actions function to reduce silt accumulation.



LEGEND

Watercourse	Bathymetry Index (1m)
Waterbody	Bathymetry Index (5m)
Area 1 Kennady Lake Area Identifier	Kennady Lake Watershed Boundary
E1 Lake Identifier	Sub-Watershed Boundary

NOTES
Base data source: National Topographic Base Data (NTDB) 1:50,000

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GAHCHO KUÉ PROJECT

Bathymetry of Kennady Lake and Sub-watersheds within the Kennady Lake Watershed

PROJECTION: UTM Zone 12
DATUM: NAD83

Scale: 1:35,000
0.5 0.25 0 0.5
Kilometres

FILE No: B-Fish-003-GIS
DATE: November 24, 2010
JOB NO: 09-1365-1004
REVISION NO: 6
OFFICE: GOLD-CAL
DRAWN: SK
CHECK: AL

Figure 8.3-32

Aquatic vegetation in Kennady Lake is extremely limited and is typically restricted to a narrow fringe of sedges in protected embayments and at tributary mouths where sediments have accumulated. A narrow band of terrestrial vegetation is typically inundated in spring when water levels in the lake rise, but this habitat usually exists for only two to three weeks during the peak spring freshet.

Deeper (greater than 4 m) offshore habitats comprise the remaining 52% (421 ha) of the lake area (Table 8.3-26). The lake bottom in this area is almost exclusively (99.8%) covered by a thick layer of loose, fine sediments. However, clean boulder/cobble substrates do exist at depths down to approximately 6 m in some areas along steep (greater than 10º), exposed shorelines where wave-generated currents are strong enough to keep silt and organic sediments from accumulating at depths deeper than most areas of the lake.

Small Lakes

Small lakes within the Kennady Lake watershed range in size from 0.09 ha (Lake A8) to 40.2 ha (Lake D7) (Table 8.3-27). Only three of these lakes are deeper than 6 m (lakes A1, A3, and I1). Most small lakes within the Kennady Lake watershed were less than 3 m deep (Table 8.3-27) and, therefore, do not provide overwintering habitat for fish. Typically 2 m of ice forms each winter and most small lakes are frozen to the bottom or have only small pockets of water in deeper areas, which likely become de-oxygenated by mid-winter. The fish-bearing status of lakes within the Kennady Lake watershed is assessed in the section on fisheries investigation below.

Most small lakes surrounding Kennady Lake are shallow depressions in the tundra with low-gradient shorelines and typically have homogenous nearshore habitats dominated by boulder substrates embedded with silt. Nearshore areas in larger lakes with sufficient fetch (i.e., the distance over open water that wind blows unobstructed from a constant direction) to create wind-generated currents typically have cleaner boulder substrates than the smaller lakes. Aquatic vegetation is rare but, where present, occurs in a narrow margin along the shoreline or in wetland areas at inlet or outlet streams. Below the 2 m depth contour, lake bottoms typically consist of fine and organic sediments.

Table 8.3-26 Summary of Nearshore and Deep Offshore Habitats in Kennady Lake

Substrate Category No.	Substrate Category	Nearshore (< 4 m) Habitat										Deep (> 4 m) Offshore Habitat								Total Area (ha)
		Depth Class I (0 m – 2 m)				Depth Class II (2 m – 4 m)				Total Area (ha)	% of Total	Depth Class III (> 4 m)						Total Area (ha)	% of Total	
		Low (L) Gradient		High (H) Gradient		Low (L) Gradient		High (H) Gradient				Low (L) Gradient		High (H) Gradient		Unknown (-) Gradient				
		Area (ha)	% of Total	Area (ha)	% of Total	Area (ha)	% of Total	Area (ha)	% of Total			Area (ha)	% of Total	Area (ha)	% of Total	Area (ha)	% of Total			
1	Bo/Co	84.7	37.6	2.2	22.0	29.1	24.1	20.7	55.6	136.7	34.8	0.0	0.0	0.7	70.0	0.0	0.0	0.7	0.2	137.4
2	Bo	39.8	17.7	3.3	33.0	2.9	2.4	2.4	6.5	48.4	12.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	48.4
3	Bd	3.0	1.3	1.6	16.0	0.1	0.1	0.7	1.9	5.4	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.4
4	Bd/Bo	2.5	1.1	0.3	3.0	0.3	0.2	0.5	1.3	3.6	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6
5	Bd/Co	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
6	Veg/Org	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
7	Veg/Bo	8.8	3.9	0.0	0.0	0.0	0.0	0.0	0.0	8.8	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.8
8	F	7.2	3.2	0.0	0.0	34.5	28.6	0.0	0.0	41.7	10.6	0.0	0.0	0.0	0.0	420.0	100.0	421.0	99.8	462.7
9	Co/Gr	2.5	1.1	1.1	11.0	0.7	0.6	1.7	4.6	6.0	1.5	0.0	0.0	0.3	30.0	0.0	0.0	0.3	0.0	6.3
10	Bo/F	42.2	18.7	0.0	0.0	26.1	21.6	8.5	22.8	76.8	19.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	76.8
11	Co/F	34.1	15.1	0.2	2.0	27.0	22.4	1.4	3.8	62.7	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	62.7
12	Bo/Gr	0.0	0.0	1.3	13.0	0.0	0.0	1.3	3.5	2.6	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6
Total		**225.1**	**100.0**	**10.0**	**100.0**	**120.7**	**100.0**	**37.2**	**100.0**	**393.0**	**100.0**	**0.0**	**0.0**	**1.0**	**100.0**	**420.0**	**100.0**	**421.0**	**100.0**	**815.0**

Note: Substrate categories are described in Annex J, Tables J3.2-1 and J3.2-2.

Bo = boulder; Co = cobble; Bd = bedrock; Gr = gravel; F = fines/organics; Veg = vegetation; Org = organics; < = less than; > = greater than; % = percent; ha = hectare; m = metre; No. = number.

Table 8.3-27 Summary of Habitat Characteristics for Small Lakes in the Kennady Lake Watershed

Lake Identifier	Lake Area (ha)	Maximum Depth (m)	Dominant Shallow Habitat[(a)]	Lake Identifier	Lake Area (ha)	Maximum Depth (m)	Dominant Shallow Habitat[(a)]
A1	34.5	8.0	8LI	E1	20.2	3.4	10LI
A2	3.07	1.1	10L1	E2	3.02	0.4	10LI
A3	23.8	12.2	10LI	E3	1.12	0.7	10LI
A4	0.4	0.4	8LI	F1	3.93	5.0	-
A5	0.14	1.0	8LI	G1	2.86	3.0	6LI
A6	0.59	-	6L1	G2	5.90	3.2	2L1
A7	0.12	0.4	8[(b)]	H1a	3.68	1.6	12L1
A8	0.09	-	7LI	H1b	3.34	-	10H1
A9	1.81	2.0	5LI	I1	13.1	11.0	8L1
B1	8.21	4.1	2LI	I2	2.07	0.9	10LI
B2	6.55	1.1	10LI	J1a	14.0	2.2	10LI
B3	1.48	-	10LI	J1b	36.1	4.3	8LI
B4	1.16	-	8LI	J2	2.03	0.9	-
C1	1.77	-	1LI	Ka1	0.94	1.0	8LI
D1	1.87	3.8	10L1	Kb1	0.18	1.5	6LI
D10	4.40	1.7	10[(b)]	Kb2	2.53	2.5	10LI
D2	12.5	1.0	10LI	Kb3	1.95	0.9	11LI
D3	38.4	2.5	10LI	Kb4	0.99	1.2	8LI
D7	40.2	4.5	1LI	Kd1	4.26	2.9	-

(a) Habitat types:

1 Boulder/cobble - Substrates generally clean due to wave action and ice scour; on average 60% boulders, 40% cobbles. Interstitial spaces generally clean.
2 Boulder - Substrates 80% or greater boulder; remainder cobble, gravel, or fine sediments.
5 Bedrock/cobble - Bedrock overlain with cobble.
6 Vegetation/organics - Submergent, emergent, or inundated vegetation on organic substrates.
7 Vegetation/boulder - Emergent or inundated vegetation; substrates of boulder or boulder and cobble.
8 Fines/organics - Substrates predominantly fines, organics, or sand.
10 Boulder/fines - Highly embedded boulders overlain with layer of fine sediments. Substrates greater than 40% boulder.
H High gradient (>10°).
L Low gradient (<10°).
I Depth - 0 to 2 m.
II Depth - 2 to 4 m.
II Depth - >4 m.

(b) No depth/gradient category, only substrate.

ha = hectare; m = metre; - = not measured; % = percent; > = greater than; < = less than; ° = degrees.

Streams

The numerous small lakes in the Kennady Lake watershed are typically drained by small streams (less than 3 m wide) with low gradients (less than 2%) and boulder/cobble substrates (Table 8.3-28). These streams typically are either entirely dry or consist of discontinuous wetted sections in summer and fall when waters recede. In streams draining larger watersheds where summer flow persists (A, B, and D watersheds), flow is generally confined in a narrow, incised channel between and under boulders. Sedges and grasses occur in some streams, and willows and alders grow along most tributary banks. Fish passage is possible in most Kennady Lake tributaries in spring when flows are highest. However, habitat suitable for spawning and rearing of Arctic grayling and other stream-dwelling fish typically is present only in the lowest streams of the largest watersheds (i.e., A, B, and D watersheds).

Table 8.3-28 Summary of Fish Habitat Quality in Kennady Lake Tributary Streams

Stream Identifier	Reference Number[(a)]	Season Surveyed	Stream Length (m)	Map Gradient (%)	Flow duration	Overall Habitat Quality Rating	Spawning Habitat Quality[(b)]		Fish Passage
							ARGR	NRPK	
A1	3	sp	100	0.0	Perm	M-H	M	H	yes
A2	3	sp	20	0.0	Perm	M-H	M	H	yes
A3	3, 5	sp	294	0.6	Perm	M	L	L	yes
B1	3, 5	sp	94	5.1	Perm	M	M	N	yes
B2	5	su	169	0.4	Ephem	L	N	L	no
B3	5	su	332	1.5	Ephem	N	N	N	no
B4	5	su	102	0.1	Ephem	N	N	N	no
C1	3	sp	691	1.8	Ephem	N	N	N	no
D1	3	sp	118	0.3	Perm	M	M	N	yes
D2	1,3	sp, su	228	1.4	Perm	M	M	L	yes
D3	3	sp	97	2.3	Perm	M	M	L-M	yes
D4	5	su	428	0.5	Perm	M	L	L	yes
D6	5	su	255	-	Ephem	N	N	N	no
D7	5	su	206	1.7	Perm	M	L	L	yes
D8	5	su	169	2.3	Ephem	N	N	N	no
D9	5	su	188	1.9	Ephem	N	N	N	no
Ka1	3	sp	170	3.6	Ephem	N	N	N	no
Kb1	3	sp	300	1.4	Ephem	N	N	N	no
Kb2	5	su	181	2.3	Ephem	N	N	N	no
Kb4	3	sp	309	0.6	Ephem	N	N	N	no
E1	3	sp	426	1.1	Perm	L-M	M	L	yes
E2	5	su	290	1.6	Ephem	N	N	N	no
F1	3	sp	168	5.9	Ephem	N	N	N	no
G1	5	su	574	1.0	Ephem	L	N	L	yes
Kd1	1	sp, su	138	1.4	Ephem	L	-	-	unknown
I1	5	su	68	1.3	Perm	L	L	L	yes
I2	5	su	193	2.6	Ephem	N	N	N	no
H1a	1,5	sp, su	331	2.1	Perm	L	N	L	yes
H1b	1	sp, su	80	0.0	Ephem	L	-	-	yes

Table 8.3-28 Summary of Fish Habitat Quality in Kennady Lake Tributary Streams (continued)

Stream Identifier	Reference Number[(a)]	Season Surveyed	Stream Length (m)	Map Gradient (%)	Flow duration	Overall Habitat Quality Rating	Spawning Habitat Quality[(b)]		Fish Passage
							ARGR	NRPK	
H2	no reference	-	175	1.9	Ephem	not surveyed			unknown
J1a	5	su	123	1.2	Perm	L	L	N	yes
J2	5	su	22	1.9	Ephem	N	N	N	no
Ke3	1	sp, su	56	1.6	Ephem	L	-	-	unknown

(a) Sources: 1: Canamera 1998; surveyed June 4 to 9 (spring) and July 2 to 28 (summer), 1996; 2: EBA and Jacques Whitford 2000; surveyed July 16 to 27 (summer), 1999; 3: EBA and Jacques Whitford 2001; surveyed June 4 to 9 (spring), 2000; 4: EBA and Jacques Whitford 2002a; surveyed July 14 (summer), 2001; 5: current baseline sampling program (Annex J); surveyed August 4 to 6, 2004.

(b) Habitat Quality Ratings: H = High; M = Moderate; L = Low; N = Nil.

ARGR = Arctic grayling; NRPK = northern pike; Perm = Permanent; Ephem = Ephemeral; sp = spring; su = summer; "-" = not applicable; m = metre; % = percent.

8.3.8.2.2 Large-bodied Fish Community

Eight species of fish are known to inhabit Kennady Lake. Round whitefish (*Prosopium cylindraceum*) are the most abundant large-bodied fish species and typically comprise more than 50% of the total large-bodied fish community (Table 8.3-29). Lake trout (*Salvelinus namaycush*) are the second most abundant species (about 20%) and are the top predator in the lake. Relative abundance of lake chub (*Couesius plumbeus*) and Arctic grayling (*Thymallus arcticus*) has varied between years but, on average, is lower (12% and 10%, respectively) than lake trout and round whitefish. The northern pike (*Esox lucius*) population in Kennady Lake is small (about 2%) due to the paucity of aquatic vegetation in the lake. A single longnose sucker (*Castostomus catostomus*) was observed in the spring of 2000 near the lake outlet (Table 8.3-33). It is believed this single fish was a stray from downstream habitats and that Kennady Lake does not support a population of longnose sucker (Annex J).

Short-duration gill netting in summer 2010 captured fewer fish than previous years. Only eight of the 72 sets captured fish and only 13 fish were captured in total (one northern pike, five lake trout, six round whitefish, and one lake chub). Overall, 85% of the catch was lake trout and round whitefish. The lake trout catch-per-unit-effort (CPUE) was 1.41 fish per 100 m^2 / 12-net hours, and the round whitefish CPUE was 1.69 fish per 100 m^2 / 12-net hours. The total (all species combined) CPUE was 3.66 fish per 100 m^2 / 12-net hours.

Burbot (*Lota lota*) are the only other large-bodied fish species in Kennady Lake but were not represented in gillnet catches. Ninespine stickleback (*Pungitius*

pungitius) and slimy sculpin (*Cottus cognatus*) are the only other fish species found in Kennady Lake and are discussed in Littoral Fish Community (Section 8.3.8.2.5). Mean length, weight, and condition factor[2] for large-bodied fish species captured by gillnetting in Kennady Lake in 1996, 1999, and 2004 are provided in Table 8.3-30.

Table 8.3-29 Species Composition, Relative Abundance, and Average Catch-Per-Unit-Effort of Fish Captured in Kennady Lake during Gillnetting Surveys, Summer Months of 1996, 1999, and 2004

Species	1996			1999			2004[(a)]		
	# of Fish	% of Catch	CPUE	# of Fish	% of Catch	CPUE	# of Fish	% of Catch	CPUE
Arctic grayling	3	0.8	0.07	39	22.7	2.11	20	7.2	2.16
Lake chub	106	29.2	2.54	9	5.2	0.46	3	1.1	0.18
Lake trout	70	19.3	1.97	36	20.9	1.98	53	19.0	4.13
Northern pike	2	0.6	0.05	5	2.9	0.28	5	1.8	0.42
Round whitefish	182	50.1	4.54	83	48.3	4.52	198	71.0	18.9
Total	**363**	**100**	**9.17**	**172**	**100**	**9.35**	**279**	**100**	**25.7**

(a) Combined results from 89 SLIN gillnet lifts and 7 experimental gillnet lifts.

CPUE = catch-per-unit-effort measured as number of fish/100 m^2/12 hours; SLIN = spring littoral index netting; # = number; % = percent; m^2 = square metre.

Table 8.3-30 Mean Length, Weight, and Condition Factor for Fish Captured in Standardized Experimental Gill Nets in Kennady Lake

Species	Length (mm)			Weight (g)			Condition Factor		
	n	Mean	Standard Deviation	n	Mean	Standard Deviation	n	Mean	Standard Deviation
Arctic grayling[(a)]	37	304	35.6	37	333	86.1	37	1.14	0.10
Lake chub[(b)]	98	94	6.6	-	-	-	-	-	-
Lake trout[(b)]	70	304	147	60	525	760	60	1.01	0.13
Northern pike[(a)]	5	699	90.0	5	2,920	1,112	5	0.81	0.05
Round whitefish[(b)]	166	244	70.8	152	195	152	152	1.01	0.24

(a) Fish captured in 1999.

(b) Fish captured in 1996.

Length = fork length; mm = millimetres; g = grams; n = number of fish; - = no fish found.

[2] Condition factor is a proxy for the general health or condition of fish. It is calculated as (fish weight [g])/(fish length [mm]). This ratio measure is often multiplied by some arbitrary factor to scale the measure to something close to one. It is not necessarily comparable among species but rather may provide an indication of spatial or temporal variation within a population or species. In EEM programs, it is often related to energy storage, i.e., higher condition equates to more energy being stored

Lake Trout

Lake trout sampled in Kennady Lake ranged in age between 1 to 26 years old (Table 8.3-31). Although based on a limited number of aged fish, growth rates of lake trout in Kennady Lake appear slower than in Great Slave Lake (Scott and Crossman 1973).

Lake trout in Kennady Lake reach sexual maturity at a minimum size of 450 mm, when most lake trout in Kennady Lake are 8 or 9 years old (Table 8.3-31). In addition, evidence from gillnetting surveys conducted since 1996 suggests that lake trout in Kennady Lake do not spawn every year. Alternate year spawning is common in lake trout populations in the NWT (McPhail and Lindsey 1970; Richardson et al. 2001), where growing seasons are short and low nutrient availability limits productivity.

Most (62%) lake trout captured in summer 1996 were less than 300 mm in length with a modal length class of 175 to 200 mm (Figure 8.3-33). In comparison, most (92%) lake trout captured in summer 1999 were greater than 300 mm with a modal length-class distribution of 500 to 525 mm (Figure 8.3-34). The difference in length-frequencies between years is difficult to interpret but may be due to differences in sample effort. The difference may also represent the growth of a particularly strong year-class of fish from 1996 to 1999.

Table 8.3-31 Mean Length- and Weight-at-Age for Lake Trout in Kennady Lake, 1996, 1999, and 2004

Age	Length (mm)				Weight (g)			
	n	Mean	Min	Max	n	Mean	Min	Max
1+	2	114	108	120	2	52	14	90
2+	9	184	131	216	9	64	15	85
3+	4	244	204	276	4	159	88	225
4+	3	212	200	219	3	101	78	124
5+	3	263	238	289	3	211	200	218
6+	2	334	287	380	2	420	260	580
7+	1	272	-	-	1	200	-	-
8+	2	482	445	518	2	1,038	890	1,186
9+	8	498	455	534	8	1,383	920	1,975
10+	6	484	457	512	6	1,242	1,070	1,400
11+	4	477	468	486	4	1,231	1,175	1,300
12+	1	508	-	-	1	2,025	-	-
13+	3	548	497	578	3	1,808	1,198	2,600
14+	2	553	498	608	3	1,930	1,375	2,714
15+	4	571	452	659	4	2,315	1,200	3,530
16+	1	603	-	-	1	2,755	-	-

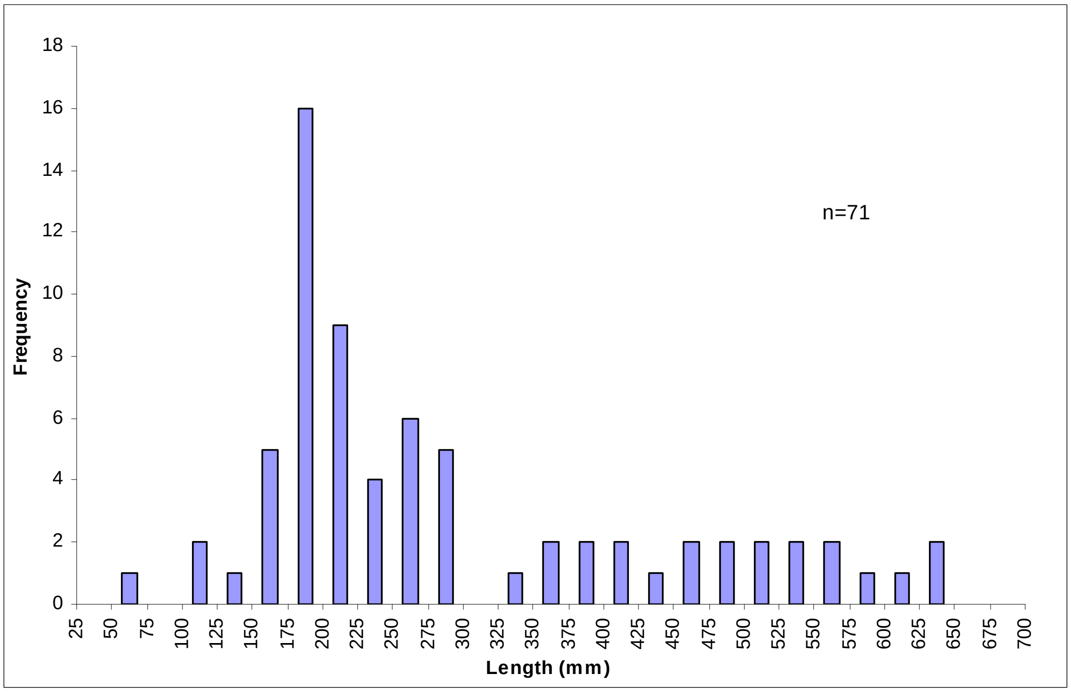
Table 8.3-31 Mean Length- and Weight-at-Age for Lake Trout in Kennady Lake, 1996, 1999, and 2004 (continued)

Age	Length (mm)				Weight (g)			
	n	Mean	Min	Max	n	Mean	Min	Max
17+	7	602	549	701	7	2,315	1,580	3,100
18+	3	632	580	780	3	2,760	2,030	5,000
19+	2	613	578	648	2	2,104	1,982	2,225
20+	-	-	-	-	-	-	-	-
21+	3	615	577	653	3	2,617	1,952	3,400
22+	1	575	-	-	1	1,940	-	-
23+	1	778	-	-	1	5,725	-	-
24+	2	690	595	785	2	3,888	1,825	5,950
25+	-	-	-	-	-	-	-	-
26+	1	658	-	-	1	4,250	-	-

Notes: 1996 (n=50); 1999 (n=2); 2004 (n=24).
mm = millimetres; g = grams; - = not applicable; n = number of fish; min = minimum; max = maximum.

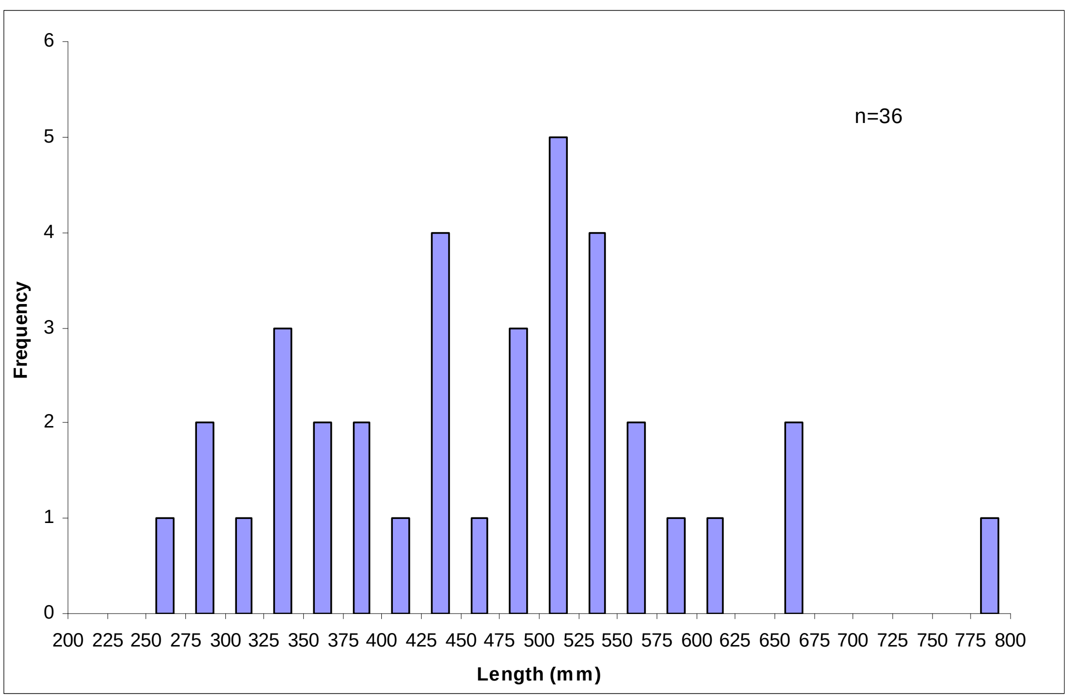
Lake trout are the top predators in Kennady Lake where they feed almost exclusively on round whitefish. In contrast, lake trout in Lake N16 in the adjacent watershed prefer lake cisco despite the relatively high abundance of round whitefish. Lake cisco are not found in Kennady Lake.

Figure 8.3-33 Length-Frequency Distribution for Lake Trout Gillnetted in Kennady Lake, Summer 1996



mm = millimetre.

Figure 8.3-34 Length-Frequency Distribution for Lake Trout Gillnetted in Kennady Lake, Summer 1999



mm = millimetre.

Round Whitefish

Round whitefish captured in gillnets in Kennady Lake ranged between 1 and 13 years old (Table 8.3-32). In Kennady Lake, most round whitefish reach sexual maturity at 250 mm in length. Round whitefish in Kennady Lake typically reach this size at five years old (Table 8.3-32). Evidence from all three years of gillnetting suggest that round whitefish in Kennady Lake spawn every year once reaching sexual maturity.

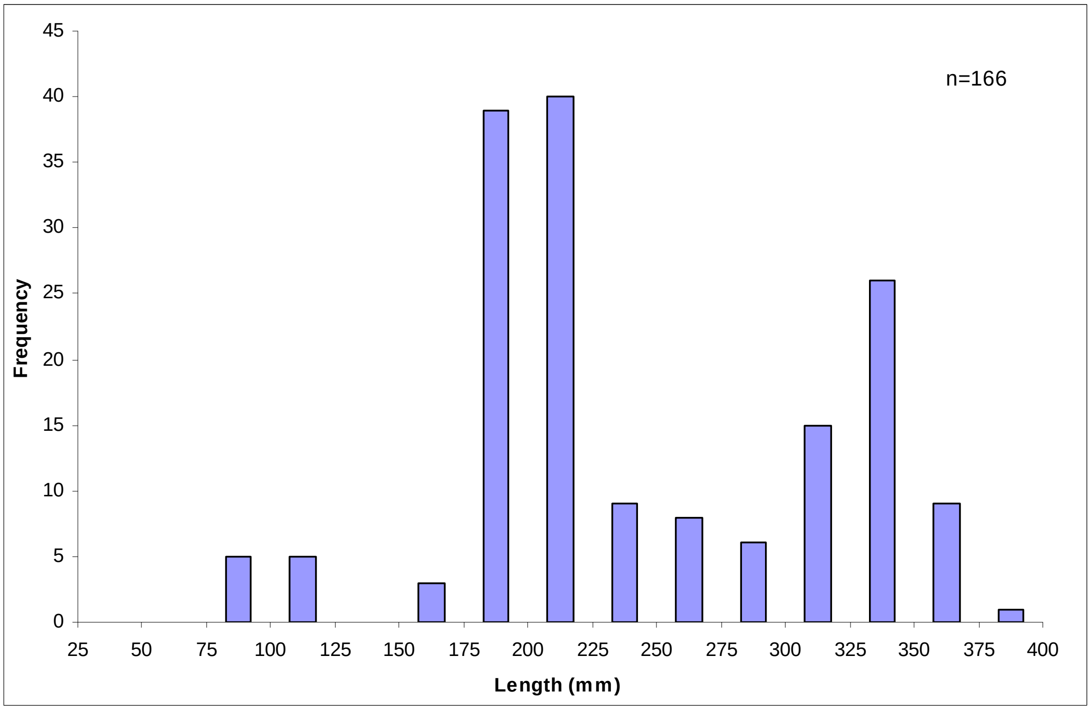
Round whitefish captured in gillnets in 1996 had a mean length of 244 mm, a mean weight of 195 g, and a condition factor of 1.01. Round whitefish ranged in length between 75 mm and 400 mm, with a modal length class of 200 to 225 mm (Figure 8.3-35); most (92%) round whitefish captured in 1996 were greater than 175 mm. Zooplankton groups were the primary prey item of round whitefish in Kennady Lake. Bivalves and gastropods were also commonly eaten.

Table 8.3-32 Mean Length-at-Age and Weight-at-Age for Round Whitefish in Kennady Lake, 1996, 1999, and 2004

Age	Length (mm)				Weight (g)			
	n	Mean	Min	Max	n	Mean	Min	Max
1+	1	118	-	-	1	14	-	-
2+	1	188	-	-	1	66	-	-
3+	19	201	184	231	19	77	55	114
4+	16	222	188	263	16	114	70	178
5+	7	273	238	298	7	225	125	325
6+	16	279	248	320	16	245	100	395
7+	25	306	265	355	25	300	200	425
8+	26	312	264	345	26	352	150	734
9+	21	334	290	365	21	422	250	558
10+	17	343	270	385	17	487	350	742
11+	8	345	330	355	8	469	425	500
12+	1	343	-	-	1	550	-	-
13+	1	348	-	-	1	525	-	-

Notes: 1996 (n=61); 1999 (n=4); 2004 (n=94).
mm = millimetres; g = grams; - = not applicable; n = number of fish; min = minimum; max = maximum.

Figure 8.3-35 Length-Frequency Distribution for Round Whitefish Gillnetted in Kennady Lake, Summer 1996



mm = millimetre.

8.3.8.2.3 Population Estimates

In the 2004 mark/recapture study, Peterson population estimates could not be calculated due to low numbers of recaptured fish in the fall. Instead, a Bayesian approach (Gazey and Staley 1986) was used to calculate the probability that the minimum population size was greater than a reference population level. Based on results of the 2004 mark/recapture experiment, there is a 95% probability that the lake trout population in Kennady Lake is greater than 2,300 fish. Population estimates for Arctic grayling and round whitefish could not be calculated because tagged individuals were not recaptured in the fall. A whole-lake population estimate for northern pike was not possible due to their patchy distribution and limited movement.

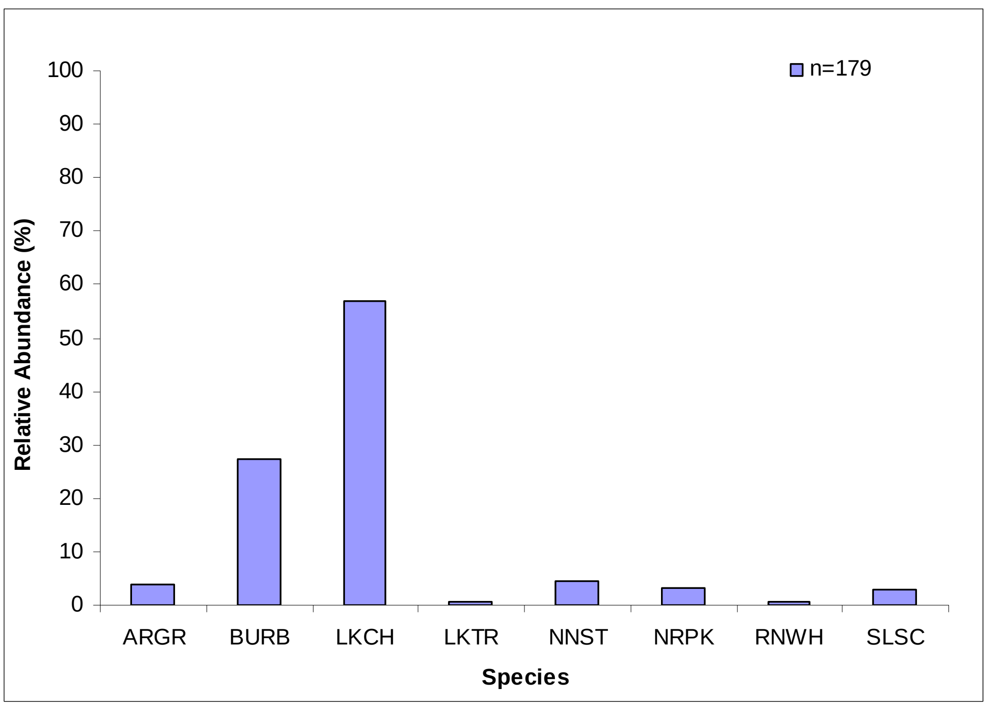
To further refine the Kennady Lake population estimates, a hydroacoustic survey of pelagic fish was conducted in late summer 2010. The fish density of Kennady Lake was calculated to be 23.3 fish per hectare (0 to 51.2 fish per hectare; 90% CI). If considering the entire wetted surface area of Kennady Lake (i.e., 814 ha), the total fish population was estimated at 18,977 fish; however, this estimate does not include fish (e.g., young-of-the year, small fish) that prefer shallow water where hydroacoustic surveys are generally ineffective. The hydroacoustic surveys showed that most of the Kennady Lake population resided in Area 6

(53%) where there was deep water (approximately 18 m in depth), and possibly, vertical thermoclines. A mean density of 13.4 lake trout per hectare was calculated (or a lake trout population of 10,925 fish).

8.3.8.2.4 Littoral Fish Community

The density of fish in the littoral areas of Kennady Lake was low (less than 2.5 fish/100 m), which is characteristic of the low productivity of Kennady Lake. Lake chub were the most abundant fish species in littoral areas comprising over 50% of the catch (Figure 8.3-36). Juvenile burbot contributed about 25% of all fish captured in the littoral areas. In contrast, few adult burbot have been captured in gillnets set offshore. The relative proportion of burbot in the Kennady Lake fish community in comparison to other large-bodied fish species is likely underestimated, as burbot are typically under-represented in gillnet catches (Jensen 1986). Small numbers of Arctic grayling, lake trout, northern pike, and round whitefish were also captured in littoral areas. Ninespine stickleback and slimy sculpin were the only other small-bodied fish species captured in the littoral areas of the lake. These two species comprised less than 5% of the littoral fish community.

Figure 8.3-36 Relative Abundance of Fish Species Captured in Littoral Areas of Kennady Lake, 1996, 1999, and 2004



ARGR = Arctic grayling; BURB = burbot; LKCH = lake chub; LKTR = lake trout; NRPK = northern pike; RNWH = round whitefish; SLSC = slimy sculpin; NNST = ninespine stickleback; n = number of fish; % = percent.

8.3.8.2.5 Spring Spawning Runs

In spring of 2000, 127 individual fish were captured in Kennady Lake tributaries and in the Kennady Lake outlet (Table 8.3-33). Arctic grayling were the most abundant species captured, followed by lake trout, burbot, and northern pike. Lake chub, ninespine stickleback, and longnose sucker were also captured in Kennady Lake tributaries in spring 2000.

Table 8.3-33 Numbers of Fish Captured, by Species, in Fish Fences Set in Kennady Lake Tributaries, Spring 2000

Species	Area 1	Area 3 and 5		Area 6	Area 7	Kennady Lake Outlet	Total
	A2[(a)]	D1[(a)]	B1[(a)]	E1[(a)]	G1[(a)]	K5[(b)]	
Arctic grayling	12	15	7	6	0	53	**93**
Burbot	1	1	0	9	0	0	**11**
Lake trout	0	0	0	0	0	12	**12**
Northern pike	7	0	0	0	0	0	**7**
Lake chub	0	0	0	0	0	1	**1**
Ninespine stickleback	0	0	0	2	0	0	**2**
Longnose sucker	0	0	0	0	0	1	**1**
Total	**20**	**16**	**7**	**17**	**0**	**67**	**127**

(a) Upstream.
(b) Downstream.

In spring 2004, 235 fish were captured in Kennady Lake tributaries and in the Kennady Lake outlet in fish fences and hoopnets (Table 8.3-34). Arctic grayling was the most abundant large-bodied species captured, followed by northern pike and lake trout. Small numbers of burbot, round whitefish, and slimy sculpin were also captured. Large numbers of ninespine stickleback were captured in Stream A1, which is likely a reflection of the smaller mesh nets (13 mm) used in Stream A1 than the absence of ninespine stickleback in other streams.

Lake trout are fall spawners and the movement of lake trout through the Kennady Lake outlet in the spring of 2000 and 2004 is most likely to feed on spawning Arctic grayling and/or their newly laid eggs.

Based on these two years of data, most adult Arctic grayling in Kennady Lake move through the Kennady Lake outlet to spawn in the series of streams immediately downstream (Figure 8.3-37). Other tributaries to Kennady Lake are also used, including streams within the A, B, D and E watersheds, but to a smaller extent. This is primarily due to their smaller size, lower flows, and steeper gradients compared to streams downstream of Kennady Lake.

Table 8.3-34 Numbers of Fish Captured, by Species and Direction of Movement, in Fish Fences and Hoopnets Set in Kennady Lake Tributaries, Spring 2004

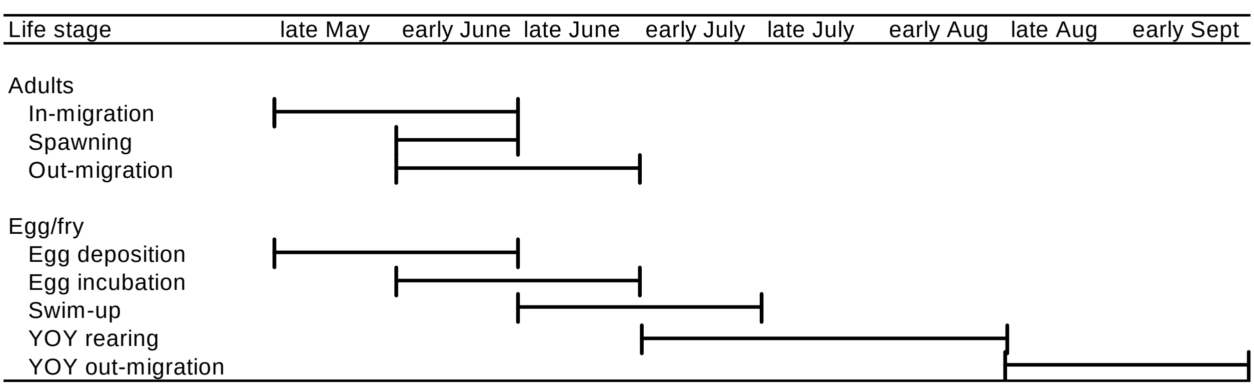
Species	Area 2		Area 1		Area 3 and 5				Area 6		Area 7		Area 8				Kennady Lake Outlet		Total
	A1		A3		B1		D2		E1		G1		H1a		J1a		K5[(a)]		
	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	
ARGR	19	1	2	0	0	12	1	1	1	1	0	0	0	0	1	0	1	48	**88**
BURB	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
LKTR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	**7**
NNST	7	82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**89**
NRPK	1	3	1	0	0	0	25	2	0	1	0	0	0	0	0	0	7	6	**46**
RNWH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**1**
SLSC	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**3**
Total	**28**	**88**	**3**	**0**	**0**	**12**	**26**	**3**	**1**	**2**	**0**	**0**	**0**	**0**	**1**	**0**	**8**	**63**	**235**

[(a)] Downstream count includes one Arctic grayling located in the wing of the fish fence.

ARGR = Arctic grayling; BURB = burbot; LKCH = lake chub; LKTR = lake trout; NRPK = northern pike; RNWH = round whitefish; SLSC = slimy sculpin; NNST = ninespine stickleback; U/S = upstream; D/S = downstream.

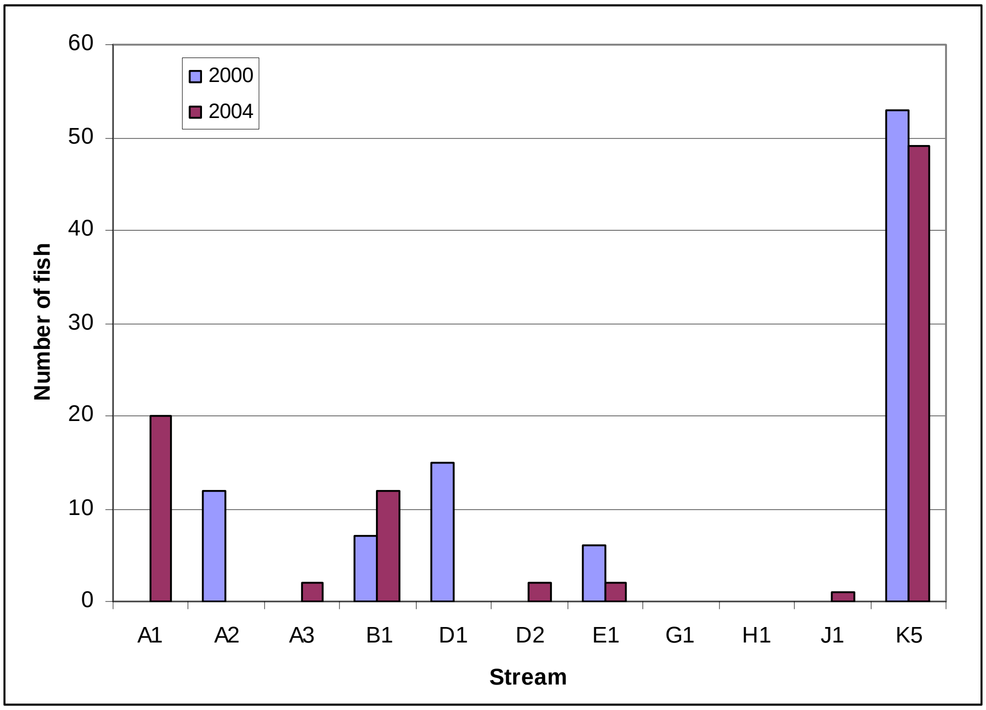
Arctic grayling in Kennady Lake exhibit an adfluvial life history (i.e., live in lakes but migrate into rivers or streams to spawn). Adults and juveniles reside in the lake for most of the year. In spring, adult Arctic grayling migrate into streams soon after ice break-up to spawn. Adults move back into the lake soon after spawning. Eggs hatch in June and young-of-the-year rear in natal streams for the summer, moving upstream to Kennady Lake or downstream to overwintering habitat in lakes by late August. Young-of-the-year Arctic grayling may move upstream or downstream depending upon their location in relation to overwintering habitat (Stewart et al. 2007).

Table 8.3-35 Timing of Stream Utilization by Adfluvial Arctic Grayling in the Northwest Territories



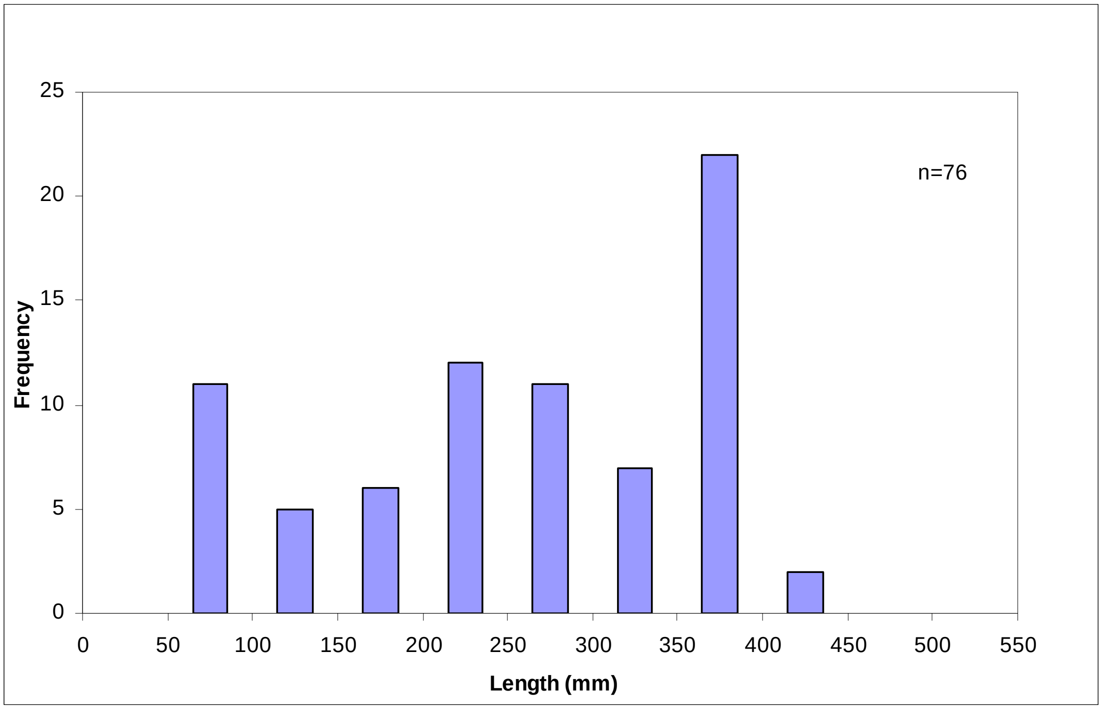
YOY = young-of-year. Adapted from Stewart et al. (2007)

Figure 8.3-37 Comparison of Arctic Grayling Movements into Kennady Lake Tributaries, Spring 2000 and 2004



Arctic grayling moving into tributaries in spring ranged in length between 50 and 450 mm but most (75%) were greater than 200 mm (Figure 8.3-38). Mean length and weight of Arctic grayling captured in tributaries in spring 2004 was 263 mm and 306 grams (g), respectively. The resulting mean condition factor for these fish was 1.1. Although aging data are limited, most Arctic grayling greater than 200 mm were three years of age or older and most of Arctic grayling greater than 350 mm were six years old (Table 8.3-36). Based on the length frequency distribution, this suggests that Arctic grayling in Kennady Lake began spawning at three years of age but the majority of spawning fish were likely six years or older. Similar age structure of spawning Arctic grayling occurs in Great Slave Lake (Scott and Crossman 1973; Stewart et al. 2007).

Figure 8.3-38 Length-Frequency Distribution for Arctic Grayling Captured Moving into Kennady Lake Tributaries, Spring 2004



mm = millimetre.

Table 8.3-36 Length-at-Age and Weight-at-Age for Arctic Grayling Captured in Kennady Lake Tributaries, Spring 2004

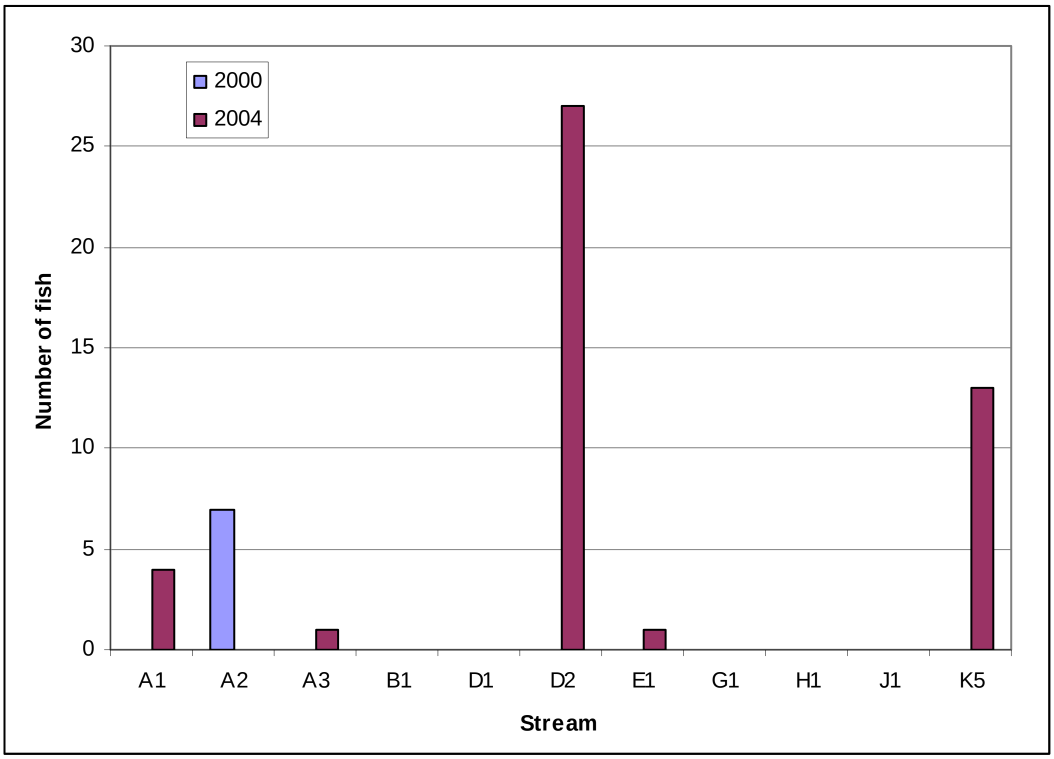
Age	Fork Length (mm)			Weight (g)		
	n	Mean	Range	n	Mean	Range
3+	5	207.4	197 to 221	5	116.0	90 to 200
4+	4	253.5	250 to 258	4	191.3	175 to 200
5+	2	211.5	201 to 222	1	126.6	-
6+	4	376.3	362 to 391	4	592.5	500 to 700
7+	1	253.0	-	1	172.5	-
8+	1	393.0	-	1	880.0	-

mm = millimetre; g = grams; n = number of fish; - = no data.

Northern pike were captured in streams of the A watershed in 2000 and 2004 and in relatively large numbers (27 fish) in the D watershed in 2004 (Figure 8.3-39). Lakes D2 and D3 on the western side of Kennady Lake appear to provide spawning habitat for a substantial proportion of northern pike in Kennady Lake. This is likely due to the abundance of aquatic vegetation in these lakes in comparison to Kennady Lake and other small lakes in the watershed.

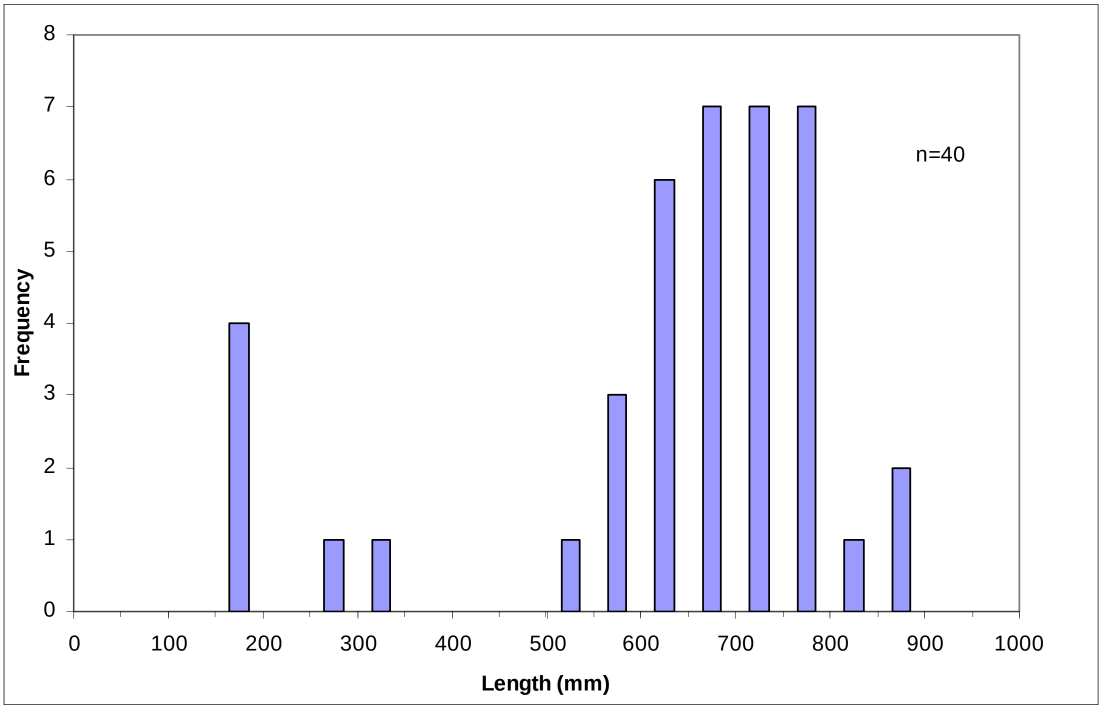
Northern pike were also observed moving out of Kennady Lake in spring (Stream K5) (Figure 8.3-39). These movements may represent spawning movements to areas of flooded aquatic vegetation along the shorelines and riparian areas of streams downstream, or may be pre-spawning feeding movements as northern pike take advantage of concentrations of Arctic grayling near the outlet of Kennady Lake.

Figure 8.3-39 Comparison of Northern Pike Movements into Kennady Lake Tributaries, Spring 2000 and 2004



Most northern pike captured in spring were large (mean length and weight of 631 mm and 2,624 g, respectively) mature fish. Northern pike ranged in length between 150 and 900 mm, but most (84%) northern pike captured in spring were greater than 550 mm (Figure 8.3-40). Although few northern pike were aged, length-at-age data indicated that most northern pike spawners in Kennady Lake are six years old or older (Table 8.3-37). This age-at-maturity is consistent with other northern pike populations at similar latitudes (Richardson et al. 2001).

Figure 8.3-40 Length-Frequency Distribution for Northern Pike Captured in Kennady Lake Tributaries, Spring 2004



mm = millimetre.

Table 8.3-37 Mean Length- and Weight-at-Age for Northern Pike Captured in Kennady Lake Tributaries, Spring 2004

Age (years)	Fork Length (mm)			Weight (g)		
	n	Mean	Range	n	Mean	Range
3+	1	340.0	-	1	150.0	-
4+	-	-	-	-	-	-
5+	-	-	-	-	-	-
6+	2	664.5	635 to 694	2	2,000.0	1,650 to 2,350
7+	3	671.3	584 to 755	3	2,641.7	1,650 to 3,875
8+	2	649.5	647 to 652	2	2,112.5	2,025 to 2,200
9+	-	-	-	-	-	-
10+	2	714.0	670 to 758	2	2,900.0	2,600 to 3,200
11+	-	-	-	-	-	-
12+	-	-	-	-	-	-
13+	1	875.0	-	1	6,700.0	-

n = number of fish; mm = millimetre; g = grams; - = no data.

8.3.8.2.6 Small Lakes Surveys

A summary of fish captured in each small lake sampled in the Kennady Lake watershed is provided in Table 8.3-38. Fish were captured in 12 of the 34 lakes sampled. Fish species captured included five sport fish (Arctic grayling, burbot, lake trout, northern pike, and round whitefish) and two forage fish species (ninespine stickleback, and slimy sculpin). For the most part, abundance of fish was low in all lakes.

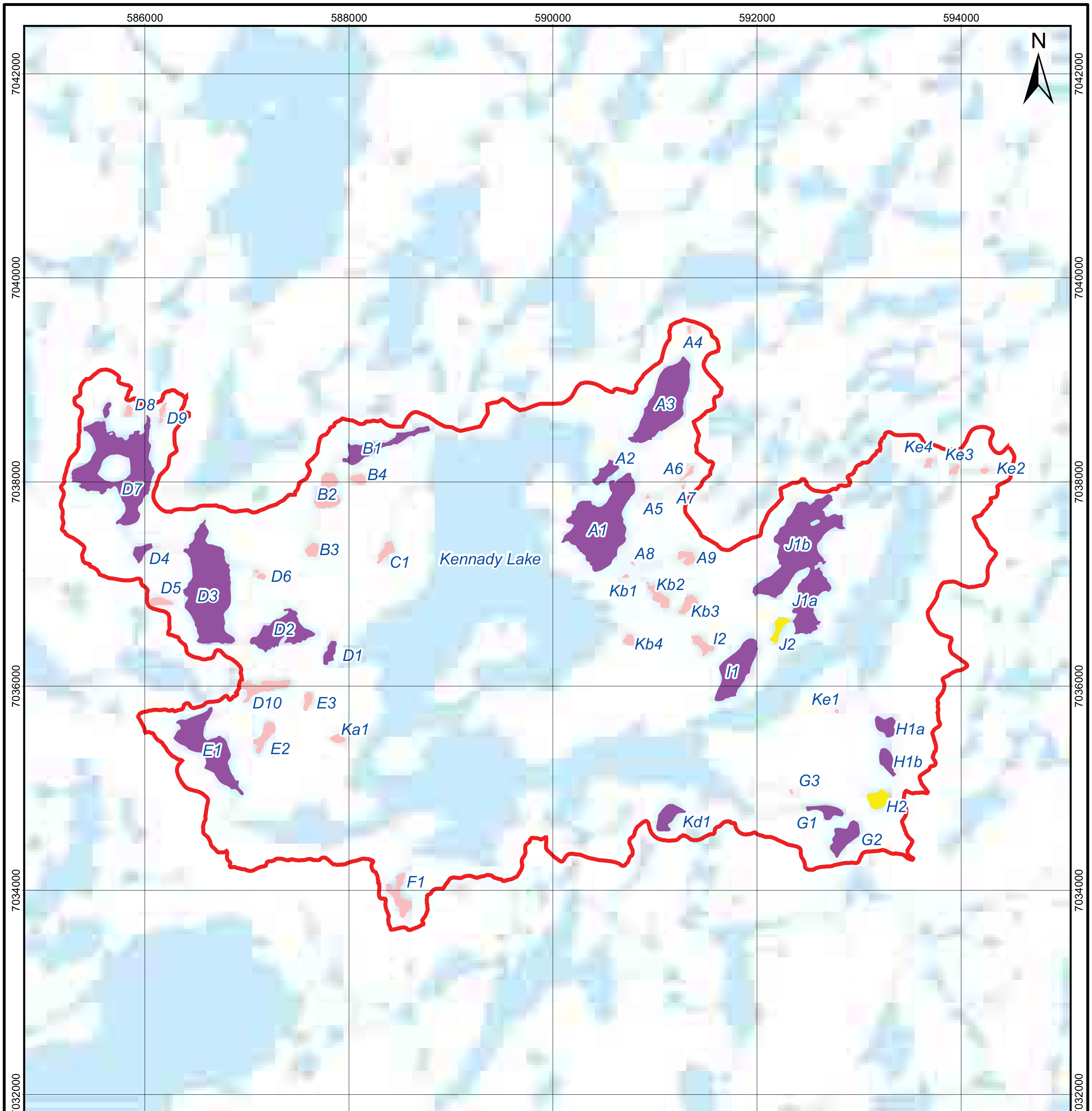
Figure 8.3-41 shows the fish-bearing status of lakes within the Kennady Lake watershed. Many of these small lakes were designated as fish-bearing, meaning fish were captured or there was a connection to another fish-bearing lake or stream. As outlined in Annex J, lakes were designated as non-fish bearing if no fish were captured, the maximum depths were too shallow for overwintering fish (i.e., less than 3 m), and there was no connection to fish-bearing lakes or streams during high flows (i.e., spring).

Lake I1 includes a self-sustaining population of lake trout; adult and juvenile lake trout were captured in this lake in 1996 and 2004. This lake has a maximum depth of 11 m and is connected to Area 8 of Kennady Lake by an ephemeral stream flowing through a shallow wetland. The presence of juvenile lake trout, the availability of cobble/boulder substrates suitable for spawning below the ice scour zone (2 m), and the ephemeral nature of Stream I1 suggests strongly that lake trout are successfully spawning and rearing in Lake I1. Arctic grayling, slimy sculpin, and ninespine stickleback were also captured in this lake in 1996.

Table 8.3-38 Fish Species Captured in Small Lakes within the Kennady Lake Watershed

Lake	Fish Species
A1	ARGR, BURB, RNWH
A2	-
A3	ARGR, BURB, LKTR, NRPK
A4	-
A5	-
A6	-
A7	-
A8	-
A9	-
B1	ARGR, LKTR, NNST, SLSC
B2	-
D1	BURB, NRPK
D2	NRPK
D3	BURB, LKTR, NRPK
D7	ARGR, BURB, NRPK
D10	-
E1	NRPK, SLSC
E2	-
E3	-
F1	-
G2	NNST
H1a	NNST, SLSC
H1b	-
I1	ARGR, LKTR, NNST, SLSC
I2	-
J1a	-
J1b	BURB
J2	-
Ka1	-
Kb1	-
Kb2	-
Kb3	-
Kb4	-
Kd1	-

ARGR = Arctic grayling; BURB = burbot; LKTR = lake trout; NRPK = northern pike; RNWH = round whitefish; NNST = ninespine stickleback; SLSC = slimy sculpin; - = no fish captured.



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LEGEND

- Watercourse
- Waterbody
- Kennady Lake Watershed Boundary
- A2 Lake Identifier

Fish Presence

- Fish-Bearing
- Non-Fish-Bearing
- Fish Presence Unknown

NOTES

Base data source: National Topographic Base Data (NTDB) 1:50,000

GAHCHO KUÉ PROJECT

Fish-Bearing Status of Small Lakes in the Kennady Lake Watershed

PROJECTION: UTM Zone 12	DATUM: NAD83	
Scale: 1:55,000 1 0.5 0 1 Kilometres		
FILE No: B-Fish-057-GIS		DATE: November 24, 2010
JOB NO: 09-1365-1004	REVISION NO: 5	
OFFICE: GOLD-CAL	DRAWN: SK	CHECK: AL

Figure 8.3-41

8.3.8.2.7 Stream Fish Inventory Surveys

Table 8.3-39 shows the fish species captured in streams sampled within the Kennady Lake watershed. In summer sampling, juvenile Arctic grayling were very abundant in streams within the Kennady Lake watershed and typically comprised over 90% of the total catch. Ninespine stickleback were also abundant at two of the sites sampled. Juvenile burbot and northern pike, and slimy sculpin were also found in streams in summer but in substantially lower numbers.

In the Kennady Lake watershed, streams in the larger catchments (i.e., A, B, and D catchments) were used by Arctic grayling for spawning and by northern pike as access corridors to upstream lakes in spring. Smaller tributaries are used primarily by slimy sculpin and ninespine stickleback.

Table 8.3-39 Fish Captured in Streams Surveyed in the Kennady Lake Watershed

Stream	Fish Species Captured
A1	ARGR, BURB, LKCH[a], NNST, NRPK, SLSC
A2	ARGR, BURB, NRPK
A3	ARGR, BURB, LKTR, NNST, NRPK
B1	ARGR
D1	ARGR, BURB, NNST
D2	ARGR, BURB, NRPK, SLSC
D4	SLSC
D7	SLSC
E1	ARGR, BURB, NNST, NRPK
G1	-
H1a	NNST, NRPK
H1b	NNST
J1a	ARGR
Kd1	NNST
Ke3	NNST

(a) Lake chub in stream A1 originally identified as peamouth. Subsequent sampling and identification has confirmed that lake chub are present, and that the peamouth were likely misidentified.

ARGR = Arctic grayling; NRPK = northern pike; BURB = burbot; SLSC = slimy sculpin; LKCH = lake chub; LKTR = lake trout; NNST = ninespine stickleback; - = no fish captured.

8.3.8.2.8 Fish Movements

Lake trout exhibit a lacustrine life history in Kennady Lake and generally conduct all of their life history requirements in the lake. Lake trout have been observed moving through the Kennady Lake outlet in spring, presumably feeding on congregations of spawning Arctic grayling. Radio-tagged lake trout moved freely between all areas of Kennady Lake but generally avoided Area 8 in summer.

This is likely due to its shallower depth and limited cover compared to other areas of the lake.

Similar to lake trout, round whitefish in Kennady Lake exhibit a lacustrine life history, conducting all of their life history requirements (spawning, rearing, foraging, and overwintering) in the lake. Too few round whitefish were radio-tagged to confirm movements in the lake. However, no round whitefish were ever observed moving out of, or into, Kennady Lake in spring. No tagged round whitefish was ever captured downstream of Kennady Lake.

Adult Arctic grayling were found primarily in offshore areas of Kennady Lake in summer and, based on radio-telemetry, move freely between all areas of the lake. Although some populations are known to make extensive migration (up to 320 km) from overwintering areas to spawning grounds (Evans et al. 2002), Arctic grayling in Kennady Lake rarely moved more than 2 km downstream in spring. Like lake trout, Arctic grayling typically avoid the shallower Area 8. Juvenile Arctic grayling were found in littoral areas in summer but are also likely to use deeper, offshore areas as well.

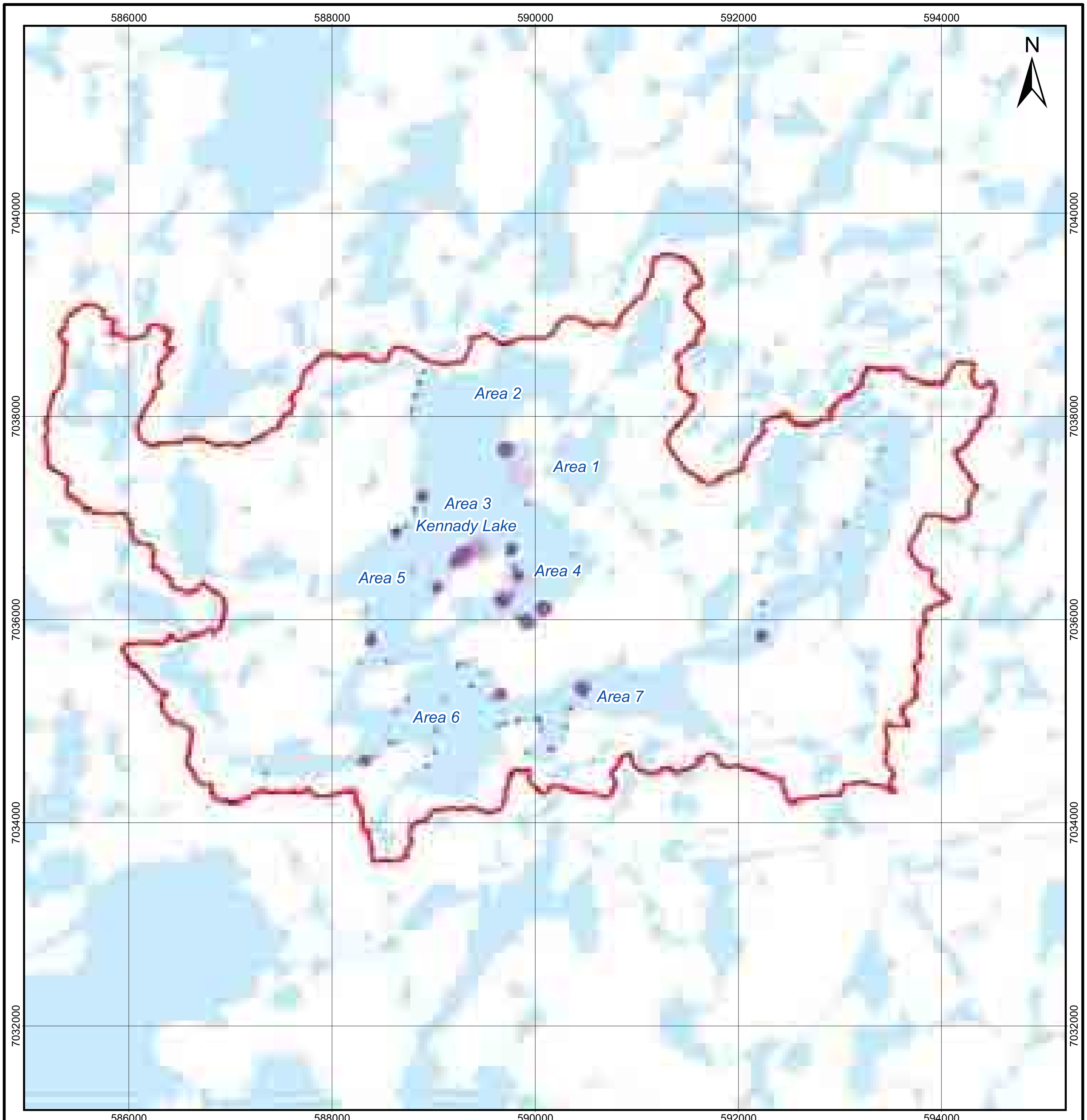
Northern pike appear to only move locally in Kennady Lake and most northern pike were located in Areas 6 and 7, where aquatic vegetation existed in protected embayments.

8.3.8.2.9 Fall Spawning Surveys

Lake trout are fall spawners and begin to congregate near spawning locations at water temperatures less than 10ºC. In Kennady Lake, this typically occurs in September or early October. Peak spawning usually occurs in late September in Kennady Lake.

The primary lake trout spawning site in Kennady Lake is the northern shore of the island separating Areas 3 and 5 from Area 4 (Figure 8.3-42). This is based on two lines of evidence:

- concentrations of ripe (pre-spawning condition) and spent (post-spawning condition) lake trout were highest in gillnets set around the northern half of this island; and
- the largest numbers of radio-tagged lake trout were also found along the Areas 3 and 5 shoreline of this island in fall.



LEGEND

- Watercourse
- Waterbody
- Kennady Lake Watershed Boundary
- *Area 1* Kennady Lake Area Identifier

Catch-Per-Unit-Effort (# of fish/100 m^2/12 hours)

- 0.0
- 0.1 - 3.0
- 3.1 - 6.0
- 6.1 - 9.0
- 9.1 - 12.0

NOTES
Base data source: National Topographic Base Data (NTDB) 1:50,000

GAHCHO KUÉ PROJECT

Lake Trout Catch-Per-Unit-Effort, Fall 2004

PROJECTION: UTM Zone 12	DATUM: NAD83		
Scale: 1:55,000 (1 0.5 0 1 Kilometres)			
FILE No: B-Fish-055-GIS			DATE: November 24, 2010
JOB NO: 09-1365-1004	REVISION NO: 5		
OFFICE: GOLD-CAL	DRAWN: SK	CHECK: AL	**Figure 8.3-42**

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Habitat along the shoreline of this island is near optimal for lake trout spawning in that it has predominantly clean boulder/cobble substrates, is located directly adjacent to deep (greater than 10 m) areas on both sides, and is exposed to the largest fetch (greater than 1.5 km) in the lake. This latter characteristic serves to keep boulder substrates clean from silt and fine organic sediment accumulation.

Lake trout are likely to use other spawning sites in Kennady Lake besides this island. Sexually mature lake trout were found in all areas of Kennady Lake during fall sampling. Most shoreline areas of Kennady Lake have boulder/cobble substrates suitable for lake trout spawning and it is likely that many of these shorelines, particularly those exposed to fetches greater than 500 m, are used by spawning lake trout.

Round whitefish spawn later in fall than lake trout, typically at water temperatures between 2 and 5.5°C (Wismer and Christie 1987) and may spawn just before lake freeze-up (Morrow 1980). This delayed spawning is the likely reason why accumulations of ripe round whitefish were not observed during fall surveys and why spawning locations in Kennady Lake could not be positively identified. However, round whitefish have similar spawning requirements as lake trout (Richardson et al. 2001) and it is likely that round whitefish in Kennady Lake use the northern shoreline of the island separating Areas 3 and 5 from Area 4 extensively for spawning.

8.3.8.2.10 Metals in Fish Tissues

The metal concentrations in the muscle tissue of lake trout from Kennady Lake and Lake N16 are summarized in Table 8.3-40. Concentrations of aluminum, antimony, beryllium, boron, silver, thallium, and tin were below analytical detection limits in 75% or more of the fish that were analyzed and are not presented here for this reason. Mean and maximum arsenic, chromium, mercury, and vanadium concentrations in lake trout muscle tissue exceeded the risk-based screening criteria for human consumption (Table 8.3-40).

Arsenic concentrations in most samples of lake trout muscle tissue were equal to or less than the analytical detection limits, which ranged from 0.01 to 0.05 mg/kg ww. Arsenic concentrations reported above the detection limits ranged from 0.02 to 0.30 mg/kg ww. Although detection limits were too high to draw definitive conclusions, naturally occurring arsenic concentrations in muscle tissue of lake trout may be above the risk-based criterion of 0.021 mg/kg ww.

Chromium and vanadium were detected in more than 50% of lake trout muscle samples from Kennady Lake and Lake N16. Chromium concentrations reported above the detection limits ranged from 0.05 to 0.79 mg/kg ww, which were higher than the risk-based criterion of 0.063 mg/kg ww. Detection limits for vanadium were higher in samples from 1996 than those from 2004, and the maximum concentrations summarized in Table 8.3-40 reflect these differences in detection limits. Vanadium was only detected in the 2004 samples, at concentrations ranging from 0.008 to 0.045 mg/kg ww, with most concentrations slightly higher than the risk-based criteria of 0.019 mg/kg ww. These values suggest that naturally occurring chromium and vanadium concentrations in muscle tissue of lake trout may be higher than the risk-based criteria.

Total mercury was detected in most of the lake trout muscle samples from both lakes. Concentrations reported above the detection limits ranged from 0.06 to 1.4 mg/kg ww, which were higher than the risk-based criterion of 0.028 mg/kg ww for methyl mercury. No analysis of methyl mercury was undertaken, but it is generally accepted that total mercury levels in fish muscle are reliable indicators of methyl mercury, as methyl mercury can contribute to at least 90% of the total methyl mercury concentration values in fish tissue (Rai et al. 2002; Lasorsa and Allen-Gil 1995). Methyl mercury is the form of mercury that poses a public health risk in fish and shellfish tissue due to its tendency to bioaccumulate (US EPA 1997). The detected concentrations of total mercury in muscle tissue of lake trout suggest that naturally occurring concentrations may exceed the risk-based criterion for human consumption.

Table 8.3-40 Overall Mean and Maximum Metal Concentrations (mg/kg wet weight) in Lake Trout Muscle Tissue Samples Collected from Kennady Lake and Lake N16 between 1996 and 2007

Parameter	Kennady Lake		Lake N16		Risk-based criteria [c]
	Mean[a]	Maximum[b]	Mean[a]	Maximum[b]	
Arsenic	0.036	0.10	0.065	0.30	0.021
Barium	0.050	0.090	0.056	0.36	54
Cadmium	0.015	0.15	0.014	<0.20	0.28
Chromium	0.15	0.64	0.17	0.79	0.063[d]
Cobalt	0.050	<0.080	0.050	<0.080	0.082
Copper	0.47	1.8	0.62	2.2	11
Iron	2.6	5.0	3.8	7.4	190
Lead	0.032	0.72	0.020	0.090	nc
Manganese	0.077	<0.16	0.099	0.36	38
Mercury	0.30	<0.79	0.36	1.4	0.028[e]
Molybdenum	0.033	<0.040	0.035	0.16	1.36
Nickel	0.10	1.4	0.15	1.6	5.4
Selenium	0.31	0.43	0.28	0.40	1.4
Strontium	0.29	0.93	0.26	1.6	162
Titanium	0.45	1.4	0.33	1.2	nc
Vanadium	0.067	<0.14	0.066	<0.14	0.019
Zinc	3.2	6.5	3.1	10	82

Note: Shaded values equal or exceed the US EPA risk-based criteria.
Metal concentrations are presented as mg/kg wet weight.

(a) Detection limits were used to calculate mean metal concentrations for individuals with metal concentrations below detection limit.

(b) When indicated by a less than sign (<), the maximum concentration was reported at below the sample-specific detection limit.

(c) Risk-based criteria for fish consumption were based on a 70 kg individual consuming 54 g of fish per day over a 70-year period (US EPA 2010). The US EPA screening values were adjusted to a carcinogenic risk of 1E-5 and a hazard quotient of 0.2 for non-carcinogens (carcinogens were multiplied by 10 and non-carcinogens were multiplied by 0.2). When criteria were available for both carcinogenic and non-carcinogenic exposure scenarios, the lowest value was used.

(d) Criterion is for hexavalent chromium.

(e) Criterion is for methyl mercury.

US EPA = United States Environmental Protection Agency; nc = no criterion; mg/kg = milligram per kilogram.

The metal concentrations in the muscle tissue of round whitefish from Kennady Lake and Lake N16 are summarized in Table 8.3-41. Concentrations of aluminum, antimony, beryllium, boron, iron, manganese, silver, tin, and vanadium were below analytical detection limits in 75% or more of the fish that were analyzed and are not presented here for this reason. Mean and maximum chromium and mercury concentrations in round whitefish muscle tissue from both lakes and mean and maximum arsenic concentrations from Lake N16 exceeded the risk-based screening criteria for human consumption (Table 8.3-41).

Concentrations of all other metals were below screening criteria, when criteria were available.

Arsenic was detected in almost all muscle tissue samples from Lake N16, but was not detected in any samples from Kennady Lake. Detection limits in the Kennady Lake samples ranged from 0.01 to 0.05 mg/kg ww, and the maximum detection limit was higher than the risk-based criterion of 0.021 mg/kg ww. In muscle tissue of round whitefish from Lake N16, arsenic concentrations ranged form 0.03 to 0.49 mg/kg ww, which suggests that naturally occurring arsenic concentrations in muscle tissue of round whitefish from Lake N16 may be above the risk-based criterion of 0.021 mg/kg ww.

Chromium concentrations in most round whitefish muscle tissue samples from Kennady Lake and Lake N16 were equal to or below the detection limits. Detection limits varied among samples, and ranged from 0.11 to 0.39 mg/kg ww. The maximum concentration reported above the sample-specific detection limit was 0.17 mg/kg ww in a fish from Lake N16. Given that detection limits were higher than the risk-based criteria, and any detected concentrations were only slightly above detection limits, it cannot be determined if naturally occurring chromium concentrations in round whitefish muscle tissue are above the risk-based criterion of 0.063 mg/kg ww.

Total mercury was detected in about 50% of the round whitefish muscle tissue samples from Lake N16, but in only three samples from Kennady Lake. Detection limits also varied among samples, and ranged from 0.02 to 0.14 mg/kg ww. The concentrations reported above the sample-specific detection limits ranged from 0.05 to 0.37 mg/kg ww, which are above risk-based criterion of 0.028 mg/kg ww for methyl mercury. As stated for lake trout, it is assumed that total mercury concentrations in fish muscle are reliable indicators of methyl mercury. The detected concentrations of total mercury in muscle tissue of round whitefish suggest that naturally occurring concentrations may exceed the risk-based criterion for human consumption.

Table 8.3-41 Overall Mean and Maximum Metal Concentrations (mg/kg wet weight) in Round Whitefish Muscle Tissue Samples Collected from Kennady Lake and Lake N16 between 1996 and 2007

Parameter	Kennady Lake		Lake N16		Risk-based criteria [c]
	Mean[a]	Maximum[b]	Mean[a]	Maximum[b]	
Arsenic	0.014	<0.050	0.15	0.49	0.021
Barium	0.035	0.14	0.056	0.31	54
Cadmium	0.013	0.030	0.011	0.028	0.28
Chromium	0.12	0.19	0.17	<0.39	0.063[d]
Cobalt	0.013	0.026	0.018	0.040	0.082
Copper	0.34	0.68	0.43	0.77	11
Lead	0.016	0.088	0.011	0.013	nc
Mercury	0.088	0.17	0.10	0.37	0.028[e]
Molybdenum	0.027	0.070	0.022	0.025	1.36
Nickel	0.024	0.048	0.038	0.13	5.4
Selenium	0.30[f]	0.30	0.40[f]	0.40	1.4
Strontium	0.50	1.7	0.58	3.0	162
Zinc	2.6	5.3	3.3	5.7	82

Note: Shaded values equal or exceed the US EPA risk-based criteria.

Metal concentrations are presented as mg/kg wet weight.

[a] Detection limits were used to calculate mean metal concentrations for individuals with metal concentrations below detection limit.

[b] When indicated by a less than sign (<), the maximum concentration was reported at below the sample-specific detection limit.

[c] Risk-based criteria for fish consumption were based on a 70 kg individual consuming 54 g of fish per day over a 70-year period (US EPA 2010). The US EPA screening values were adjusted to a carcinogenic risk of 1E-5 and a hazard quotient of 0.2 for non-carcinogens (carcinogens were multiplied by 10 and non-carcinogens were multiplied by 0.2). When criteria were available for both carcinogenic and non-carcinogenic exposure scenarios, the lowest value was used.

[d] Criterion is for hexavalent chromium.

[e] Criterion is for methyl mercury.

[f] Only one fish was sampled.

US EPA = United States Environmental Protection Agency; nc = no criterion; mg/kg = milligram per kilogram.

8.4 WATER MANAGEMENT PLAN SUMMARY

8.4.1 Introduction

The following section provides a summary of the Water Management Plan that has been developed for the Gahcho Kué Project (Project). The primary purpose of this plan is to reduce the effect of the Project on the aquatic ecosystem of Kennady Lake and downstream environments during construction, operations, and closure phases.

The most significant water-related activity that will take place during the Project will be the dewatering of Areas 2 to 7 of Kennady Lake to allow access to the lake bed and underlying kimberlite pipes, and the subsequent restoration of the lake. The dewatering process will begin during the first year of construction (Year -2) and will take place during the open water season. To facilitate the dewatering process, natural drainage from the upper portion of the watershed will be diverted to the adjacent N watershed by the establishment of several earth filled dykes. Area 8 will be separated from the rest of Kennady Lake by the construction of a water retaining dyke (Dyke A).

It is expected that about half the water in Kennady Lake can be removed in the initial dewatering process. During this time, the discharge water will be partitioned between Area 8 and Lake N11, located northwest of Kennady Lake. As water levels in the lake decrease, particularly in Area 7, the concentrations of totals suspended solids (TSS) in the water are expected to increase, which will limit the period of time that water from Area 7 can be discharged to Area 8. During operations, water will be pumped from Areas 3 and 5 (the Water Management Pond [WMP]) to Lake N11; where necessary, water entering Area 5 may be treated with flocculants to reduce the TSS in the WMP.

The water management strategy developed for the Project considered economic and environmental constraints. This strategy is included in technical memoranda in Appendix 8.I, Attachment 8.I.1 for the construction and operations phases and Appendix 8.I, Attachment 8.I.2 for the closure phase. The Water Management Plan described herein is based on these technical memoranda, with emphasis placed on water quality considerations.

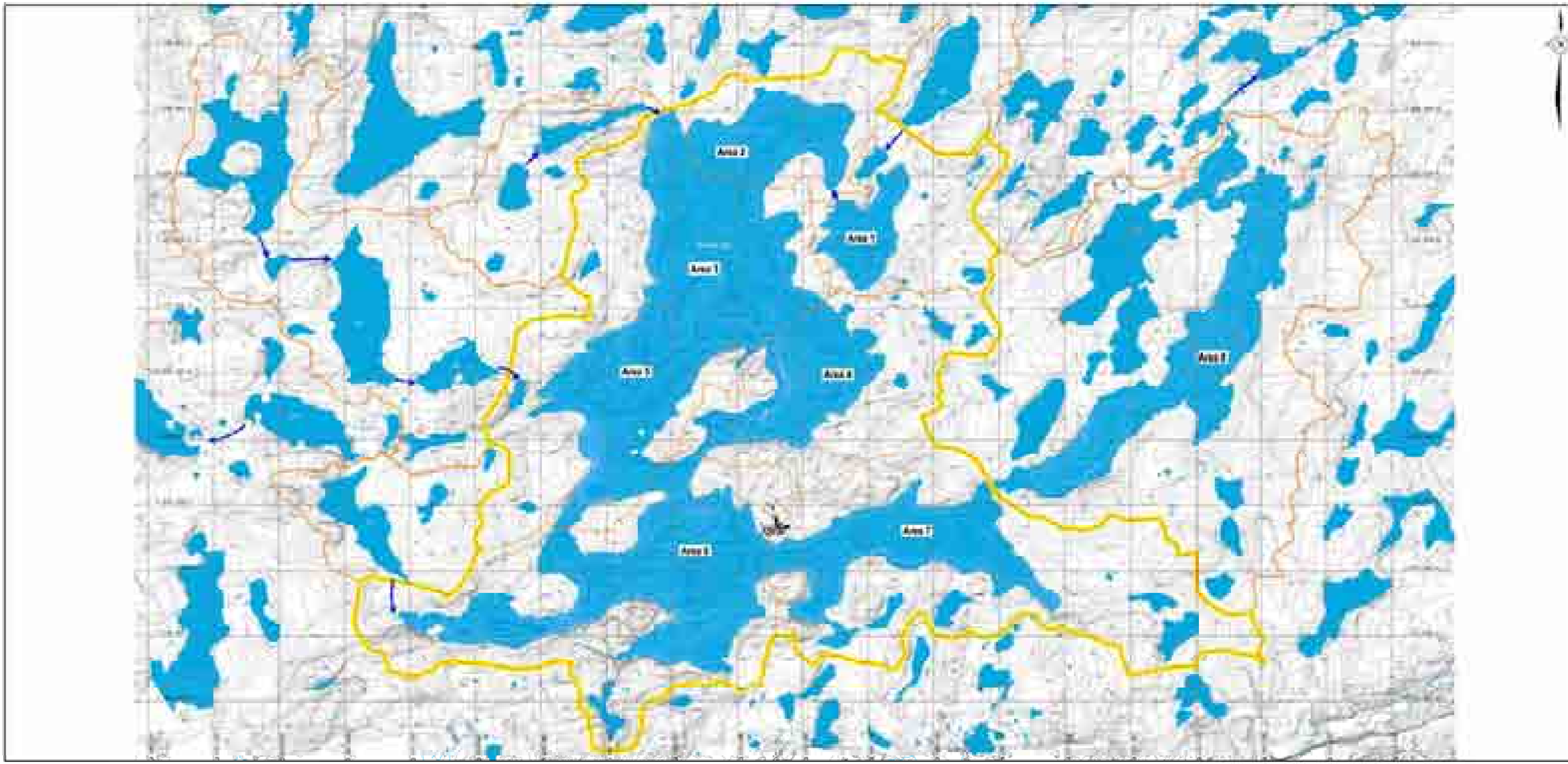
Respecting the constraints and considerations listed in Appendix 8.I, Attachments 8.I.1 and 8.I.2, the key objectives of the Water Management Plan are to:

- minimize the amount of water requiring discharge to downstream receptors during the initial dewatering period;
- manage mine water during the closure period to minimize water quality impacts within the WMP during the closure and post-closure periods; and
- manage waters within the Kennady Lake catchment area until the water quality is suitable for release, marking the transition to the post-closure period.

To facilitate the design of the Project Water Management Plan, Kennady Lake is divided into six principal areas whose limits are truncated by impermeable, earth-filled dykes and a filter dyke, as discussed in Section 8.4.2.3. Figure 8.4-1 illustrates the areas of Kennady Lake, their distinct watersheds and the upper watersheds of Kennady Lake. Table 8.4-1 provides a brief description of each area. The Water Management Plan presented in the subsequent sections is discussed with reference to these areas.

The Water Management Plan is also discussed in terms of the following time periods:

- Construction phase (initial dewatering) – Years -2 to -1. Kennady Lake is drawn down to increase available capacity and facilitate dyke construction; water is discharged to Lake N11 and Area 8.
- Operational phase – Years 1 to 11. Water is diverted from mine pits and lake areas to the WMP; water is discharged from the WMP to Lake N11, as long as the water quality in the WMP meets specific discharge criteria.
- Closure phase – Years 12 to 20. Water is transferred from the WMP to Tuzo Pit and Kennady Lake is refilled from natural drainage and water pumped from Lake N11.
- Post-closure (i.e., beyond closure) – Years 21 onwards. Kennady Lake receives only natural drainage and releases water to Area 8.



LEGEND

- Existing Ground Contours 5m Index + 1m Intermediate
- Bathymetry Contours 5m Index + 1m Intermediate
- Controlled Area Boundary
- Marsh Area
- Shrub
- Sub-watershed Boundary
- Drainage Flow Direction

NOTES
Base data source: EBA Figure 4.5 - Stage 2 - Water Management During Mine Operation Years 1 to 3 (2015 to 2017)

GAHCHO KUÉ PROJECT

Kennady Lake and its Watersheds

PROJECTION: UTM Zone 12	DATUM: NAD83
FILE No: E-SWQ-001-CAD	DATE: December 13, 2010
JOB No: 09-1365-1004	REVISION No: 1
OFFICE: GOLD - SAS	DRAWN: TAH/AJL / CHECK: JF

Figure 8.4-1

The construction phase of the Water Management Plan is described in Section 8.4.2. During construction the key activities related to water management will be the diversion of upper watersheds that flow into Kennady Lake, the initiation of dewatering of Kennady Lake, the construction of a dyke that separates the most downstream basin of Kennady Lake (Area 8) from Area 7, and the establishment of the WMP.

Table 8.4-1 Summary of Kennady Lake Areas

Area	Description
Areas 1 and 2 (Fine Processed Kimberlite Containment Facility)	Located in the northeast embayment of Kennady Lake (Area 2) and most of the A watershed (Area 1). Areas 1 and 2 are designated for fine processed kimberlite deposition.
Areas 3 and 5 (i.e., Water Management Pond)	This area will operate as the site Water Management Pond and will provide the primary source of process reclaim water. It is located in north of Kennady Lake.
Area 4	Located to the southeast of the Water Management Pond. Location of the Tuzo kimberlite pipe.
Area 6	Located to the south of the Water Management Pond. Location of the 5034 and Hearne kimberlite pipes.
Area 7	Truncates Area 6 to the east.
Area 8	East basin of Kennady Lake outside of Project footprint.

The operations phase of the Water Management Plan is described in Section 8.4.3. During operation, Project activities associated with the Water Management Plan will be designed to minimize the discharge of site water to downstream waterbodies unless specific water quality criteria are met, and to recycle process water to the greatest extent possible. During the operations phase of the Project, water for use in the processing plant will be sourced from the WMP. After the Fine Processed Kimberlite Containment (PKC) Facility has been closed, the groundwater flowing into the open pits will be the primary source of make-up water for the processing facility.

The closure phase of the Water Management Plan is discussed in Section 8.4.4. At closure, the WMP (Areas 3 and 5), and Area 7 will contain water, Area 4 will be effectively dewatered and Area 6 will be partially dewatered. After mining has been completed, the natural drainage system in the Kennady Lake watershed will be restored and refilling of the dewatered lake-beds will begin. Refilling of the lake is scheduled to start in Year 12 and is expected to take eight years. Runoff from the mine rock piles, Coarse PK Pile, Fine PKC Facility, plant site, and airstrip will flow to the lake and be used to assist in refilling the lake. Water will also be pumped from Lake N11 during the last three weeks of June and the first three weeks of July of each year. Once Areas 3 to 7 are refilled to the same elevation as Area 8, and the water quality within the refilled lake is acceptable, the in-lake portion of Dyke A will be removed, and the refilling of Kennady Lake will be complete. Flow from Areas 3 to 7 of Kennady Lake to Area 8 will then resume.

Annual inflows to and outflows from the close-circuit site water management system (e.g., the Project mechanism to which all elements of site contact and mine contact water, potable and plant water supply, pumped inflows and discharges, and natural inflows and outflows are managed and facilitated) are briefly summarized in Table 8.4-2; however, the water balance in Section 8.4.5 provides a quantitative summary for the construction, operations, closure and post-closure phases of the Project.

Table 8.4-2 Description of Inflows to and Outflows from the Water Management System

Source of Inflows	Destination of Outflows
- direct precipitation and surface runoff from the Project site and natural surface runoff from adjacent catchments - groundwater inflows to the open pits - drainage from the mine rock and Coarse PK piles, and Fine PKC Facility - freshwater drawn from Area 8 - freshwater pumped from Lake N11 to expedite refilling of Kennady Lake	- water pumped to Area 8 and Lake N11 during the dewatering of Kennady Lake - water pumped to Lake N11 during operations - natural discharge from Area 8 - evaporation and evapotranspiration losses

PK = processed kimberlite; PKC = Processed Kimberlite Containment.

The potential sources of change to water quality resulting from Project activities, including solid waste disposal, chemical storage and handling, and mine rock and PK disposal are discussed in Section 8.4.6. The potential accidents and malfunctions relevant to the Water Management Plan, including petroleum spills, ammonium nitrate spills, and dyke failures are also examined in Section 8.4.7.

For the Base Project Case assessed for the EIS, the Water Management Plan does not account for fish habitat compensation that may be constructed as part of the No Net Loss Plan. It is assumed that any environmental impacts associated with the No Net Loss Plan will be evaluated as part of the application to Fisheries and Oceans Canada (DFO).

8.4.2 Construction Phase

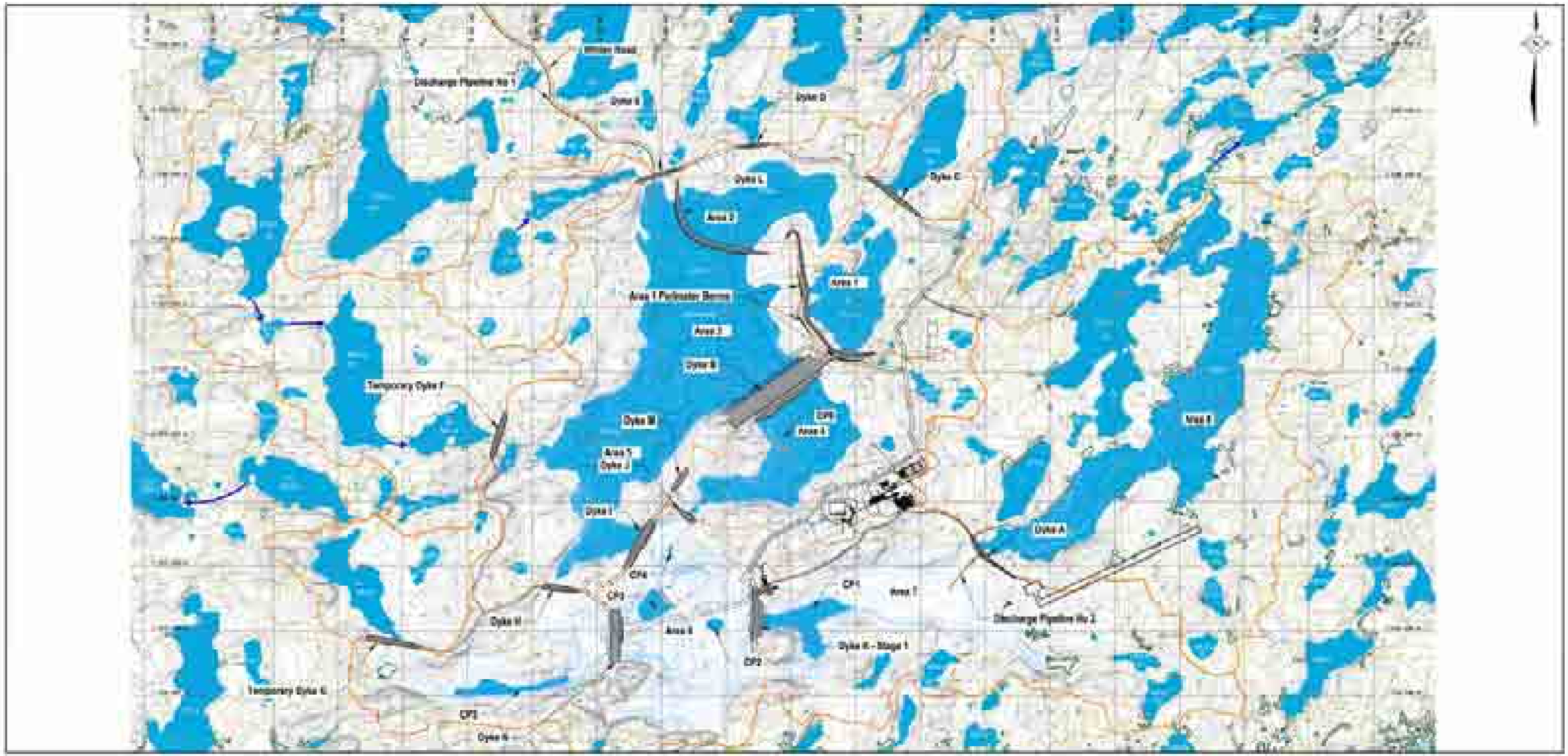
The following key water-related activities will take place during the construction phase of the Project:

- the majority of the upper Kennady Lake watershed (sub-watersheds A, B, D and E) will be diverted through the construction of dykes to facilitate the dewatering of Kennady Lake and Lake A1, and to isolate the WMP during operations;
- Kennady Lake will be dewatered to allow access to the lake-bed and the underlying kimberlite pipes;
- Dyke A will be constructed to separate Area 8 from Area 7 of Kennady Lake; and
- a WMP will be established in Areas 3 and 5 to collect mine water, process water, groundwater inflow, and drainage from the mine site and surrounding area.

8.4.2.1 Diversion of A, B, D and E Watersheds

The Fine PKC Facility will be located in the A watershed and the northeast embayment of Kennady Lake, which are identified as Areas 1 and 2, respectively. Area 1 includes the majority of the A watershed (i.e., Lakes A1 and A2) that drains into Kennady Lake in the northeast corner, but excludes Lake A3. Lake A3 will be isolated from Lakes A1 and A2 through the construction of a permanent saddle dyke (Dyke C) between Area 1 and Lake A3 to the north (Figure 8.4-2). Dyke C will serve to raise the level of Lake A3 to a point where the Lake A3 outlet will be permanently diverted into Lake N8. Lake A1 will be partially dewatered into Lake A3 after Dyke C is constructed.

To reduce surface inflows to Kennady Lake, a portion of the upper Kennady Lake watershed (watersheds B, D and E) will be isolated or diverted, so that the runoff from these watersheds is directed away from Kennady Lake. The diversion system will rely on temporary, earth-filled dykes that will be placed across the outlets of the B, D and E watersheds. Runoff from the B, D and E watersheds will be diverted to lakes in the N watershed. The surface water diversions from Kennady Lake are illustrated in Figure 8.4-3.



LEGEND

Existing Ground Contours
5m Index - 1m Intermediate

Bathymetry Contours
5m Index - 1m Intermediate

CP Collection Pond

Winter Road

Marsh Area

Scrub

Subwatershed Boundary

Drainage Flow Direction

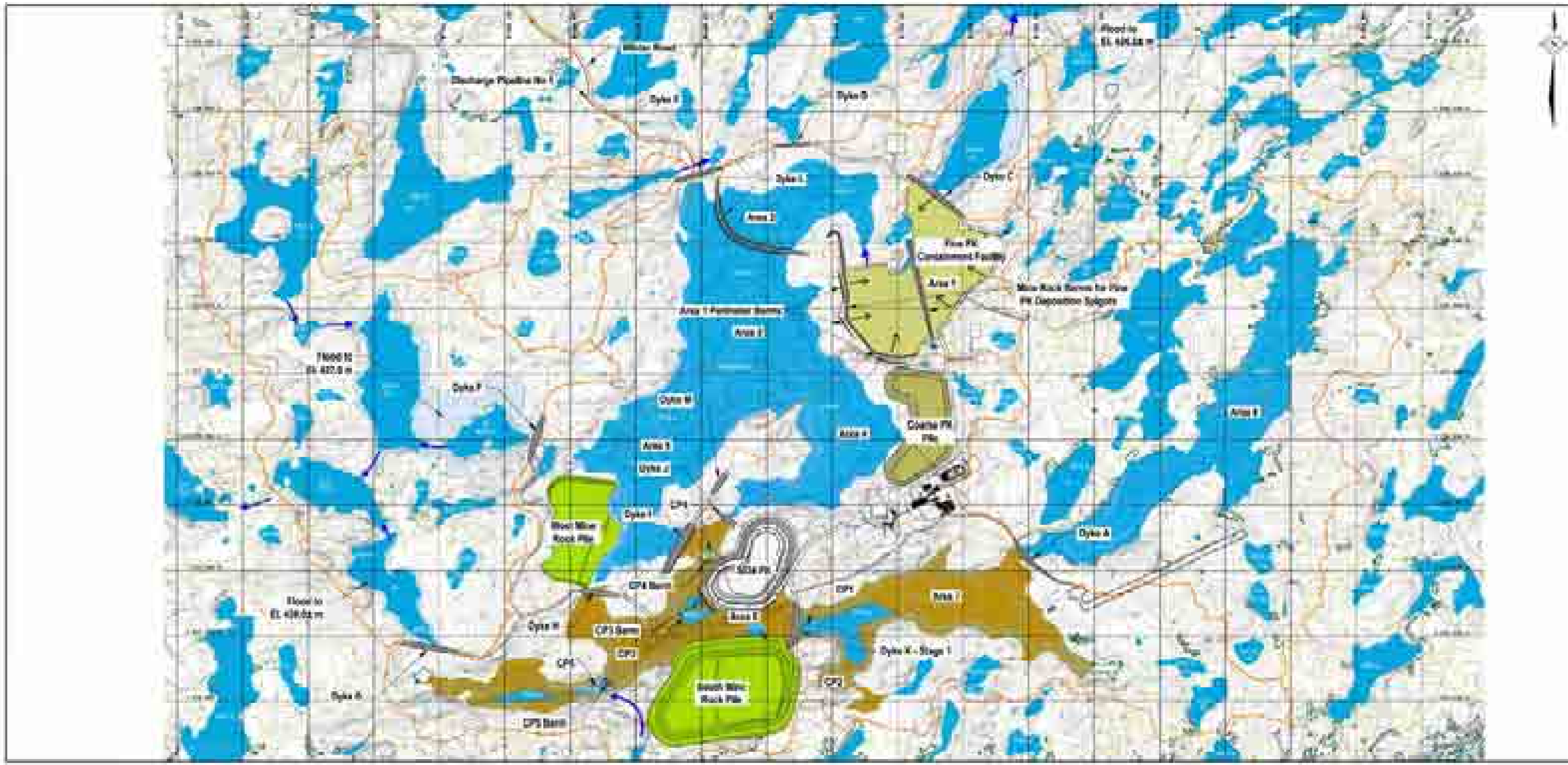
Discharge Pipeline

NOTES
Base data source: EBA Figure 4.2 - Stage 1 - Initial Lake Dewatering (June-July, 2013)

GAHCHO KUE PROJECT

Watershed Management Areas and Infrastructure Associated with the Project

PROJECTION: UTM Zone 12	DATUM: NAD83		
FILE No: E-SWQ-002-CAD			DATE: November 2, 2010
JOB No: 09-1365-1004	REVISION No: X		Figure 8.4-2
OFFICE: GOLD - SAS	DRAWN: AKG/TAH	CHECK: JF	



LEGEND

Existing Ground Contours 5m Index - 1m Intermediate
Bathymetry Contours 5m Index - 1m Intermediate
CP Collection Pond
Winter Road
Marsh Area
Shrub
Sub-watershed Boundary
Drainage Flow Direction
Discharge Pipeline
Coarse PK
Drained Area
Fine PK
Flooded Areas
Lake/Pond
Mine Rock

NOTES
Base data source: EBA Figure 4.5 - Stage 2 - Water Management During Mine Operation Years 1 to 3 (2015 to 2017)

GAHCHO KUE PROJECT

Surface Water Diversions Associated with the Project - Mining Operations Years 1 to 3 (2015 - 2017)

PROJECTION: UTM Zone 12
DATUM: NAD83
FILE No: E-SWQ-003-CAD
DATE: November 2, 2010
JOB No: 09-1365-1004
REVISION No: X
OFFICE: GOLD - SAS
DRAWN: AKG/TAH
CHECK: JF

Figure 8.4-3

8.4.2.2 Use of Area 8 as the Potable Water Supply

During construction and operations, potable water, fire protection water, and other fresh water requirements will be sourced from Area 8. The freshwater intake and pumphouse will be located on the northern shore. The intake design will consist of a prefabricated pumping station located on a rockfill embankment, with a submerged intake pipe located in the lake. The intake will be screened per DFO guidelines (DFO 1995) to limit fish entrainment in the pumps, and any piping exposed to freezing temperatures will be heat traced.

8.4.2.3 Dewatering of Kennady Lake

Dewatering of Kennady Lake is expected to begin in Year -1 and will continue throughout the operational period. Dewatering will entail pumping water from Kennady Lake to provide access to the open pits. Fish salvage will be conducted to remove fish before and during dewatering. The water will be pumped to Lake N11, which is located approximately 2 km northwest of Kennady Lake. Dewatering activities are sequenced to coincide with the mine production plan (Table 8.4-3). Area 7 will be initially dewatered to Area 8 to permit access to the 5034 Pit, and subsequent mining of the Hearne and Tuzo pits will require complete dewatering of Areas 6 and 4, respectively. Once water quality in Area 7 approaches specific criteria, which will likely include turbidity or TSS concentrations, discharge to Area 8 will cease.

Table 8.4-3 Mine Production Plan

Year	Production Pit
-2	5034
-1	5034
1	5034
2	5034
3	5034
4	5034/Hearne
5	5034/Hearne/Tuzo
6	Hearne/Tuzo
7	Hearne/Tuzo
8	Tuzo
9	Tuzo
10	Tuzo
11	Tuzo

To retain water in the appropriate Kennady Lake areas and to manage potentially large recharge volumes, several dykes will be constructed. The dykes will be designed to achieve the following objectives:

- divert water from upstream catchment areas (e.g., A, B, D and E catchments) to minimize Kennady Lake recharge during the construction and operational phases (Section 8.4.2.1);
- permanently separate the contents of the Fine PKC Facility from Lakes A3 and N7;
- provide additional storage capacity for water management facilities (e.g., WMP) that are required during operations; and
- isolate areas of Kennady Lake (e.g., Area 4 and Area 6) that require dewatering for open pit access.

A description of the key dykes that will be required to manage Kennady Lake water is provided in Table 8.4-4. The location of these dykes is presented in Figure 8.4-2.

Table 8.4-4 Summary of Project Dykes

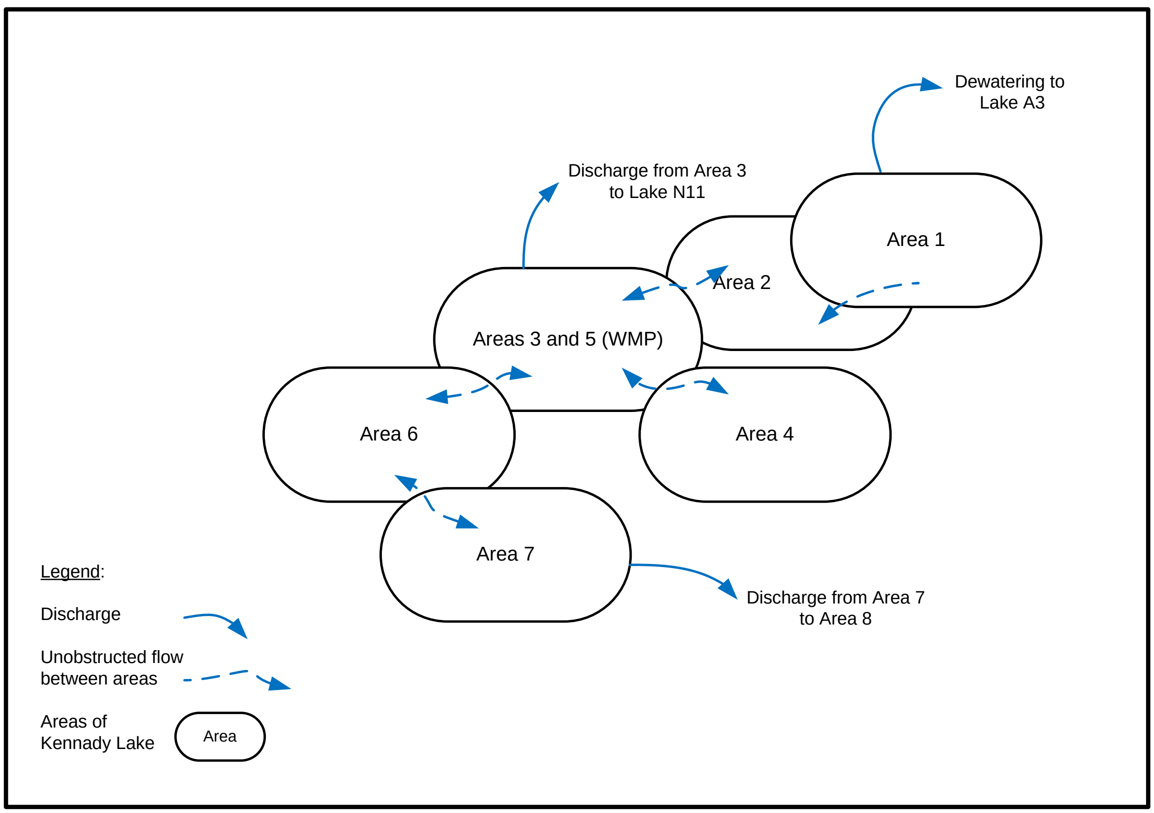
Dyke	Description
Dyke A	Isolates Kennady Lake from Area 8.
Dyke C	Separates Lake A3 from the Fine PKC Facility (Areas 1 and 2). Raises the lake elevation in Lake A3 to divert runoff from Lake A3 to Lake N9.
Dyke F	Used to raise the lake elevation in Lakes D1 and D2 to divert outflow to Lake N14.
Dyke G	Used to raise the lake elevation in Lake E1 to divert outflow to Lake N14.
Dyke L	Filter dyke used to minimize suspended solids load from the Fine PKC Facility to the WMP.
Dyke E	Diverts runoff from the B Lakes watershed into the N Lake system.
Dyke D	Separates the Fine PKC Facility (Areas 1 and 2) from Lake N7.
Dykes H, I and J	Internal dykes used to separate Area 5 from Area 6 to allow complete dewatering of Area 6.
Dykes B, J and M	Dykes located between Area 4 and the WMP. Permits dewatering of Area 4 in preparation for mining the Tuzo open pit.
Dyke K	Isolates Area 6 from Area 7. Permits refilling of Area 7.
Dyke N	Located east of the Hearne Pit. Permits refilling of Hearne Pit and Area 6.

PKC = Processed Kimberlite Containment; WMP = Water Management Pond

Key water management flows during the initial dewatering period are presented in Figure 8.4-4. The initial dewatering period will commence following completion of Dyke A, which will isolate the majority of Kennady Lake from Area 8. At this point, water will be pumped from the WMP to Lake N11 and from Area 7 to

Area 8. As the water level is drawn down in Area 6 and Area 7, it is expected that lakebed sediment disturbance will increase TSS concentrations in these areas. Water quality will be monitored, and when it is determined that water quality parameters, such as turbidity or TSS, are approaching specific criteria, discharge to Area 8 will cease. All the water pumped out of Kennady Lake from this point onwards will be released into Lake N11 at a maximum discharge rate of 500,000 m^3/d. Water in Area 6 and Area 7 will be treated in-line as it is pumped to the WMP for flocculation and settling and subsequently discharged to Lake N11. All other site waters, such as dewatering discharge from the Fine PKC Facility (Areas 1 and 2) and Area 4, will report to the WMP to be pumped to Lake N11 during the initial dewatering period.

Figure 8.4-4 Diagram of Initial Dewatering during Construction



A pervious dyke may be constructed within Area 5, if required, to assist settling of floc-treated water pumped from Areas 6 and 7. The dyke would consist of the north-eastern edge of the West Mine Rock Pile (toe of the pile) and be constructed of mine rock. The dyke would create a calm area to reduce any impacts of northerly winds in the settling zone for flocculated sediments to settle. More specifically, if the wind direction aligns with the long fetch from Area 3 and causes increased wave heights, the dyke would be constructed to reduce the effect of the wind and limit waves. This settling area would also contain flocculated sediments within the area that will eventually be covered by the West Mine Rock Pile.

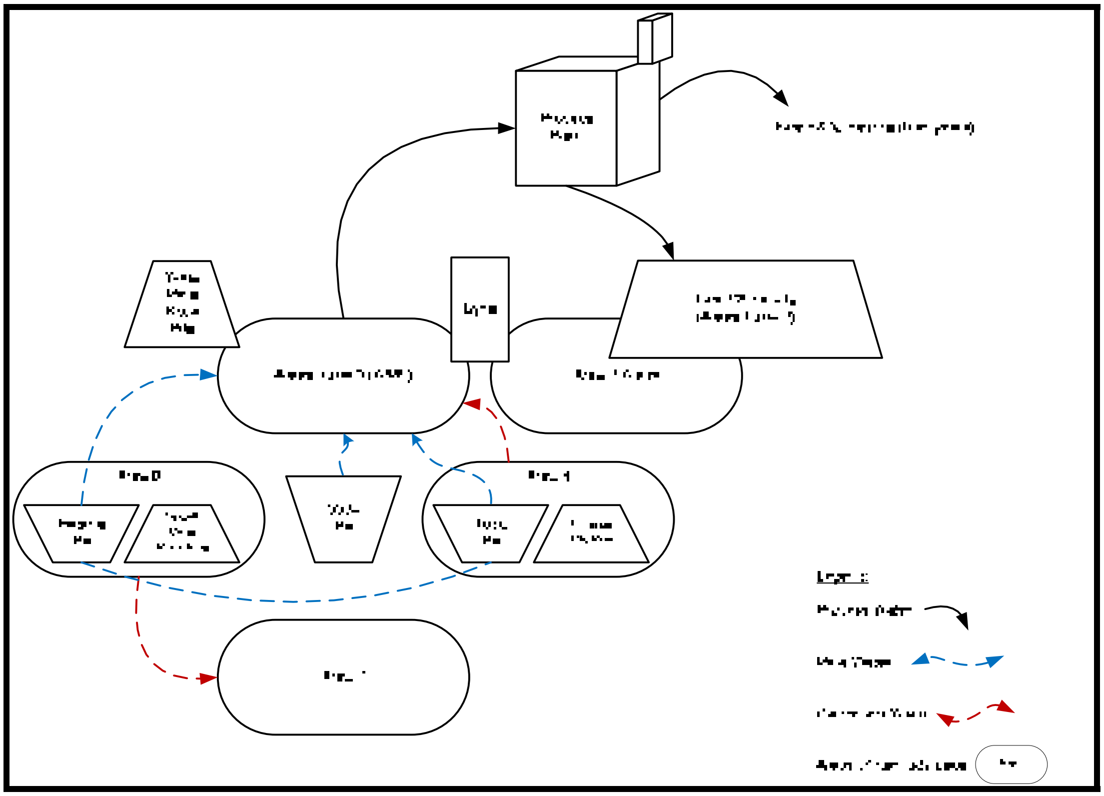
The initial discharge water from Kennady Lake will be pumped to Area 8 and Lake N11, which forms part of the N watershed situated to the northwest of Kennady Lake. The water will be proportioned between Area 8 and the adjoining northern watershed to eliminate erosion concerns and associated effects on fisheries. Discharge flow rates to Area 8 and Lake N11 will be restricted to one-in-two year flood levels, except at outlets where there is sufficient protection. The projected initial pumping rates are a maximum of 114,000 cubic metres per day (m^3/d) to Area 8 and 500,000 m^3/d to Lake N11. This maximum pumping rate to Lake N11 will depend on the discharge from the N1 outlet (downstream of Lake N11), and will occur only if the discharge from the N1 outlet does not exceed the two-year peak discharge.

The potential for erosion of lake-bottom sediments in Area 8 and Lake N11 will be reduced during dewatering pumping with the use of diffusers on the discharge pipe outlets. These diffusers will be placed close to the lake surface at the discharge points in Area 8 and Lake N11 to increase the distance between the outfall and the bottom sediments. The discharge point will also be located in relatively deep sections of the receiving waters. Although some sediment may be mobilized despite these measures, the extent of any effect is likely to be limited to the zone of turbulence immediately adjacent to the diffuser. Sediment resuspension will quickly diminish with distance from the outfall.

8.4.3 Operations Phase

The proposed Water Management Plan during the operational phase is presented in Figure 8.4-5. The key objective of the Water Management Plan during the operational period is to minimize the discharge of site water to downstream receptors by utilizing mined out facilities (e.g., 5034 and Hearne pits) for additional water and mine rock and PK storage. As such, the Water Management Plan and associated routing of mine water during the operational period is sequenced to coincide with open pit development (Table 8.4-2). Operational water management strategies for each mine facility and Kennady Lake area are provided in the subsequent subsections.

Figure 8.4-5 Diagram of Water Management in Operations



8.4.3.1 Water Management Pond

During construction and operations, a WMP will be developed in Areas 3 and 5 with a maximum storage capacity of 18.8 million cubic metres (Mm^3). The WMP will collect and store water from the following sources during the operational period:

- Fine PKC Facility (Areas 1 and 2) drainage through filter Dyke L;
- runoff and seepage from the West Mine Rock Pile;
- Area 4 open water drainage (including runoff and seepage from the Coarse PK Pile) prior to the construction of Dyke B;
- water pumped from Areas 6 and 7 during dewatering of Kennady Lake, which will include runoff and seepage from the South Mine Rock Pile;
- open pit inflows;
- treated effluent discharge from the sewage treatment plant;
- process water; and
- disturbed and undisturbed site runoff.

The WMP will be the primary reservoir for storage of site water and will supply water to the process plant during mining of the 5034 and Hearne pits. In addition, the WMP will be the primary source of dust suppression water for the site.

8.4.3.2 Fine Processed Kimberlite Containment Facility (Areas 1 and 2)

During the operational period of the mine, Areas 1 and 2 will be required for deposition of fine PK. A filter dyke (Dyke L) will be constructed to separate these areas from Area 3 (Figure 8.4-2). During the initial years of operations, fine PK will be deposited into Area 1. The Fine PKC Facility will eventually expand into Area 2 when Area 1 becomes completely inundated with fine PK. At this stage, surface runoff, seepage and liberated process water from Area 1 is expected to report to Kennady Lake via Area 2. As fine PK deposition expands into Area 2, runoff, seepage and process free water from the Fine PKC Facility will report to the Area 3 region of the WMP via filter Dyke L.

Fine PK deposition will be redirected to the mined out Hearne Pit following the cessation of mining in this pit during Year 8. At this time, the Fine PKC Facility will be progressively reclaimed as terrestrial landscape. Subsequently, runoff and seepage from the Fine PKC Facility resulting from precipitation will continue to report to the WMP (Area 3) via filter Dyke L. The volume and chemical composition of the runoff and seepage will be dependant on the degree to which the fine PK is isolated within the facility. For the purposes of the assessment, all runoff and precipitation was assumed to have come into contact with the fine PK and be available as seepage.

8.4.3.3 Coarse Processed Kimberlite Pile

A site storage facility will be required for the deposition of coarse PK produced during processing of kimberlite. The proposed footprint of the Coarse PK Pile is located immediately east of Area 4. Runoff and seepage from this facility will report to Area 4, where it will initially flow to the WMP when there is an open water connection between Areas 3 and 4 in Kennady Lake. Following the completion of Dyke B in August Year 5, and dewatering of Area 4, Coarse PK Pile runoff and seepage will report to the Area 4 collection pond (CP6) and subsequently be pumped to the WMP.

8.4.3.4 Mine Rock Piles

Two facilities will be required to store mine rock at the mine: the West Mine Rock Pile and the South Mine Rock Pile. The West Mine Rock Pile will be constructed within the catchment of the WMP at the watershed divide with Area 6. Seepage and runoff from this facility will report to the WMP. To minimize the amount of seepage reporting to the dewatered Area 6 from the West Mine Rock Pile, Dykes H and I will be constructed along the southern and eastern limits of the facility, respectively.

The proposed footprint of the South Mine Rock Pile is located immediately south of Area 6. All runoff and seepage from this facility will be directed to the Area 6 collection pond (CP2), where it will be subsequently pumped to the WMP, Area 7 or the mined out Hearne Pit, depending on the operational year.

8.4.3.5 Open Pits

Following the start of full-scale mining activities in each pit, groundwater inflows entering the pit will require removal. A system of ditches and sumps will be constructed, maintained, and upgraded throughout the operation phase of the Project to ensure optimum collection of pit inflows.

The Water Management Strategy developed by EBA Engineering Consultants Ltd. (Attachment 8.1.I) indicated that water would only be discharged to the environment during Year -1 to Year 3. This estimate was based on site precipitation data and groundwater quantity studies completed by Hydrological Consultants Inc. (HCI 2005) for SRK Consulting [Canada] Inc. More recent groundwater inflow estimates (Section 11.6 [Subject of Note: Permafrost, Groundwater, and Hydrogeology], Appendix 11.6.I) indicate that the open pits would yield higher quantities of groundwater throughout the operational period (Table 8.4-5) than previously estimated, surpassing the amount of available storage capacity in the WMP. Therefore, under the more conservative assumptions of the updated groundwater analysis, the additional groundwater inflow is expected to require water release from the site during open water seasons until Year 10 of operations. The additional discharge has been accounted for in the Hydrology (Sections 8.7 and 9.7) and Water Quality (Sections 8.8 and 9.8) evaluations.

During the operational period, water reporting to the open pits will be pumped to the WMP, where it will be recycled to the process plant, used for dust suppression or pumped to Lake N11 during the operational period. Dewatering of open pits to the WMP will cease when mining is complete in the Hearne Pit in Year 7. Thereafter, the Tuzo Pit will be the only active pit, and water captured in the Tuzo collection pond will be directed to the process plant to supplement process water requirements.

Table 8.4-5 Summary of Estimated Annual Rates of Passive Inflow to Pits during Mine Operation

Year	Estimated Passive Inflow to Pit (m^3/d)			
	5034	Hearne	Tuzo	Total
-1	2,100	-	-	2,100
1	2,300	-	-	2,300
2	2,100	-	-	2,100
3	2,400	-	-	2,400
4	2,600	400	-	3,000
5	2,500	800	600	3,900
6	2,200	1,200	800	4,200
7	1,200	1,400	1,100	3,800
8	1,400	700	1,800	3,900
9	1,400	300	2,100	3,800
10	1,400	100	2,200	3,700
11	1,400	50	2,400	3,850

m^3/d = cubic metres per day

During operations, the groundwater flowing into the open pits will range from a minimum of about 2,100 m^3/d during Year -1 to about 4,100 m^3/d in Year 8 when the size and depth of the open pits reaches a maximum (Table 8.4-5). After Year 8, the gradual refilling of the open pits will reduce the hydraulic gradient and, therefore, limit groundwater inflows to the open pits. Perimeter berms will be constructed around the circumference of the open pits to reduce surface runoff inputs from the exposed lake-beds that may report to the pits.

Mining of the 5034 Pit is expected to be complete during Year 5, when it will be backfilled with mine rock and flooded. In addition to groundwater and surface water inflows reporting to the mined out pit, approximately 3.6 Mm^3 of water will be siphoned from Area 4 to permit access to the Tuzo kimberlite pipe. The total capacity of the mined out 5034 Pit is approximately 13.5 Mm^3 and will progressively decrease as additional mine rock is introduced. It is expected that mine-rock pore space can accommodate approximately 3.1 Mm^3 of water once the 5034 Pit is backfilled with mine rock. During closure, additional mine rock will be placed in the 5034 Pit and the void water capacity will increase to approximately 10 Mm^3. Surplus water present in the pit void spaces displaced by backfilling of the 5034 Pit will be pumped into Area 6.

The Hearne Pit is expected to become inactive during Year 7, at which time it will be backfilled with fine PK and flooded. It is assumed for the purposes of water management planning that fine PK slurry will be discharged into the pit at approximately 30 percent (%) wet weight (w/w) and will settle to 50% w/w.

Approximately 3.3 Mm^3 of water is expected to be locked up in fine PK void space in the Hearne Pit once backfilling is complete.

Mining in the Tuzo Pit is expected to commence during Year 5 and continue until the end of the operational period (i.e., Year 11). Water reporting to the open pit sump from groundwater and surface runoff will initially be dewatered to the WMP until mining is complete in the Hearne Pit. Thereafter, water reporting to the Tuzo Pit will be directed to the process plant.

The Tuzo Pit will be actively flooded during the closure period. To expedite Tuzo Pit flooding, water stored in other Kennady Lake areas will be drawn down to elevation 417 m. This transfer represents a volume of approximately 16.4 Mm^3 of water directed to Tuzo Pit. Additional details of water management strategies during closure are provided in Section 8.5.

8.4.3.6 Water Management in Area 6 and Area 7

During the operational period, a water-retaining dyke (Dyke K; Figure 8.4-2) will be constructed between Areas 6 and 7. Construction of Dyke K is not expected to be completed prior to Year 9; however, Phase 1 construction of the dyke is scheduled to be finished prior to the end of Year -1. Dyke K will allow water to be temporarily stored in Area 7, minimizing the storage demand requirements on the WMP. During operations, when mining is active in the 5034 Pit, water reporting to Areas 6 and 7 will be collected in sumps and pumped to the WMP. Following the cessation of mining in 5034 Pit, water reporting to the Area 6 collection pond will be pumped to Area 7 until mining is completed in the Hearne Pit in Year 7. During this stage of operations, water reporting to the Area 6 and 7 collection ponds will be directed to the mined out Hearne Pit and the 5034 Pit will capture precipitation and groundwater within its footprint.

8.4.3.7 Water Management in Area 4

Mining of the Tuzo Pit will commence during Year 5. Access to this facility will require the construction of Dyke B to isolate Area 4 from the WMP to allow dewatering of Area 4. Dyke B will be constructed during two stages. The underwater portion will be constructed while mining in the 5034 and Hearne pits is active, and final construction is scheduled to coincide with the cessation of mining in the 5034 Pit during Year 5.

Following the completion of Dyke B, Area 4 will be dewatered. Initially, approximately 3.6 Mm^3 of water will be siphoned to the mined out 5034 Pit to drawdown the water level in Area 4. The remaining volume and water captured in the Area 4 collection pond during the remainder of the operational period will be pumped to the WMP.

8.4.3.8 Sewage Treatment Plant

A modular sewage treatment system to handle a peak load of 432 people will be provided as part of initial construction. Treated effluent will be discharged to Area 3 of Kennady Lake initially and later, during operations, added to the fine PK slurry pipeline. Sewage sludge will be dewatered and land filled on-site. If possible, the sludge may be composited and used as a soil treatment.

The sewage treatment technology will consist of a membrane bioreactor system. Membrane bioreactors include a suspended growth, aerated biological reactor integrated with a microfiltration or ultra-filtration membrane system. Sewage Treatment Plant effluent will meet stringent water quality criteria to limit the effect to water quality. Nutrient inputs, particularly phosphorus, will be managed through the restriction of phosphate-based cleaning products used on-site. Treated effluent will be discharged to Area 3 of Kennady Lake initially and later, during operations, added to the PK slurry pipeline. The sewage sludge will be dewatered and disposed in the landfill on site. If possible, the sludge may be composted or used as a soil treatment.

Feed water quality, operating parameters, and discharge water quality will be monitored regularly. Sewage treatment plant effluent rates are estimated to be 150 and 75 m^3/d during construction and operations, respectively. Effluent from the STP will be monitored to determine that discharge quality is consistent or better than specification standards. Should the system become incapable of producing effluent of desired quality, untreated sewage will be stored in tanks, until the issue(s) preventing treatment have been resolved.

8.4.3.9 Process Water

The water used in the processing plant will be recycled as much as possible. Additional make-up water will be required continually for process water requirements because PK will absorb water during processing.

During the mine life, the primary source of process make-up water for the plant will be from Area 3 within the WMP. Water reclaimed from the process plant thickener, as well as water from the WMP, will be stored in a process raw water tank for distribution throughout the processing plant. During operation, reclaimed water from the Fine PKC Facility will be used as a source of make-up water for the plant. Additional make-up water will be drawn from the WMP as required. Water reclaimed from the Fine PKC Facility, as well as water from the WMP will be filtered and then stored in a clarified water tank for distribution throughout the processing plant. After the Fine PKC Facility has been closed, the groundwater flowing into the open pits will be the primary source of make-up water for the processing facility.

8.4.3.10 On-site Surface Water Management

Runoff from the site not directly received by the WMP will be handled by a series of ditches and collection ponds throughout the Project area. Ponds will be constructed in Areas 4, 6, and 7 in low topographic areas of the dewatered basins to take advantage of the natural drainage patterns and minimize earthworks (Figure 8.4-2). Collection pond (CP) 1 is located in Area 7, CP2 to CP5 are located in Area 6, and CP6 is located in Area 4.

Collection Pond 4 will receive pumped discharge from the western region of Area 6, bound by Dyke N, if the water level rises to a point that exceeds the capacity of the impoundment. Water in CP4 can be pumped directly to the WMP, with in-line flocculation treatment, if required.

8.4.3.10.1 Non-Point Source Water Management

Sedimentation traps and collection ponds will collect sediment generated from runoff in outlying areas such as the access roads, airstrip, explosives management facilities (e.g., ammonium nitrate storage facility, bulk emulsion plant and explosives storage magazines). The traps will be located at points of concentrated runoff and overflows will be allowed to flow to adjacent watercourses. Sediment accumulating in the traps will be removed periodically and placed in a mine rock pile.

The airstrip has a total surface area of 150,000 square metres (m^2), and is situated within terrain that will result in 75% of runoff reporting directly to Area 8. The remaining 25% of the runoff will be transferred to the WMP via ditches, collection ponds, and pumps, as required.

8.4.4 Closure Phase

This section describes the following key water-related activities that will take place during the closure phase of the Project:

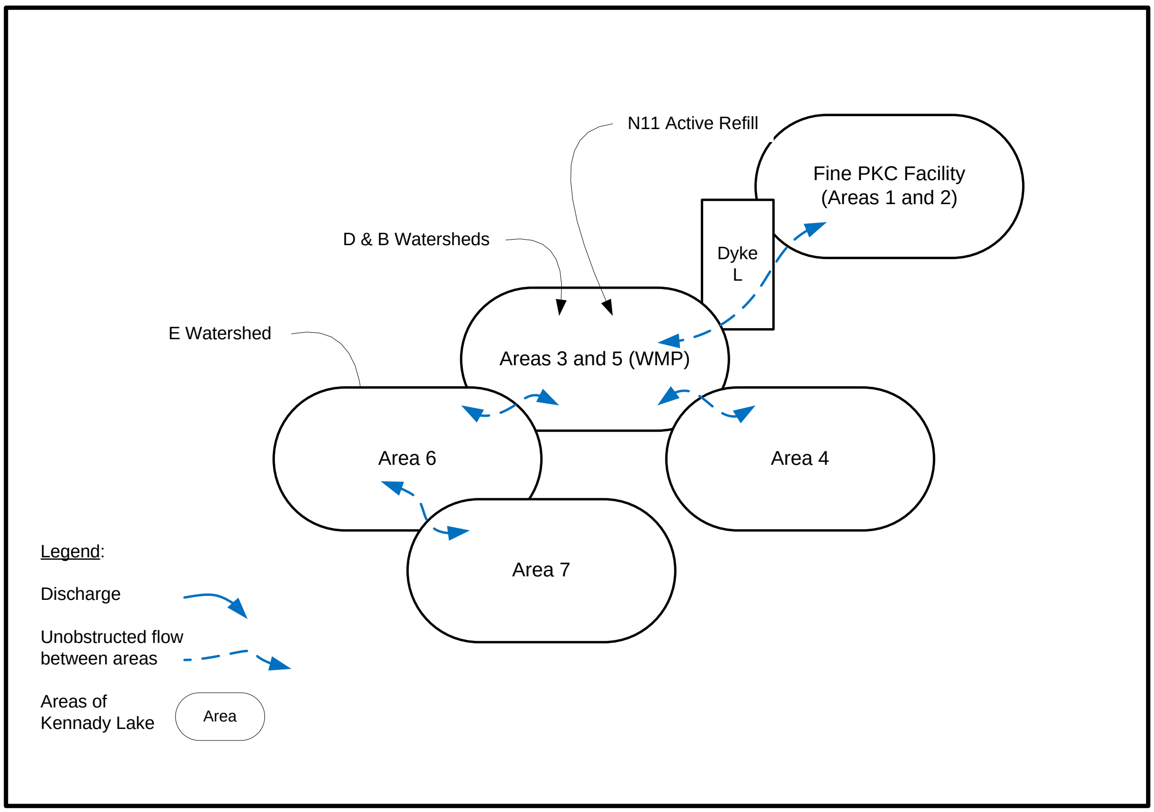
- restoration of Kennady Lake; and
- site-wide drainage and linkages to surrounding watersheds.

The key water management flows during the closure (refilling) period is presented in Figure 8.4-6.

8.4.4.1 Restoration of Kennady Lake

At the completion of mine operations, Area 3 of Kennady Lake is expected to be restored to near original water quality conditions and will be connected with the Tuzo Pit by means of an overflow channel. The Hearne Pit will have been partially backfilled with fine PK; the 5034 Pit will be partially backfilled with mine rock; while the Tuzo Pit will be open and empty. Area 1 and Area 2 will be filled with fine PK and reclaimed with a coarse PK and mine rock cover with the objective of encouraging permafrost development and the isolation of the fine PK. Area 4 will be drained as this area is adjacent to the Tuzo Pit.

Figure 8.4-6 Diagram of Kennady Lake Re-filling during Closure



After the planned within-lake reclamation activity has been completed, such as the construction of the fish compensation habitat and the decommissioning of any roads, diversion channels, and pipelines, the refilling process for Area 6 will begin. Area 7 will have been filled during operations with natural recharge near the end of operations.

At the end of operations, the water elevations in all water storage areas within Area 1 to 7 will be lowered to 417.0 masl by siphoning water from Areas 3 and 5, west of Area 6, and Area 7 to the mined-out Tuzo Pit. After the water elevations are lowered, a portion of the dyke crest for each of in-lake Dykes B, N, and K will be excavated down to an elevation of 417.0 masl to create a temporary spillway for extra runoff water flowing from the upstream side to the downstream side of the dewatered areas during when the water elevations in the drained basins are below 417.0 masl. This activity will lower each of these dyke structures to a level below the expected restored lake level. At the same time, the temporary diversion Dykes E, F and G will be breached and removed to allow the upper watersheds to resume their flow into Kennady Lake. Natural runoff from these upper watersheds and supplemental pumping from Lake N11 will be used to refill Kennady Lake. It is expected to take approximately eight years to fill the lake back to the original levels.

Supplemental water will be pumped from Lake N11 to Area 3 during the early high-water season. Pumping will typically begin in June and end in July, although it may extend into August. In wet years, flow forecasts, based on snow pack conditions and seasonal precipitation trends, will be used to estimate annual water yields from Lake N11. Planned pumping sites will be set accordingly to ensure that the total annual outflow from Lake N11 does not drop below the one-in-five-year dry condition. During the pumping season, pumping rates will be adjusted as required to meet this objective. In years where the Lake N11 outflow is forecast to naturally fall below the one-in-five-year dry condition, no pumping will occur.

The total annual diversion from Lake N11 will be in the order of 3.7 million cubic metres per year (Mm^3/y), which represents no more than 20% of the normal annual flow to Lake N11. The 20% cut-off will be used to ensure that sufficient water remains in Lake N11 to support downstream aquatic systems in the N watershed. The value of 3.7 Mm^3/y represents the difference between the flow reporting to Lake N11 under median/normal flow conditions, and that which occurs under one-in-five-year dry conditions. Based on a six-week pumping period, the average daily pumping rate will be 88,100 m^3/d. It is anticipated that more water will be withdrawn during wetter years (i.e., up to a maximum of 175,200 Mm^3/d). In drier years, less water will be withdrawn. At no time will the diversion result in an outflow from Lake N11 below that which occurs under a one-in-five-year dry condition.

8.4.4.2 Site-wide Closure Drainage Patterns

At the start of closure, the temporary diversion dykes will be removed to restore the baseline B, D and E watershed boundaries of Kennady Lake. These watersheds will be returned to their natural drainages patterns. During the restoration of Kennady Lake, runoff from the Fine PKC Facility, mine rock and Coarse PK piles, plant site, and airstrip will flow to the lake and contribute to the refilling of Kennady Lake.

8.4.4.2.1 Linkages to Surrounding Watersheds

Once Areas 3 through 7 are refilled to the same elevation as Area 8, and the water quality within the refilled lake is acceptable, the in-lake portion of Dyke A will be removed. The refilling of Kennady Lake, and its reconnection with the downstream watersheds, will then be completed. The breaching and removal of Dyke A will be undertaken using heavy machinery, such as long-armed backhoes. Only if necessary will explosives be used.

8.4.5 Water Balance

A water balance model has been developed that provides a prediction of monthly inflows and outflows from the water management system for each phase of the Project. Table 8.4-6 shows a summary of the inflows to and outflows from the water management system during the construction, operations, and closure phases of the Project. The table was compiled using data for the one-in-two wet year freshet (median values).

Table 8.4-6 Summary of Inflows to and Outflows from the Water Management System

Project Phase	Total Annual Flow (m^3/y)	Proportional Flow (m^3/y)
Construction (Year -2 to Year -1)		
Inflows	3,466,300	
Natural surface runoff from watershed A		340,000
Natural surface runoff from watershed B		241,000
Natural surface runoff from watershed C		15,500
Natural surface runoff from watershed D		762,000
Natural surface runoff from watershed E		215,000
Natural surface runoff from watershed F		57,800
Natural surface runoff from watershed G		125,000
Natural surface runoff from watershed K (Area 1 to Area 7)		1,650,000
Fresh water supply from Area 8		60,000
Outflows	21,450,000	
Water Pumped to Area 8 from Area 7		8,550,000
Water pumped to Lake N11		12,900,000
Operations (Year 1 to Year 11)		
Inflows	4,205,932 to 5,173,321	
Groundwater inflows entering the open pits		839,500 to 1,533,000

Table 8.4-6 Summary of Inflows to and Outflows from the Water Management System (continued)

Project Phase	Total Annual Flow (m^3/y)	Proportional Flow (m^3/y)
Runoff from Fine PKC facility		108,470 to 473,737
Runoff from Coarse PK Pile		28,639 to 79,968
Runoff from West Mine Rock Pile		72,135
Runoff from South Mine Rock Pile		81,900 to 163,800
Disturbed area runoff		1,022,272 to 1,358,497
Runoff from the airstrip		118,000
Natural surface runoff from watershed C		15,500
Natural surface runoff from watershed D1		72,800
Natural surface runoff from watershed F		57,800
Natural surface runoff from watershed G		125,000
Natural surface runoff from watershed K (inside)		1,012,892 to 1,707,037
Fresh water supply from Area 8		27,000
Outflows	1,790,000	
Water pumped to Basin N11		1,790,000
Closure to Refilled Kennady Lake (Year 12 to Year 19)		
Inflows	6,834,300	
Lake N11		3,270,000
Natural surface runoff from watershed B		241,000
Natural surface runoff from watershed C		15,500
Natural surface runoff from watershed D		762,000
Elevated surface runoff from watersheds D and E (from Operations)		188,000
Natural surface runoff from watershed E		215,000
Natural surface runoff from watershed F		57,800
Natural surface runoff from watershed G		125,000
Natural surface runoff from watershed H		149,000
Natural surface runoff from watershed I		130,000
Natural surface runoff from watershed J		245,000
Natural surface runoff from watershed K (inside)		1,960,000
Natural surface runoff from watershed Ke		628,000
Outflows	0	
Post-Closure Period (Year 20+)		
Inflows	3,376,300	
Natural surface runoff from watershed B		241,000
Natural surface runoff from watershed C		15,500
Natural surface runoff from watershed D		762,000
Natural surface runoff from watershed E		215,000
Natural surface runoff from watershed F		57,800
Natural surface runoff from watershed G		125,000
Natural surface runoff from watershed K (inside)		1,960,000
Outflows	3,248,000	
Natural discharge from Area 7 to Area 8		3,428,000

Note: Surface runoff = total precipitation - snow sublimation loss - lake evaporation – evapotranspiration.

m^3/y = cubic metres per year

8.4.5.1 Inflows

Inflows to the water management system will consist of fresh water drawn from Area 8, groundwater entering the open pits, surface runoff from the Project site, natural surface runoff from adjacent watersheds and drainage from the Fine PKC Facility and the mine rock and Coarse PK Piles. During closure, additional water will also be pumped from Lake N11 to expedite the refilling of Kennady Lake.

During construction, approximately 60,000 cubic metres per year (m^3/y) (i.e., 163 m^3/d) of fresh water will be taken from Area 8 for potable water needs (i.e., peak employment in Year -1 of approximately 432 persons in camp). During operations, as much as 27,000 m^3/y (i.e., 90 m^3/d) of freshwater will be drawn from Area 8 for potable water needs (i.e., peak employment in Years 2 to 8 of approximately 190 persons), in addition to a portion of the make-up water requirements for the processing plant facility, which is estimated to be 740 m^3/d. At the plant site, water will be recycled to reduce the freshwater requirements.

During operations, water volumes entering the open pits from groundwater inflows will range from a minimum of about 839,500 m^3/y (i.e., 2,300 m^3/d) during Year 1 to about 1,533,000 m^3/y (i.e., 4,200 m^3/d) in Year 6, when the size and depth of the open pits reaches a maximum. The average inflow volume during operations (i.e., Years 1 to 11) is estimated to be about 1,190,000 m^3/y. Backfilling activities will gradually add water to the open pits, thereby reducing hydraulic gradients and subsequent groundwater inflows.

Natural inflows to Kennady Lake (i.e., Areas 2 to 7) include watersheds A to G. During operations, inflows from the upstream watersheds will be altered due to the diversion of the A, B, D and E watersheds. Inflows from these upstream watersheds will be reduced (watershed A) or diverted (watersheds B, D and E). Watershed A will be permanently altered as a result of the Project. In the first year of construction (Year -2), Dyke C will be constructed between Lakes A1 and A2 (Area 1), and Lake A3 to the north. Inflows from Area 1 will be limited to drainage from Area 1 (i.e., Fine PKC Facility) to Area 2. During operations, natural runoff from watersheds B, D and E will be diverted to lakes in the N watershed. At closure, natural inflows from the B, D and E watersheds will be redirected to Kennady Lake. Altered inflows from watershed A to Kennady Lake will remain during the closure and post-closure periods.

Drainage from the mine rock and Coarse PK piles and the Fine PKC Facility will include runoff from direct precipitation. As new material is continuously deposited on these Project facilities between Years 1 and 11, the net annual runoff yield is estimated to increase as their area increases and the storage material becomes saturated[3]. This will result in drainage increasing from about 219,000 m^3/y early in the Project life to about 790,000 m^3/y in Year 7. At the end of operations, drainage will be reduced to about 727,000 m^3/y. Drainage from these Project facilities will continue at this rate during closure and post-closure unless reclamation activities substantially change the drainage pattern. There are no plans to cover or revegetate the mine rock piles. The Coarse PK Pile will be covered with a mine rock layer, and the Fine PKC Facility will be covered with layers of coarse PK and mine rock.

8.4.5.2 Outflows

Outflows from the water management system will consist of water pumped to Area 8 and Lake N11 as a result of the dewatering of Kennady Lake during construction and operations. During closure, no outflows are anticipated from the water management system due to the refilling activities of Areas 3 to 7. In post-closure, after the reconnection of Areas 3 to 7 with Area 8, outflows will be associated with natural discharge from Area 7.

8.4.5.3 Area 8

The natural outflow from Area 8 during construction (following construction of Dyke A), operations, and closure is assumed to be equal to the volume of inflows (i.e., snow and rain inputs) to Area 8 from watersheds H, I, J, and Ke minus evaporation from the surface of Area 8. Table 8.4-7 shows a summary of the inflows and outflows from Area 8. This table was compiled using data for the one-in-two wet year freshet (median values). Discharge from the outlet of Area 8 flows into Lake L3.

During construction when Area 8 is isolated from the upstream areas of Kennady Lake, Area 8 will receive pumped discharge from Area 7 as part of the dewatering activities associated with the drawdown of Areas 2 to 7 in Kennady Lake, and natural inflows from watersheds H, I, J, and Ke. During operations and closure, inflows to Area 8 will be limited to natural runoff from watersheds H, I, J, and Ke. In post-closure, after the reconnection of Area 8 with Area 7, the natural outflows from Area 8 will include the flow inputs from the upper areas of Kennady Lake, with natural outflow estimated to be approximately 4,400,000 m^3/y.

[3] The estimate of runoff volumes from the mine rock and coarse PK piles and fine PKC facility does not consider the degree of saturation of each facility

Table 8.4-6 Summary of Inflows to and Outflows from Area 8

Project Phase	Total Annual Flow (m^3/y)	Proportional Flow (m^3/y)
Construction (Year -2 to Year -1)		
Inflows	9,702,000	
Natural surface runoff from watershed H		149,000
Natural surface runoff from watershed I		130,000
Natural surface runoff from watershed J		245,000
Natural surface runoff from watershed Ke (Area 8)		628,000
Water pumped from Area 7		8,550,000
Outflows	1,150,000	
Freshwater supply to the Water Management System		60,000
Natural Discharge from Area 8		1,090,000
Operations (Year 1 to Year 11)		
Inflows	1,152,000	
Natural surface runoff from watershed H		149,000
Natural surface runoff from watershed I		130,000
Natural surface runoff from watershed J		245,000
Natural surface runoff from watershed Ke (Area 8)		628,000
Outflows	1,190,000	
Freshwater supply to the Water Management System		27,000
Natural Discharge from Area 8		1,163,000
Closure to Refilled Kennady Lake (Year 12 to Year 19)		
Inflows	1,152,000	
Natural surface runoff from watershed H		149,000
Natural surface runoff from watershed I		130,000
Natural surface runoff from watershed J		245,000
Natural surface runoff from watershed Ke (Area 8)		628,000
Outflows	1,152,000	
Natural Discharge from Area 8		1,152,000
Post-Closure Period (Year 20+)		
Inflows	4,528,300	
Natural surface runoff from Areas 3 to 7		3,376,300
Natural surface runoff from watershed H		149,000
Natural surface runoff from watershed I		130,000
Natural surface runoff from watershed J		245,000
Natural surface runoff from watershed Ke (Area 8)		628,000
Outflows	4,400,000	
Natural discharge from Area 8		4,400,000

Note: Surface runoff = total precipitation - snow sublimation loss - lake evaporation – evapotranspiration.

m^3/y = cubic metres per year

8.4.6 Potential Sources of Change to Site Water Quality

This section describes the potential sources of change to water quality at the Project site, as follows:

- the use of a landfill for disposal of solid waste;
- the storage and handling of explosives, petroleum products, and other chemicals; and
- disposal of mine rock and PK from mining.

8.4.6.1 Landfill

An active landfill will be available during the construction and operation phase to contain and store inert solid wastes. The landfill will be located within small areas of the mine rock piles or the Fine PKC Facility that will be above the level of the refilled Kennady Lake at closure. The landfill in the mine rock piles will represent a single landfill in operation at any given time, which likely will be covered and buried from year to year to coincide with the mine rock pile developments.

8.4.6.2 Explosives

Explosive use will be managed with the primary environmental goal of limiting loss of ammonia to mine rock and kimberlite, which could subsequently leach into runoff at the Project site or be processed at the processing plant. Emulsions will be used for wet blasting; ammonium nitrate fuel oil (ANFO) will be used for dry blasting to limit ammonia leaching. Packaged explosives will be kept on-site where required. All runoff from the ammonium nitrate storage areas, mine pits, and mine rock piles will be contained within the water management system during operations, although some of these areas will be flooded at closure.

8.4.6.2.1 Ammonium Nitrate

Contained facilities for the storage of ammonium nitrate will be located to the west of A3 (the primary ammonium nitrate storage facility), and to the southeast of the Fine PKC Facility (the operational ammonium nitrate storage building). Storage of ammonium nitrate in a contained facility away from waterbodies reduces the risk of ammonia loss to waterbodies. Ammonium nitrate readily dissociates in water to ammonia, which can be toxic to fish and other aquatic organisms.

Ammonium nitrate will be stored in supersacs that will be stacked outdoors in rows on two storage pads in a bermed area and covered with tarps for weather protection. A geofabric will be installed under the storage pad to prevent seepage into underlying soils in case of a spill. Any broken bags will be treated as spills and dealt with accordingly. All runoff from the ammonium nitrate storage areas will be contained within the controlled area boundary of the Kennady Lake watershed.

8.4.6.2.2 Emulsion Plant

All emulsion materials will be stored at the emulsion plant, which is located to the southeast of the Fine PKC Facility. Any spills of emulsion materials will be contained within the building. The emulsion plant will use ammonium nitrate to manufacture a water resistant emulsion-type explosive. Bulk ANFO explosives that are not water resistant will be used only under appropriate dry hole conditions. The emulsion plant will operate intermittently and produce only the quantities of finished product required for immediate use so that storage of bulk explosives materials in the plant is not required.

8.4.6.2.3 Explosives Trucks Wash

Trucks used for transporting explosives will be washed at a facility separated from the plant site to comply with Workers Compensation Board regulations. Water from the truck wash will likely have elevated concentrations of ammonia and nitrate from residual ammonium nitrate from the explosives transported on the truck. It may also contain petroleum residues. The presence of these residues in the wash water makes the water unsuitable for discharge to a receiving waterbody. This water will therefore be collected in a sump/oil separator, pumped out as required and trucked to the Fine PKC Facility, or a mined-out open pit.

8.4.6.2.4 Explosives Residues

Based on the experience at other open-pit diamond mines in the Canadian Arctic, the largest potential source of ammonia in runoff water will be from explosives residues from blasting. Blasting residue in runoff at the Project will be transferred from the mine rock piles and the Fine PKC Facility to the WMP. Ammonia in blasting residue from the walls of the open pits will be pumped from the pits to the WMP or a mined-out open pit. Ammonia in kimberlite will be processed through the plant and transferred to the Coarse PK Pile or the Fine PKC Facility.

8.4.6.3 Petroleum Products

Petroleum products are classified as hazardous substances under the *Transportation of Dangerous Goods Act* (Government of Canada 1992) and regulations. Special handling is required to ensure the safe transportation, storage, and use of these products. At the Project, all petroleum products will be stored in approved containers, in areas with secondary containment. Secondary containment ensures that any accidental release of petroleum products does not result in environmental effects. Petroleum products will only be handled by Project personnel who have received appropriate training. All fuel transfers will be carried out by trained personnel. All fuel distribution points will have containment areas and specific spill recovery/abatement plans. A Spill Response Plan has been developed for the Project and can be found in the Emergency Response and Contingency Plan which is an attachment to Section 3, Appendix 3.I. Waste petroleum products will be collected and transported off-site.

8.4.6.3.1 Emulsion Materials

All emulsion materials are acutely toxic to aquatic life, except at low concentrations. Ethylene glycol is a petroleum hydrocarbon that will be used in the heating system and is water-soluble. Because the release of any of these compounds directly to receiving waterbodies would likely have negative effects on aquatic life, these materials will be stored at the emulsion plant where any spills can be fully contained within the building.

De-icing fluids (e.g., propylene glycol) will be used for aircraft de-icing. Any spilled de-icing fluids will be treated as an environmental spill and handled accordingly. Any contaminated soils will be excavated and either permanently encapsulated in a secure area, treated on-site to an acceptable standard, or stored in appropriate sealed containers for off-site shipment and disposal. In contrast to ethylene glycol, propylene glycol is generally recognized as safe, rarely causing toxic effects. Based on experience at the Snap Lake Project, aircraft de-icing is expected to be required on a limited basis.

8.4.6.3.2 Landfarm

A landfarm for the bio-remediation of hydrocarbon-contaminated solids from spills may be constructed depending on the need. This dyke-bounded cell would be located adjacent to the fuel storage area and would consist of an arctic geo-membrane liner placed under fill material. Hydrocarbon-contaminated soils would be placed in the landfarm and spread during summer months. Any soil that has subsequently reached acceptable levels of hydrocarbon degradation would be removed and reused, or transferred to the landfill.

Arctic conditions, when combined with the type of contaminated soil, may impede the remediation of contaminated soil through natural microbiological processes. If remediation of hydrocarbon-contaminated soils in the landfarm proves to be ineffective and no other remediation system has proved effective in northern climates, the contaminated soils will be collected and shipped to suitable disposal facilities in Alberta.

8.4.6.4 Other Fluids

All other toxic materials will be stored in sealed steel or plastic drums and shipped off-site for disposal. Chemicals such as acids, solvents, battery acids, and laboratory agents will be collected in lined trays and drums, and stored in suitable sealed containers in the waste transfer area. These chemicals will be shipped off-site for disposal or recycling.

8.4.6.5 Mine Rock and Processed Kimberlite

Most of the mine rock from the excavation of the open pits will be stored in one of the following repositories: the West Mine Rock Pile in the southwest of Kennady Lake, the South Mine Rock Pile to the south of Kennady Lake, the mined-out 5034 Pit, and the mined-out Hearne Pit (if required).

Runoff from the mine rock piles is designed to remain within the controlled area and to take advantage of the natural drainages present. Runoff will be managed within Area 5 or Area 6; Area 5 runoff will flow to the WMP and Area 6 runoff will flow to the Hearne Pit. No substantial runoff and seepage from the mine rock piles is expected.

Runoff from the mine rock piles will flow and/or be directed as described below:

- Runoff along the northern perimeter of the West Mine Rock Pile will flow directly to Area 5.
- Runoff from the western perimeter of the West Mine Rock Pile will either flow along the mine rock pile to Area 5 or percolate into the mine rock pile.
- Runoff from the eastern face of the West Mine Rock Pile will flow directly to Area 5.
- Minor runoff from the southern perimeter will flow into the Hearne Pit, which will have pit sumps that will be pumped out periodically to the process plant.
- Runoff from the South Mine Rock Pile will flow to and be contained within the Area 6 dewatered lake bottom collection ponds.

Any potentially acid-generating (PAG) mine rock, as well as any barren kimberlite, will be sequestered within the interior of the mine rock piles. Till from ongoing pit stripping will be used to cover PAG rock placed within the interior of the structure to keep water from penetrating into that portion of the repository. Further, the PAG rock will be enclosed within enough non-acid generating (NAG) rock to prevent the active zone (typically 2 m) from extending into the enclosed material. Runoff will occur on the NAG rock cover areas. While all the water will not be stopped completely from penetrating a till and non-AG rock envelope, the amounts that may penetrate deeper into the pile are expected to be trapped in void spaces and freeze. Minimal water is expected to penetrate to the PAG rock areas. To confirm that the lower levels remain frozen, temperature monitoring systems will be placed in the mine rock piles as they are being constructed.

Barren kimberlite, or mine rock mixed with barren kimberlite, will not be placed directly on the tundra soils. Experience at Ekati Diamond Mine shows that coarse kimberlite in direct contact with the naturally acidic tundra soils can lead to drainage with a low pH. Any mine rock containing kimberlite will be separated from the tundra by at least 2 metres (m) of inert and kimberlite-free rock.

The Coarse PK Pile will not be designed to have a single point of release for seepage and runoff. Any runoff will flow through natural channels within the controlled area and be retained in the collection pond associated with Area 4, which in later years represents the Tuzo Pit area.

The only water to enter the Fine PKC Facility, other than the water contained within the fine PK, will be precipitation. Runoff and seepage from the Fine PKC Facility will eventually flow into the WMP through Dyke L. The volume and chemical composition of the runoff and seepage will be dependant on the degree to which the fine PK is isolated within the facility. For the purposes of the assessment, all runoff and precipitation was assumed to have come into contact with the fine PK and be available as seepage.

8.4.7 Potential Accidents and Malfunctions Relevant to Water Management

This section describes the potential accidents and malfunctions relevant to the Water Management Plan that could lead to effects to water quality. These include:

- petroleum spills;
- ammonium nitrate spills; and
- dyke failures.

8.4.7.1 Petroleum Spills

A petroleum spill may result from a leak in tanks, valves, or piping; from catastrophic failure of a tank; during fuelling/re-fuelling of storage tanks and vehicles; and from vehicles on Project roads. To prevent such an occurrence, all tanks, piping, and valves will meet all applicable standards or requirements, and be installed by experienced contractors. The design of the containment area will be based on requirements of the *Environmental Code of Practice for Aboveground and Underground Storage Tank Systems Containing Petroleum and Allied Petroleum Products* (CCME 2003), the National Fire Code of Canada, and any other standards that are required. The fuel farm, fuel supply tanks, valves, and piping will be routinely inspected to ensure no leakage has occurred. All fuel storage areas will have secondary containment. All fuel tanks will have a spill containment provision.

Vehicle fuelling stations will be located on a concrete pad sloping toward a drain connected to a sump. Any spills of fuel would flow to the sump, which would be pumped out to a container for shipment off-site during winter resupply. Crawler equipment will be fuelled at the worksite by trained employees in the Mine Services Group and the likelihood of routine spills will therefore be minimized. Any spills that do occur will be cleaned up immediately and contaminated soils transferred to the landfarm for bioremediation. Contaminated snow will be segregated in a contained drainage area to melt. Any residue remaining will be transferred to the landfarm for bioremediation.

Any spills at the explosives manufacturing and storage plant will be contained within the explosives building sump system and be pumped into a waste container for shipment off-site during winter resupply. Any spilled de-icing fluid will be treated as an environmental spill and handled accordingly.

Small spills at the workshop will be cleaned up with an absorbent material and the absorbent removed from the site as hazardous waste. Large spills (up to 205 litres [L]) outside of the spilled area would flow to the sump and be pumped into a container for shipment off-site during the winter resupply.

Leaks of fuel or other petroleum fluids from vehicles may occur periodically on roads, or anywhere service or ore trucks frequent, including the open pits, mine rock piles, the Coarse PK Pile and Fine PKC facilities. Most areas where vehicles travel will be within controlled drainage areas. Therefore, in the event of a spill, runoff would be contained where it would be recovered and transferred to an oil-water separator, before being transferred to the landfarm at the time of the mishap. Contaminated soil and snow would be treated as described above.

8.4.7.2 Ammonium Nitrate Spills

In the unlikely event of an ammonium nitrate spill, any spills (from torn bags) at the ammonium nitrate storage facility (a component of the explosives management facilities) will be cleaned up immediately and reported. All contaminated or ripped bags of prill (a granular, free flowing form of ammonium nitrate) and spilled prill will be recovered and used at the Project; used empty bags will be collected and managed appropriately with other solid waste from the Project site.

An accident involving an explosives truck could potentially lead to a spill of ammonium nitrate on the site road between the ammonium nitrate storage facility and the open pit. This road is within a controlled area where runoff is collected and discharged to the WMP in operation at the time. Any spilled ammonium nitrate would be cleaned up by employees licensed to handle explosives.

8.4.7.3 Dyke Failure

Dykes will be inspected daily by site personnel and annually by a qualified geotechnical engineer. Downstream seepage of external dykes will be monitored continuously during the summer by means of piezometers. Any significant increase in seepage will be cause for corrective action.

8.4.7.3.1 Dyke A

A failure of Dyke A during operations would result in water from Area 8 flowing into Area 7 with potential impacts on fish populations and habitat, both in Area 8 and downstream in the outlet stream. If a rupture occurred at the base of the dyke, water from downstream of Area 8 in the L watershed could flow backwards into Area 8, and then through the breached Dyke A into Area 7. The gradient is low and this would occur over several hours to days allowing time for emergency repairs to Dyke A. Dyke A will hold back a maximum height of 3 m of water; therefore, this is estimated to be a low-risk event.

8.4.7.4 Dykes C and D

Dyke C is a permanent water diversion dyke located on the northeast side of Area 1, which initially allows the dewatering of a portion of Area 1 into Lake A3. Later, it separates the Fine PKC Facility from Lake A3 (Figure 8.4-2). As the facility is filled with fine PK slurry, Dyke C prevents seepage from the Fine PKC Facility from entering Lake A3, which is a fish-bearing lake.

Dyke D is a permanent water retention dyke located on the north edge of Area 2 that prevents water from Area 2 from flowing north into Lake N7 during the late stage of mine operation (Figure 8.4-2). It also prevents the submerged fine PK and water released from settled fine PK from flowing into Lake N7.

Failure of either Dyke C or Dyke D would lead to water and fine PK slurry discharging into Lake A3 or Lake N7, respectively. Failure of either dyke could be considered a spill risk if PK material from the Fine PKC Facility reached a watercourse or waterbody outside of the controlled area boundary, and would be reported to the NWT 24-hour spill line operated by the GNWT with appropriate follow-up. Mining would stop until repairs were completed and the water redistributed back into the WMP. In the case of a spill to the environment, coffer dams could be quickly constructed to prevent further migration of water or slurry. Dykes C and D will not be removed at closure.

8.4.7.4.1 Upper Watershed Dykes E, F and G

Failure of the Dykes E, F, and G in the N, B, D, and E watersheds would lead to partial flooding of the mine workings but no release of water to the environment. Failure of these dykes would not be considered a spill risk because water would not reach a watercourse or waterbody outside of the controlled area boundary. Mining would stop until repairs were completed and the water redistributed back into the WMP.

8.4.7.4.2 Dykes B, J, N and K

Failure of the internal Dykes B, J, N and K in Areas 3 through 7 would lead to partial flooding of the mine workings but no release of water to the environment. Failure of these dykes would not be considered a spill risk because no water would reach a watercourse or waterbody outside of the controlled area boundary. Mining would stop until repairs were completed and the water redistributed back into the WMP.

8.4.7.4.3 West Mine Rock Pile – Dykes H and I

The west mine rock dykes will be located at the east and south ends of the mine rock pile. Failure of a dyke could result in water and slurry spilling into Area 6; no water or slurry would be released to the environment. Failure of the dykes would therefore not be considered a spill risk because no water would reach an uncontrolled area. Repairs would be affected by mine personnel, and the slurry and water pumped back into the WMP once dyke repairs were completed.

8.4.7.4.4 Fine Processed Kimberlite Containment Dykes

The Area 1 perimeter berms and Dyke L will contain fine PK and slurry away from Kennady Lake. Dyke L is a filtration dyke between Areas 2 and 3. Runoff and seepage from the Fine PKC Facility will eventually flow into the WMP.

Failure of the berms and the dyke's dam could result in slurry and water spilling into Areas 3 and 4; no water or slurry would be released to the environment. Failure of Dyke L and the berms could result in loss of water and slurry from the Fine PKC Facility, but flow would be into the Project site where drainage is controlled. In either case, repairs would be performed immediately, and slurry and water pumped back into the Fine PKC Facility.

8.5 ASSESSMENT APPROACH

The assessment approach for this key line of inquiry follows the overall approach described in Section 6 of the environmental impact statement (EIS). The assessment approach described herein (Section 8.5) provides summary details of specific aspects of the approach that are particularly relevant to the assessment of the effects of the Project on water quality and fish in Kennady Lake.

8.5.1 Pathway Analysis

The pathway analysis for this key line of inquiry is provided in Section 8.6. The potential pathways reflect potential linkages between the Project and the physical and biological properties of the Kennady Lake ecosystem, and the small lakes and streams in the Kennady Lake watershed. The pathway analysis identifies and screens the linkages between Project components or activities (e.g., Kennady Lake dewatering) and the potential effects to receptors within the environment (e.g., lake trout [*Salvelinus namaycush*]). Pathways were screened for activities during the construction, operations, and closure phases of the Project.

Pathway analysis is a screening step that uses largely qualitative information to distinguish valid pathways from no linkage and secondary pathways. The analysis examines all potential pathways relevant to this key line of enquiry, and environmental design features and mitigation integrated into the Project that remove the pathway or limit the effects along a primary or secondary (minor) pathway (e.g., fish salvage prior to, and during, the dewatering of Kennady Lake). Environmental design features include the Project design and environmental best practices, management policies and procedures, and social programs. Primary pathways are those that continue to exist after environmental design features have been applied (i.e., those that are expected to lead to residual effects after mitigation).

No linkage and secondary pathways are described in Section 8.6 and an explanation provided detailing why they have been characterized as such. No linkage pathways are removed by environmental design features and mitigation, so that the Project results in no detectable environmental change and residual effects to a valued component (VC) relative to baseline or guideline values. Secondary pathways could result in a minor environmental change, but would have a negligible residual effect on a VC relative to baseline or guideline values. No linkage and secondary pathways are not carried forward into the effects analysis.

All primary pathways are carried forward in the assessment for detailed effects analysis, in Section 8.7.

8.5.2 Valued Components

A VC is a component of the environment that people consider to be ecologically, culturally, socially, or economically important. Valued components occur at different levels, and levels may be determined naturally (e.g., ecological importance of a top predator) or through the importance placed on them by people.

In this EIS, VCs can be found at the beginning, middle, or end of pathways. In Kennady Lake, VCs can be found at the bottom, middle, or top trophic level of food chains. For example, in sub-Arctic lake systems, changes to water quality (such as increased nutrient concentrations) represent initial steps along pathways that can lead to changes in phytoplankton communities, which influence other lower trophic level organisms (e.g., zooplankton), forage fish, and, ultimately, large-bodied fish, that represent the highest trophic level.

The selection of VCs specific to this key line of inquiry resulted from issues scoping sessions for the Project with community members, federal and territorial regulators, and other stakeholders. The Terms of Reference provides a list of important biophysical components that were identified in the issues contained in the Report of Environmental Assessment (MVEIRB 2006). The Terms of Reference also define different levels of importance attributed to the biophysical components. For this key line of inquiry, the water quality and fish were identified as being the most important components, that is, VCs (Gahcho Kué Panel 2007). Key biophysical components identified as contributing to, or comprising an important feature of, these VCs are discussed in the following section.

8.5.2.1 Water Quality

Within this EIS, water quality has both an important ecological and a human health value. It can provide a basis for evaluating aquatic ecosystems to determine whether water quality during each phase of the Project meets acceptable levels for the protection of aquatic life. Water quality can also be compared to drinking water standards and used in a risk assessment to assess effects on human health. Since changes to water quality may ultimately affect fish, wildlife, and human health, the selection of water quality as a VC is appropriate. The societal goals that make water quality a VC are the protection of both drinking water and aquatic life.

The water quality of a lake or stream is the product of the physical (e.g., climate and resulting water inputs), chemical (e.g., weathering of bedrock, interaction with groundwater), and biological (e.g., algal growth) processes in the watershed and within the waterbody. It can be directly measured by the physico-chemical and chemical analysis of water column samples.

The key biophysical components within the Project area that influence water quality include the following:

- permafrost;
- groundwater quality and quantity (i.e., groundwater and hydrogeology);
- water levels and flow patterns (i.e., hydrology);
- water chemistry; and
- sediment quality.

The potential of the Project to have both direct and indirect effects on the water quality of Kennady Lake and the waterbodies within its watershed is high. Changes in environmental components tend to occur sequentially (e.g., highly saline, deep groundwater, if not managed appropriately, could cause an increase in total dissolved solids [TDS] in surface water leading to water quality that might affect fish health). Understanding the resulting pathways to fish in this example would require an analysis of the measurement endpoints associated with hydrogeology, hydrology, water quality, and aquatic health (see Section 8.5.3).

8.5.2.1.1 Permafrost

Permafrost is an important feature of the Project area. It was identified in the technical issues scoping for water issues (MVEIRB 2006), and, therefore, it is included as a key biophysical component. Changes to permafrost conditions within the Project area are relevant, because they may be part of potential pathways by which the Project affects VCs such as water quality and fish (e.g., through changes in fish habitat).

Permafrost is part of a specific subject of note (Section 11.6). A detailed assessment of potential effects to permafrost is not provided in this key line of inquiry; however, a summary of the effects of potential changes to permafrost, which could potentially alter water quality and fish habitat in Kennady Lake and its watershed, is provided. For example, the partial and complete dewatering of waterbodies and basins in Areas 1 through 7 of Kennady Lake during the construction and operation phases of the Project will expose a substantial area of the lake bed to freezing temperature. These colder temperatures will result in the development of permafrost in the lake bed not normally subjected to freezing. Similarly, the development of temporary and permanent dykes in the upper watersheds and the resulting increase in water level will result in a loss of permafrost conditions in the newly inundated zones. Where relevant, the implications of these changes to water quality, and also fish habitat, in the construction and operation phases and their potential for reversal at closure when the dewatered basins are refilled, will be considered.

8.5.2.1.2 Groundwater Quantity and Quality

Groundwater is also an important feature of the Project area. Like permafrost, it is part of a separate subject of note (Section 11.6); therefore, a detailed assessment of potential effects to groundwater will not be provided in this key line of inquiry.

Groundwater is another key biophysical component that occurs along a pathway leading to effects on VCs. Groundwater is not an assessment endpoint itself in this EIS, because it is not used as a source of drinking water, particularly at Kennady Lake. Potential impacts and interactions were, however, identified during the technical issues scoping (MVEIRB 2006), indicating that, although groundwater is not an endpoint, it provides a measurement endpoint for changes to the assessment endpoint associated with VCs (e.g., surface water quality).

The hydrogeology of the Project area is interconnected with the surface water within the Kennady Lake watershed. Groundwater may also affect sediment quality. Groundwater can be divided into two primary groundwater regimes:

- the shallow groundwater regime, which is directly related to the surface water expression; and
- the deep groundwater regime.

The development of the Project, from dewatering Kennady Lake to mining the pits and refilling the lake, has the potential to affect each of these groundwater regimes. The implications of the Project’s effects to groundwater regimes and the potential for groundwater to affect surface water through seepage during the construction, operations, and closure phases are discussed herein.

8.5.2.1.3 Hydrology

Hydrology focuses on surface water levels, flows, and channel/bank stability. It is an important feature of the Kennady Lake watershed. In addition, because downstream effects of Kennady Lake dewatering and refilling were identified during the technical issues scoping (MVEIRB 2006), hydrology is considered a key biophysical component. Hydrology provides a measurement endpoint to pathways between the Project and potential effects to water quality and fish. The Project, through the diversion of the upper watersheds of Kennady Lake, and the dewatering and refilling of Kennady Lake, will affect the hydrology of the watershed in terms of water quantity and seasonal patterns of flow. Changes to hydrology may result in effects to fish habitat through changes to water level, flow rates, and the stability of stream channels. Erosion and resuspension of sediment may affect water quality (e.g., increased nutrients, metals, and total suspended solids [TSS]). Each of these potential pathways is considered in the EIS, and discussed in more detail in Section 8.6.

8.5.2.1.4 Water Chemistry

Water chemistry is a principal component of water quality, which was identified as an issue related to fish during the technical issues scoping (MVEIRB 2006). It comprises the chemical constituents that characterize the waterbody and reflects the geomorphology and condition of the watershed. Water chemistry is highly responsive to changes in watershed runoff and input sources, and can provide an indication of the productivity of the waterbody. Changes in water chemistry may result in effects to lower trophic levels, and ultimately fish and people.

8.5.2.1.5 Sediment Quality

Sediment quality is an important feature of the Kennady Lake watershed, and chemical changes in sediment were identified in the technical issues scoping for fish issues; therefore, sediment quality is considered a key biophysical component. It also provides a measurement endpoint to pathways to water quality and fish through the potential for exchange between the bed sediment, aquatic habitat and overlying water column. Additionally, alterations to the lake bed or stream bed from Project activities can lead to increased sediment deposition, which can smother aquatic habitat, or to the deposition of metals and nutrients, which can affect water chemistry and aquatic health. Changes in sediment quality, therefore, have the potential to affect fish, and ultimately people who may eat the fish or use the overlying water as a source of drinking water.

8.5.2.2 Fish

8.5.2.2.1 Importance of Fish

Fish are important to traditional and non-traditional land users. Fish also provide a direct link between potential effects to water quality and human health. The potential for the Project to affect the abundance, behaviour, and health of fish in Kennady Lake and the Kennady Lake watershed is high. Therefore, selecting fish as a VC is appropriate. Any changes in measurement endpoints, such as fish abundance, behaviour, and health, may ultimately affect humans.

The VC represented by fish includes individual fish species, because interactions between each Project activity and the unique habitat requirements and life history characteristics of fish can be fully assessed only at the species level.

The productivity of key fish species (e.g., lake trout) is linked directly and indirectly to physical habitat, hydrology (e.g., water levels in lakes and flow velocities in streams), water chemistry (e.g., nutrients), lower trophic levels, which provide the base of the food web, and forage fish. As described for water quality, a pathway may include several key biophysical components that represent pathways that lead to fish, which are the VCs.

8.5.2.2.2 Fish Habitat

Fish habitat is not a VC for this assessment, because it is the fish that are ultimately valued by people rather than the habitat that supports them. Fish habitat is represented by the streams and lakes within the Kennady Lake watershed for this key line of inquiry. While these streams and lakes undoubtedly have value to people, it is their ability to support fish that is most important. Fish habitat is a key biophysical component that contributes to fish species selected as VCs. As such, changes to fish habitat is a measurement endpoint that is used to determine Project-related effects to fish species.

Effects of Project activities on fish habitat are included in the effects assessment. The federal *Fisheries Act* defines fish habitat as, “spawning grounds and nursery, rearing, food supply, and migration areas on which fish depend directly or indirectly to carry out their life processes”. By this definition, fish habitat is the integration of physical, chemical, and biological parameters that combine to create the space, food, competitors, predators, and abiotic features that determine the growth and survival of individual fish and, ultimately, the productivity of the population. Because fish habitat is required to produce fish, Project activities that affect fish habitat will ultimately affect fish. Similarly, measures taken to reduce effects to fish habitat will reduce effects to fish.

8.5.2.2.3 Fish Species Selected as Valued Components

Fish species that are characterized as being important to people have been selected from the list of fish species present in the Kennady Lake watershed in order to focus the assessment. At least eight fish species in the Kennady Lake watershed could be considered as VCs (Table 8.5-2). The following criteria were used to select valued fish species from the list of fish species present:

- traditional importance to Aboriginal communities (i.e., subsistence, cultural, and spiritual values);
- economic importance to traditional and non-traditional land users (e.g., commercial sport fisheries);
- current status with respect to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), the *Species at Risk Act* (SARA), or the Government of the Northwest Territories;
- relative abundance in Kennady Lake;
- unique life history characteristics or requirements; and
- current ecological niche in Kennady Lake (e.g., top predator).

There is no commercial fishery within the Kennady Lake watershed, nor within the regional study area (i.e., the Lockhart River watershed) as defined in the Fisheries and Aquatic Resources Baseline (Annex J). As a result, the importance of a fish species to commercial fishing was not included in the VC selection criteria.

There are no federally listed fish species in the Kennady Lake watershed, or within the regional study area. Arctic grayling are rated as “sensitive” in the Northwest Territories due to the increasing pressures of resource development and climate change (GNWT 2006). There are no other “sensitive” or “may be at risk” species in the watershed, or within the regional study area.

Based on the above criteria and the analysis outlined in Table 8.5-1, lake trout, Arctic grayling (*Thymallus arcticus*), and northern pike (*Esox lucius*) were selected as valued fish species for this key line of inquiry. The rationale for selecting each of these species as a VC is described in the following sections, as well as reasons for not selecting other species.

Table 8.5-1 Valued Component Evaluation for Fish Species Found in the Kennady Lake Watershed

Species	Importance to Aboriginal Communities[(a)]	Importance to Non-traditional Land Users[(b)]	Abundance in Kennady Lake	Ecological Niche	Valued Component	Rationale
Lake trout	subsistence use and as dog food	popular sport-fish in NWT	most abundant predator	piscivore; top-predator in Kennady Lake	yes	abundant, top predator in Kennady Lake; valued by local Aboriginal communities and sport anglers in the NWT
Arctic grayling	subsistence use	popular sport-fish in NWT	third most abundant large-bodied fish species	invertivore; adfluvial life history	yes	important to Aboriginal communities and sport anglers in the NWT; adfluvial life history suitable for assessing affects to streams; listed as “sensitive” in NWT
Round whitefish	subsistence use	none	most abundant large-bodied fish	Invertivore; principal prey species for lake trout	no	most abundant large-bodied fish in Kennady Lake but not an important sport fish in the NWT and is less valued than lake whitefish as a food source by Aboriginal communities due to its smaller size
Northern pike	subsistence use	popular sport-fish in NWT	small population due to lack of vegetation	piscivore; top-predator dependent on aquatic vegetation habitat	yes	important sport fish in the NWT; present in Kennady Lake but in small numbers only; dependent on aquatic vegetation for spawning and rearing
Burbot	subsistence use	none	found in low numbers	omnivore	no	marginally important sport fish and subsistence fish for Aboriginal communities; small population present in Kennady Lake
Lake chub	none	none	most abundant forage fish	invertivore	no	forage fish species not valued by Aboriginal communities or sport anglers in the NWT
Slimy sculpin	none	none	more abundant in streams than in lakes	invertivore	no	forage fish species found in streams but not valued by Aboriginal communities or by sport anglers in the NWT
Ninespine stickleback	none	none	found in small numbers in streams	invertivore	no	forage fish species not valued by Aboriginal communities or sport anglers in the NWT

(a) Traditional Knowledge and Traditional Land Use Baseline (Annex M).

(b) Non-traditional Land Use and Resource Use Baseline (Annex N).

NWT = Northwest Territories.

Lake Trout

Lake trout was selected as a valued fish species for this assessment for the following reasons:

- high abundance in Kennady Lake;
- position as the top predator in Kennady Lake;
- important to Aboriginal communities and non-traditional land users; and
- high potential for the Project to affect lake habitats upon which lake trout depend.

Lake trout is the second most abundant fish species in Kennady Lake after round whitefish, accounting for about 20% of the large-bodied fish community. In addition, lake trout is one of the most highly valued fish species for food by Aboriginal peoples who have fished in the Lockhart River watershed (Section 5). Along with Arctic grayling and northern pike, lake trout is one of the most prized fish species in the NWT for resident and non-resident sport anglers.

Lake trout completes all of its life history in lakes. Nearshore areas are more important to lake trout than deeper, offshore areas. In Kennady Lake, lake trout spawn on cobble/boulder substrates found primarily between the 2 and 4 m depth contours along wave-washed shorelines. These areas are used, because they are typically kept clean of sediments by wave-generated currents. Clean substrates are important for egg survival and incubation. Habitats deeper than 4 m are generally covered in a thick layer of silt and organic debris and provide only foraging and overwintering habitat for lake trout.

Lake trout are also suitable for assessing potential effects of water quality changes. Because of their position at the top of the food chain, any changes in lower trophic organisms or forage fish will ultimately have an effect on lake trout. Lake trout are also appropriate for assessing potential effects of metals or other substances that have the potential to bioaccumulate.

Arctic Grayling

Arctic grayling was selected as a valued fish species for this assessment, because of its importance to Aboriginal communities and to the Northwest Territories (NWT) sport fishery, and its unique life history in the Barrenlands region of the NWT. Arctic grayling in the Barrenlands has an adfluvial life history and is the only species that uses stream habitat exclusively for spawning and rearing within the watersheds that are expected to be affected by the Project.

The Project has the potential to alter the physical and hydrological characteristics of streams in the Kennady Lake watershed and downstream of Kennady Lake. Therefore, potential effects to streams will have a direct effect on Arctic grayling recruitment and the ability of populations to be sustainable. Any measures that can be implemented to minimize or eliminate effects to stream channels and flows will provide protection to Arctic grayling.

Northern Pike

Northern pike was selected as a valued fish species for this assessment, because of its importance to Aboriginal communities as a food source, its importance to the NWT sport fishery, and its dependence on aquatic macrophytes for spawning, rearing, and foraging. Aquatic macrophytes in Kennady Lake are scarce and are restricted to tributary mouths and isolated nearshore areas where fine sediments accumulate. As a result, the northern pike population in Kennady Lake is small and restricted to areas where aquatic macrophytes exist. These areas include some of the small lakes downstream of Kennady Lake and in the upper Kennady Lake watershed.

The Project has the potential to affect water levels in these small lakes in addition to the water level in Kennady Lake. Water level fluctuations may increase or decrease the abundance of aquatic vegetation in these lakes, and alter their distribution, depending on whether lake levels rise or fall. Notable changes in the aquatic macrophyte community, positive or negative, will ultimately affect northern pike. These effects would not be identified or would be inadequately assessed using lake trout alone. For this reason, northern pike are included as a VC in this assessment.

Other Fish Species

There are at least five other fish species that could have been selected as VCs for this assessment. They include round whitefish, burbot, lake chub, slimy sculpin, and ninespine stickleback. Each of these species did not meet at least one of the criteria listed above and were, therefore, not selected as a VC (Table 8.5-1). Despite being found in the Fisheries and Aquatic Resources Baseline (Annex J) Local Study Area, longnose sucker, white sucker, lake cisco, and lake whitefish were not found in Kennady Lake.

Round whitefish is the most abundant large-bodied fish species in Kennady Lake and is the primary prey species for lake trout and northern pike. It was not selected, because it is valued to a lesser extent by Aboriginal communities and sport fishermen than lake trout. Round whitefish use very similar nearshore habitat as lake trout for spawning and rearing; therefore, potential effects to round whitefish from alteration of lake habitats are likely to be identified, assessed, and mitigated by using lake trout as a VC.

Slimy sculpin is the only other stream-dwelling fish species besides Arctic grayling in the Kennady Lake watershed. Slimy sculpin was not selected as a VC fish species, because it has little value to traditional and non-traditional land users and has very similar habitat requirements to Arctic grayling. Inclusion of Arctic grayling is likely to provide sufficient indication of potential effects to stream habitat to slimy sculpin.

8.5.3 Assessment Endpoints and Measurement Endpoints

Assessment endpoints are the ultimate properties of the VCs that should be protected or developed for use by future human generations. They are general statements about what is being protected (e.g., suitability of water quality to support a thriving aquatic ecosystem).

Measurement endpoints are quantifiable (i.e., measurable) expressions of the aquatic environment that influence the assessment endpoints. For example, for water quality, the assessment endpoint is the suitability of water quality to support a viable aquatic ecosystem, and the relevant measurement endpoints include projected concentrations of nutrients (e.g., nitrogen and phosphorus nutrients), ionic constituents (e.g., dissolved salts, such as calcium and chloride) and metals (e.g., copper and iron) in Kennady Lake over time.

The effects analyses are completed with a focus on measurement endpoints. They are organized around specific effects statements that summarize the elements of the aquatic environment under investigation, and the results of the analyses are used to evaluate projected impacts to the associated assessment endpoints. The overall significance of Project impacts on VCs is predicted by linking residual changes in measurement endpoints to impacts on the associated assessment endpoint.

A summary of the aquatic-based assessment endpoints considered in this key line of inquiry is provided in Table 8.5-2, along with a summary of the associated measurement endpoints.

Although wildlife and human health are also VCs that are briefly discussed in this key line of inquiry, potential effects to wildlife and human health have not been classified in this section of the EIS. Classification of potential effects to wildlife and human health requires the consideration of all pathways by which effects to wildlife and human health can occur. These pathways include the inhalation of air and the consumption of terrestrial-based foods, the quality of which may potentially be affected by the Project. These pathways are not the subject of this key line of inquiry and are not discussed herein. As such, a summary of potential effects to wildlife and human health has been provided in this section of the EIS (i.e., Section 8.12), but a classification of the potential effects has not.

Table 8.5-2 Aquatic-based Assessment Endpoints and Measurement Endpoints for Valued Components Identified for Water Quality and Fish in Kennady Lake

Valued Components	Key Biophysical Components	Assessment Endpoints	Measurement Endpoints
Water Quality Fish (lake trout, Arctic grayling and northern pike)	• Permafrost • Hydrogeology and Groundwater • Surface Water Quantity • Sediment Quality • Aquatic Health • Fish Habitat	• Suitability of Water Quality to Support a Viable Aquatic Ecosystem • Abundance and Persistence of Desired Population(s) of Lake Trout • Abundance and Persistence of Desired Population(s) of Northern Pike • Abundance and Persistence of Desired Population(s) of Arctic Grayling	• permafrost depth and distribution, location and size of taliks near waterbodies and watercourses • groundwater level and flow rate, groundwater quantity and quality • surface topography, drainage boundaries, and waterbodies (e.g., streams, lakes, and drainages), stream flow rates, and spatial and temporal distribution of surface water, shoreline and channel morphology • physical characteristics of water (e.g., pH, conductivity, turbidity), concentrations of major ions, nutrients, total and dissolved metals and trace organic compounds in water • physical and chemical properties of sediment • physical aquatic habitat characteristics, habitat quantity and quality • plankton community structure and composition • benthic invertebrate community structure and composition • fish habitat availability and use • fish numbers, movement and behaviour, fish survival and reproduction, fish reproductive condition and health • access to fish and wildlife • human health

8.5.4 Spatial and Temporal Boundaries

The Terms of Reference identify the importance of spatial scale when analyzing and predicting the effects from the Project on VCs. It also emphasizes that the spatial scope of the study must be appropriate for the potential effect being assessed. For example, as lake trout spend all of their life history within a lake environment, individuals within populations of lake trout in Kennady Lake or any of the fish-bearing lakes within its watershed can be affected by the Project. For this species, the spatial boundary for the assessment of effects for this key line of inquiry was defined by the range of the population (i.e., Kennady Lake or applicable lakes within the Kennady Lake watershed), which conforms to the requirements of the Terms of Reference.

The approach used to determine the temporal scales of effects from natural and human-related disturbances on VCs is similar to the approach used to define spatial boundaries. In the EIS, the temporal boundaries are linked to the construction, operation, and closure phases of the Project, and also to the post-closure period. Effects could occur in any of these phases, and could extend into the post-closure period.

The duration of some changes induced by Project activities, such as potential changes to local air quality, are expected to end when Kennady Lake has been refilled. In contrast, effects to fish will likely continue beyond the closure phase, because it will take some time for the fish community to re-establish itself in Kennady Lake after refilling. Thus, the temporal boundary for a VC is defined as the amount of time between the start and end of a relevant Project activity or stressor (which is related to development phases), plus the duration required for the effect to be reversed.

After removal of the stressor, reversibility incorporates the likelihood and time required for a VC or system to return to a state that is similar to the state of systems of the same type that are not affected by the Project. For effects that are reversible, the EIS provides an estimate of the duration or time required to reverse the effect on the VC or system. Some effects may be reversible soon after removal of the stressor, such as effects to water flows to Kennady Lake from the B, D and E watersheds with the removal of temporary dykes E, F and G at closure. Other effects may require a longer duration before changes are reversed. For example, after Kennady Lake has been refilled and dyke A is breached, it may take a few years for the lower trophic community structure within Kennady Lake to return to an ecological state that will allow fish to successfully return to the lake.

Examples of irreversible effects include permanent loss of lake habitat. The placement of fine and coarse PK material and mine rock in areas of Kennady Lake will result in a permanent and irreversible loss of lake habitat.

8.5.5 Effects Analysis

In the EIS, the effects analysis considers all primary pathways that likely result in measurable environmental changes and residual effects to VCs (i.e., after implementing environmental design features and mitigation). Thus, the analysis is based on residual Project-specific (incremental) effects that are predicted to be primary in the pathway analysis. Residual effects to VCs are analyzed using measurement endpoints and expressed as effects statements (e.g., Effects of Project activities to water quality in Kennady Lake and Area 8 during and after refilling, and effects of closure activities to fish and fish habitat in Kennady Lake, Area 8, and streams and lakes within the Kennady Lake watershed). Effects statements may have more than one primary pathway that link a Project activity with a change in the environment and an effect on a VC. For example, the pathways for effects to fish and fish habitat include alteration of local flows and drainage areas, and water quality.

A detailed description of the spatial and temporal boundaries, and methods used to analyze residual effects from the Project is provided for each VC. The analyses are quantitative, where possible, and include data from field studies, scientific literature, government publications, effects monitoring reports, and personal communications. To limit the degree of technical information in the main text, specific details on modelling and statistical techniques, assumptions, analyses, and data sources are provided in appendices. Available traditional knowledge and community information are incorporated into the analysis and results, where appropriate. Due to the amount and type of data available, some analyses are qualitative and include professional judgment or experienced opinion.

The effects to water quality and fish in Kennady Lake and its watershed are assessed during construction, operations, and closure phases of the Project. The assessment requires the synthesis of information generated by each of the assessment components for which there are valid pathways: hydrology, water quality, aquatic health, fish and fish habitat, long-term recovery, and related effects to wildlife and human use. The detailed description of the methods used to analyze the effects from the Project on the VCs for each component is provided in Sections 8.7 to 8.12.

Assessment components focusing on the physical and chemical environment (e.g., hydrology and water quality) use baseline information and known processes in the sub-Arctic environment in combination with the Project design to develop mathematical models to predict conditions during the Project phases. Models are calibrated to baseline data and source input values, and scenarios are created representing periods during mine construction and operations when the greatest effects are expected to occur (e.g., highest or lowest flows, highest emissions). Model predictions are developed for locations (i.e., nodes) chosen to represent areas of concern regarding biological communities, such as stream reaches used by fish during spawning or migrations, or input points to downstream waterbodies (e.g., major inflows to Kennady Lake).

Results of models simulating physical changes are either used directly by the biological components (e.g., flow data by fish and fish habitat) to predict potential effects based on known habitat relationships of individual VCs (e.g., swimming ability of a fish species in relation to predicted current velocity or flow rates), or are used as part of the input data for other models. For example, water quality modelling incorporates physical processes (e.g., hydrology model results), mine-related water inputs and their estimated flow rates and chemistry (e.g., geochemistry fluxes from mine rock and PK material to porewater, groundwater inflows to open pits), baseline water quality, and natural physico-chemical processes to predict surface water quality at key locations in the Kennady Lake watershed.

Water quality model results, in combination with model results for physical conditions (i.e., changes to water levels and flow rates), are used by the fish and fish habitat components to predict direct effects to highly valued fish species, or indirect effects through changes in biological components of fish habitat (e.g., lower trophic communities, including plankton and benthic invertebrates). In addition to direct effects from changes in physical habitat (e.g., stream flows), direct and indirect effects due to changes in water chemistry are also evaluated by the aquatic health component (e.g., potential to cause effects to fish from changes in concentrations of metals or ammonia through direct exposure, or through fish tissue accumulation). Indirect effects through lower trophic communities consider potential direct effects (i.e., toxicity) and effects on productivity through nutrient enrichment from discharges of site water.

The assessment of the long-term recovery of Kennady Lake after refilling involved a different approach. It consisted of a three-step process. The first step incorporated a literature review to determine the documented recovery of lakes after flooding or refilling, and to identify, to the extent possible, the main drivers that control the rate and direction of recovery. The second step evaluated how the information compiled in the literature review applies to Kennady Lake, given its location and physical structure. The final step involved predicting how the aquatic ecosystem in Kennady Lake will likely recover.

Following the effects analysis, a summary of residual effects is provided in Section 8.13. Where possible, every effort is made to express the expected changes quantitatively or numerically. For example, the magnitude (intensity) of the effect may be expressed in absolute or percentage values above baseline (existing) conditions or a guideline value. The geographic extent of effects is expressed in area (hectares [ha]) or distance (kilometres [km]) from the Project. The expected duration would be expressed in years. In addition, the direction, likelihood, and frequency of effects may also be described, where applicable.

The technical information is then explained using non-technical descriptions. The quantitative description of effects is interpreted for a broader audience. For example, the appearance of a stream experiencing a one-in-two-year flood would be described, for example, in terms of flow rate and water level.

Expressions such as “short-term” duration or “moderate” magnitude are not used in the summary of residual effects. These expressions are reserved for the classification of impacts, where definitions of these expressions are provided. The classification follows the summary of residual effects in this key line of inquiry.

8.5.6 Cumulative Effects

Existing and planned projects in the NWT are located outside of the Kennady Lake watershed. As such, there is no opportunity for the releases of those projects to interact with those of the Project within the Kennady Lake watershed. Consequently, there is no potential for cumulative effects to fish or water quality in Kennady Lake or small lakes and streams in the Kennady Lake watershed.

8.5.7 Residual Impact Classification

To assess the environmental significance of the projected changes to the hydrology, water quality, and aquatic communities of the Kennady Lake watershed resulting from the Project, a residual impact classification system is applied to the VCs considered in this key line of inquiry. Firstly, each residual impact to one of the five assessment endpoints is rated for a series of criteria (Section 8.5.5.1), based on the results of the effects analysis and their linkages to the endpoints. Secondly, the criteria ratings are combined to classify environmental consequence (Section 8.5.5.2), which represents the overall impact of the Project on the assessment endpoint. In the final step, the projected impacts are evaluated to determine if they are of environmental significance (Section 8.5.5.3).

8.5.7.1 Criteria

The classification of residual impacts for this key line of inquiry is provided in Section 8.14. The purpose of the residual impacts classification is to describe the residual effects from the Project on the VCs using a scale of common words (rather than numbers and units). The classification of impacts is based on the following criteria specified in the Terms of Reference:

- direction;
- magnitude;
- geographic extent;
- duration;
- reversibility;
- frequency;
- likelihood; and
- ecological context.

These criteria are defined and explained in Section 6 of this EIS, with more specific details on the scale of each criteria provided herein in Section 8.14. The definitions for these scales are ecologically or logically based on the characteristics of the VC in question and the associated assessment endpoint, although the use of professional judgment is inevitable in some cases.

8.5.7.2 Significance

The evaluation of significance for biophysical VCs considers the entire set of primary pathways that influence a particular assessment endpoint, but significance is not explicitly assigned to each pathway. Rather, the relative contribution of each pathway is used to determine the significance of the Project on assessment endpoints, which represents a weight of evidence approach.

Environmental significance is used to identify predicted impacts that have sufficient magnitude, duration, and geographic extent to cause fundamental changes to a VC. Significance is determined by the risk to desired water quality and the persistence of fish populations (i.e., population level effects) within aquatic ecosystems. It is difficult to provide generalized definitions for environmental significance that are universally applicable to each assessment endpoint. Consequently, specific definitions are provided for each assessment endpoint.

Some of the key factors considered in the determination of environmental significance include:

- Results from the residual impact classification of primary pathways are used to evaluate the significance of impacts from the Project on the assessment endpoint of VCs.
- Magnitude, geographic extent, and duration (which includes reversibility) of the impact are the principal criteria, with frequency and likelihood as modifiers.
- Professional judgment, experienced opinion, and ecological principles, such as resilience, are used to predict the duration and associated reversibility of impacts.

The following is an example of definitions for assessing the significance of impacts on the aquatic VCs, and the associated continued opportunity for traditional and non-traditional use of the VCs.

Not significant – impacts are measurable but are not likely to decrease resilience and increase the risk to the persistence of specific fish populations.

Significant – impacts are measurable and likely to decrease resilience and increase the risk to the persistence of specific fish populations. A number of high magnitude and irreversible impacts at the population level would be significant.

These lower and upper bounds on the determination of significance are relatively straightforward to apply. It is the area between these bounds where ecological principles and professional judgment are applied to determine significance.

8.5.8 Uncertainty

Most assessments of effects embody some degree of uncertainty. EIS Section 8.15 includes a discussion of the key sources of uncertainty for each component (e.g., hydrology, water quality). It describes how uncertainty has been addressed to increase the level of confidence that potential effects have not been under-estimated. Confidence in effects analyses can be related to many elements, including the following:

- adequacy of baseline data for understanding existing conditions and future changes unrelated to the Project (e.g., climate change);
- model inputs (e.g., change in chemical concentrations in water over time and space);

- degree to which the models used in the assessment accurately describe the key processes that dominate the functioning of the systems being modelled;
- understanding of Project-related impacts on complex ecosystems that contain interactions across different scales of time and space (e.g., how and why the Project will influence surface hydrology); and
- knowledge of the effectiveness of the environmental design features for reducing or removing impacts (e.g., environmental performance of the mine rock management area).

8.5.9 Monitoring and Follow-up

For this key line of inquiry, the monitoring and follow-up is provided in Section 8.16. In this section, monitoring programs will be proposed to deal with the uncertainties associated with the impact predictions and environmental design features and mitigation. In general, monitoring will be used to test (verify) impact predictions and determine the effectiveness of environmental design features and mitigation. To meet the Terms of Reference, the monitoring programs that may be applied during the development of the Project will be distinguished among the following:

- **Compliance inspection**: monitoring the activities, procedures, and programs undertaken to confirm the implementation of approved design standards, mitigation, and conditions of approval and company commitments.
- **Environmental effects monitoring**: monitoring to track conditions or issues during the development lifespan, and subsequent adaptation of Project management.
- **Follow-up**: programs designed to verify the accuracy of impact predictions, to reduce uncertainty, and to determine the effectiveness of mitigation.

These programs will form part of the environmental management system (EMS) for the Project. If monitoring or follow-up detects effects beyond those predicted or the need for improved or modified design features, then adaptive management strategies will be developed and implemented, as required.

8.6 PATHWAY ANALYSIS

8.6.1 Methods

Pathway analysis identifies and assesses the issues and linkages between components or activities associated with the Gahcho Kué Project (Project), and the correspondent potential residual effects on water quality and fish in Kennady Lake. Pathway analysis is a three-step process for identifying and validating linkages between Project activities and environmental effects that are assessed in Sections 8.7 to 8.12. Potential pathways through which the Project could influence water quality and fish in Kennady Lake were identified from a number of sources including:

- potential pathways identified in the *Terms of Reference for the Gahcho Kué Environmental Impact Statement* (Gahcho Kué Panel 2007) and the Report of Environmental Assessment (MVEIRB 2006);
- a review of the Project Description and scoping of potential effects by the environmental assessment and Project engineering teams for the Project; and
- consideration of potential effects identified for the other diamond mines in the Northwest Territories (NWT) and Nunavut.

The first part of the analysis is to produce a list of all potential effects pathways for the Project. This step is followed by a summary of environmental design features and mitigation that can be incorporated into the Project to remove the pathway or limit (mitigate) the effects to water quality and fish in Kennady Lake. Environmental design features include Project designs and environmental best practices and mitigation, and management policies and procedures. Environmental design features and mitigation practices were developed through an iterative process with the Project design and environmental assessment teams.

Knowledge of the ecological system and environmental design features and mitigation is then applied to each of the pathways to determine the expected amount of Project-related changes to the environment and the associated residual effects (i.e., after mitigation) on water quality and fish in Kennady Lake. For an effect to occur there has to be a source (Project component or activity) and a primary connection (pathway) to water quality and fish in Kennady Lake.

Project activity → change in environment → effect on a valued component (VC)

Pathway analysis is a screening step that is used to determine the existence and magnitude of linkages from the initial list of potential effects pathways for the Project. This screening step is largely a qualitative assessment, and is intended to focus the effects analysis on pathways that require a more comprehensive assessment of effects on water quality and fish in Kennady Lake. Pathways are determined to be primary, secondary (minor), or as having no linkage using scientific and traditional knowledge, logic, and experience with similar developments and environmental design features and mitigation. Each potential pathway is assessed and described as follows:

- no linkage – pathway is removed by environmental design features and mitigation so that the Project results in no detectable environmental change and residual effects to a VC relative to baseline or guideline values;
- secondary – pathway could result in a measurable and minor environmental change, but would have a negligible residual effect on a VC relative to baseline or guideline values (e.g., an increase in a water quality parameter that is small compared to the range of baseline values and is well within the water quality guideline for that parameter); or
- primary – pathway is likely to result in a measurable environmental change that could contribute to residual effects on a VC relative to baseline or guideline values.

Primary pathways require further effects analysis and impact classification to determine the environmental significance from the Project on the suitability of water quality to support a viable aquatic ecosystem, persistence of desired population(s) of key fish species, continued opportunity for traditional and non-traditional use of water and fish and the protection of human health. Pathways with no linkage to water quality and fish in Kennady Lake or that are considered minor are not analyzed further or classified in Sections 8.7 to 8.11 because environmental design features and mitigation will remove the pathway (no linkage) or residual effects to water quality and fish in Kennady Lake can be determined to be negligible through a simple qualitative evaluation of the pathway (secondary). Pathways determined to have no linkage to water quality and fish in Kennady Lake or those that are considered secondary are not predicted to result in environmentally significant effects to water quality, fish, continued opportunity for traditional and non-traditional use of water and fish, and the protection of human health. All primary pathways are assessed in Sections 8.7 to 8.11.

The section is organized by Project phase. The pathways for Construction and Operations are described in Section 8.6.2.1, and the pathways for Closure are described in Section 8.6.2.2.

8.6.2 Results

Pathways potentially leading to effects on water quality and fish in Kennady Lake include direct and indirect effects. These changes may ultimately affect the suitability of water quality to support a viable aquatic ecosystem, persistence of desired population(s) of key fish species, continued opportunity for traditional and non-traditional use of water and fish and the protection of human health. Evaluation of effects on water quality and fish in Kennady Lake also considers changes to permafrost, hydrogeology, hydrology, and air quality, and during the construction and operations, and closure phases of the Project, as well as effects remaining after closure. Table 8.6-1 and Table 8.6-2 (found in Section 8.6.2.1.3) summarize the environmental design features and mitigation that were incorporated into the Project to eliminate or reduce effects to water quality, fish, and fish habitat in Kennady Lake during construction, operations, and closure.

Potential pathways are based primarily on public concerns identified during the Mackenzie Valley Environmental Impact Review Board (MVEIRB) scoping process (MVEIRB 2006). The issues are screened and considered for inclusion as pathways for that could lead to effects. Some issues may not represent actual pathways, and in other instances, the preliminary screening and/or analysis may show that potential effects considered during issues scoping are so small that they are not relevant. Other concerns may be screened out through the incorporation of environmental design features and mitigation during the development of the Project, which address these issues by reducing or eliminating potential effects. Other potential pathways may be primary pathways and are included in the effects analysis. The following sections discuss the potential pathways relevant to water quality and fish in Kennady Lake.

8.6.2.1 Potential Pathways during Construction and Operations

Table 8.6-1 summarizes the potential direct and indirect effects of the Project on the suitability of water quality to support a viable aquatic ecosystem, persistence of desired population(s) of key fish species, continued opportunity for traditional and non-traditional use of water and fish and the protection of human health during construction and operations.

Table 8.6-1 Potential Pathways for Effects to Water Quality and Fish in Kennady Lake during Construction and Operations

Project Component/Activity	Effects Pathways	Environmental Design Features and Mitigation	Pathway Assessment
Project footprint (e.g., dykes, mine pits, mine rock and coarse PK piles, Fine PKC Facility, access roads, mine plant, airstrip)	• reduction in watershed areas may change flows, water levels, and channel/bank stability in streams and small lakes in the Kennady Lake watershed, and affect water quality, fish habitat and fish	• backfilling the mined-out 5034 and Hearne pits with processed kimberlite (PK) and mine rock to decrease the on-land Project footprint and reduce the volume of deep pit lakes within a reclaimed Kennady Lake. • compact layout of the surface facilities to limit the area that is disturbed by construction and operation.	Primary
	• impediments to fish passage at stream crossings (e.g., airstrip and roads) may affect fish	• installation of properly sized culverts with natural substrates, including Stream Ha1 underneath airstrip	No Linkage
	• seepage and runoff from the mine rock piles, Coarse PK Pile and the Fine PKC Facility, may change water quality in the Kennady Lake watershed, and affect aquatic health and fish	• runoff and seepage from these Project facilities will flow naturally to collection ponds in the dewatered areas of Kennady Lake • the Coarse PK Pile will not be designed to have a single point of release for seepage and runoff; any runoff will flow through natural channels within the Project footprint and be retained in the collection pond associated with Area 4 • seepage and runoff directed to the dewatered area of Kennady Lake will not be directly released to the environment; water will be sequestered into Areas 3 and 5 (Water Management Pond [WMP]), and later into the process plant or the Fine PKC Facility and then to the backfilled mine pits • release of blasting residues from mined rock material will be reduced by containing and permanently storing all water inflow to the mine and kimberlite process water; emulsions will be used for wet blasting, and ammonium nitrate fuel oil (ANFO) will be used for dry blasting to limit ammonia leaching • explosives will be managed to limit the loss of ammonia to mine rock and kimberlite, which could subsequently leach into runoff at the Project site or be processed at the processing plant • seepage from the mine rock and Coarse PK piles, and the Fine PKC Facility will not be directly released to Area 8; water will be sequestered into the WMP, and later into the process plant or the Fine PKC Facility and then to the backfilled mine pits • during reclamation, only non-reactive mine rock will be placed on the upper and outer surfaces of the mine rock pile. The thickness of the cover layer is predicted to be sufficient so that the active freeze-thaw layer remains within the non-acid generating (NAG) mine rock with the development of permafrost	No Linkage

Table 8.6-1 Potential Pathways for Effects to Water Quality and Fish in Kennady Lake during Construction and Operations (continued)

Project Component/Activity	Effects Pathways	Environmental Design Features and Mitigation	Pathway Assessment
Project footprint (e.g., dykes, mine pits, mine rock and coarse PK piles, Fine PKC Facility, access roads, mine plant, airstrip) (continued)	• seepage and runoff from the mine rock piles, Coarse PK Pile and the Fine PKC Facility, may affect water quality in the Kennady Lake watershed, and result in changes to aquatic health and fish (continued)	• thermistors will be installed within the mine rock piles to monitor the progression of permafrost development. The upper portion of the thick cover of clean mine rock over the repository will be subject to annual freeze and thaw cycles, but any PK and potentially acid-generating (PAG) rock sequestered are predicted to remain frozen • during reclamation, the Coarse PK Pile and Fine PKC Facility will be shaped and covered with a layer of mine rock of a minimum 1 m to limit surface erosion and to direct surface drainage and seepage to Kennady Lake	No Linkage (continued)
	• construction of site infrastructure may result in sediment releases through the drainage network that will change water and sediment quality, and affect fish habitat and fish	• standard erosion and sediment control measures (e.g., silt curtains, runoff management) will also be used during construction around areas to be disturbed • construction will take place during the winter when streams within or adjacent to the Project site are not flowing, or after the spring freshet when flows are generally low	No Linkage
	• project development in the Kennady Lake watershed will result in the loss of fish habitat	• preparation of a compensation plan to develop fish habitat of equivalent or higher productive capacity where prevention of harmful habitat alteration or loss is not feasible	Primary
Dewatering of Kennady Lake	• dewatering of Kennady Lake and other small lakes may cause mortality and spoiling of fish	• fish salvage in Kennady Lake and other lakes will be conducted to remove fish before and during dewatering; the fish salvage will be designed and implemented in consultation with DFO and local Aboriginal communities	Primary
	• impingement and entrainment of fish in intake pumps during dewatering may cause injury and mortality to fish	• appropriately sized fish screens, which meet DFO guidelines, fitted to pumps to limit fish access and to limit fish entrained to the smallest species and life stages	Secondary
	• release of sediment to Area 8 during the construction of Dyke A may change water and sediment quality, and affect fish habitat and fish	• silt curtains will be placed upstream and downstream of the construction area to control the release of sediment to Area 8	Secondary
	• erosion of lake-bottom sediments in Area 8 near the outfall may cause changes to water and sediment quality and affect fish habitat and fish	• pumped discharge to Area 8 will be directed through properly designed outfalls/diffusers to prevent erosion	No Linkage
	• alteration of groundwater flows from dewatering Kennady Lake may change the surface water levels in nearby lakes, and affect water quality and quantity, fish habitat and fish	• none	Secondary

Table 8.6-1 Potential Pathways for Effects to Water Quality and Fish in Kennady Lake during Construction and Operations (continued)

Project Component/Activity	Effects Pathways	Environmental Design Features and Mitigation	Pathway Assessment
Dewatering of Kennady Lake (continued)	• dewatering of Area 7 to Area 8 may change flows, water levels, and channel/bank stability in Area 8	• direct discharge of clean water to Area 8 while water quality discharge criteria are met; discharge from Area 7 is proposed to cease after Year -2 • discharge during the first phase of dewatering of Kennady Lake will be monitored so that the lake surface in the dewatering area remains at a level that limits suspended sediment concentrations reaching levels that exceed specific water quality discharge criteria • during dewatering, sediments may become suspended in the water, therefore, in-line flocculant treatment and temporary storage of the runoff collected in storage areas and pit water may be used to reduce total suspended solids transferred to the Water Management Pond (Areas 3 and 5), prior to release to the environment • lake dewatering discharge will be sampled regularly to monitor for compliance with discharge criteria, and any water not meeting the criteria will be stored within the controlled Water Management Pond • as a contingency scenario, the Project is capable of operating without discharge beyond the controlled areas of the Kennady Lake watershed after initial lake dewatering is complete • direct discharge flow rates to Area 8 will be restricted to 1-in-2 year flood levels to eliminate erosion concerns	Primary
	• dewatering of Area 7 and pumping to Area 8 may change water quality, and affect aquatic health and fish		No Linkage
	• reduction in upper watershed flow to Area 8 may change surface water levels, and affect water quality, fish habitat and fish		Secondary
Isolation and diversion of upper Kennady Lake watersheds	• release of sediment during construction of dykes in the A, B, D and E watersheds may change water and sediment quality, and affect fish habitat and fish	• all mine rock used to construct the dykes will be NAG • construction of dykes will raise the water level in various areas and subsequently create new fish habitat • preparation of shoreline areas to be flooded by selectively removing vegetation to limit organic loading from decaying vegetation to the water column • cobble and boulder placement to reduce erosion potential • silt curtains will be placed upstream and downstream of the construction area to control the release of suspended sediments • implementation of a quality assurance program during construction of each of the dykes so that construction-sensitive features of the design are achieved; the specific requirements and testing frequencies for the quality assurance process will be set out in the Construction Specifications prepared during final designs • monitoring of the performance of the dykes throughout their construction and operating life; instrumentation including piezometers, thermistors, and survey monitoring markers together with systematic visual inspection will provide early warning of many conditions that can contribute to dyke failures and incidents • monitoring of new shorelines associated with the raised lakes	Secondary
	• changes to permafrost conditions in the flooded shoreline zone of the raised lakes due to increased water levels may lead to erosion and affect fish habitat		Secondary
	• alteration of the A, B, D and E watershed areas and flow paths may change flows, water levels, and channel/bank stability in the Kennady Lake watershed, and affect water and sediment quality, fish habitat and fish		Primary

Table 8.6-1 Potential Pathways for Effects to Water Quality and Fish in Kennady Lake during Construction and Operations (continued)

Project Component/Activity	Effects Pathways	Environmental Design Features and Mitigation	Pathway Assessment
Isolation and diversion of upper Kennady Lake watersheds (continued)	• alteration of water levels in Lakes A3, D2, D3, and E1 may result in shoreline erosion, re-suspension of sediments, and sedimentation, and affect water and sediment quality, fish habitat and fish		Primary
	• release or generation of nutrients, mercury, or other substances into Lakes A3, D2, D3, and E1 from flooded sediments and vegetation may change water quality, and affect aquatic health and fish	• areas to be flooded by raising water levels of Lakes A3, D1, D2, and E1 will be surveyed and where necessary, will be prepared by removing vegetation cover to reduce the release of organic material upon flooding. • shoreline areas susceptible to extensive erosion will be armoured by cobbles and boulders to reduce erosion and associated resuspension of fine sediments	Secondary
	• change of flow paths and construction of retention and diversion dykes in the A, B, D and E watersheds may change fish migration	• diversion channels will be designed to provide spawning and rearing habitat, and permit fish passage	Primary

Table 8.6-1 Potential Pathways for Effects to Water Quality and Fish in Kennady Lake during Construction and Operations (continued)

Project Component/Activity	Effects Pathways	Environmental Design Features and Mitigation	Pathway Assessment
Pit development	• removal of bedrock and kimberlite material from the active mining of pits may change groundwater quantity in the Kennady Lake watershed, and the water level in small lakes in the watershed	• mined-out pits will be augmented by fresh water during refilling	Secondary
	• removal of saline groundwater inflows during pit development to the WMP may affect water quality in Areas 3 to 7, and affect aquatic health and fish	• water inflow to the dewatered area of Kennady Lake will not be directly released to Area 8; water will be sequestered into Areas 3 and 5, and later into the process plant or the Fine PKC Facility and then to the backfilled mine pits • backfilling the mined-out pits with PK and mine rock will allow for containment of deep groundwater in the open pits • storage ponds located in the open pits will be capable of holding the maximum predicted daily base case groundwater inflow, in addition to the 1-in-100 wet year freshet event	No Linkage
	• alteration of the groundwater regime from groundwater flows to the mined out pits may change water quality and water quantity in other lakes in the watershed	• none	Secondary
	• blasting and excavation near fish-bearing lakes may result in pressure changes and vibrations, and affect fish	• all blasting and excavation will occur in the dewatered areas of Kennady Lake where no water or fish will be present	No Linkage

Table 8.6-1 Potential Pathways for Effects to Water Quality and Fish in Kennady Lake during Construction and Operations (continued)

Project Component/Activity	Effects Pathways	Environmental Design Features and Mitigation	Pathway Assessment
Use of Area 8 as the potable water supply and additional fire suppression capacity	• impingement and entrainment of fish in potable water intake pumps in Area 8 may cause injury and mortality to fish and affect fish populations	• appropriate sized fish screens following DFO guidelines will be used on the pump intakes to limit fish entrained	Secondary
	• extraction of potable water requirements for the Project may change surface water levels in Area 8, and affect fish habitat	• the process plant design is based on the recycling and reusing of waste streams (i.e., WMP) and rain water, where practical, to limit fresh water usage	Secondary
Site Water Management	• treated effluent discharge from the sewage treatment plant (STP) to the WMP may change water quality in the Areas 3 to 7, and affect aquatic health and fish	• treated liquid effluent from the sewage treatment system will be directed to Area 3 in Year -1, and then to the process plant for disposal with the fine PK stream from Year 1 on • water in the WMP will not be directly released to Area 8; water will be sequestered into the WMP, and later into the process plant or the Fine PKC Facility and then to the backfilled mine pits • sewage sludge will be dewatered and land filled on-site	No Linkage

Table 8.6-1 Potential Pathways for Effects to Water Quality and Fish in Kennady Lake during Construction and Operations (continued)

Project Component/Activity	Effects Pathways	Environmental Design Features and Mitigation	Pathway Assessment
Site Water Management (continued)	• changes to the drainage network within the Kennady Lake watershed due to the Project may change surface water runoff and cause soil erosion, and affect water quality, fish habitat and fish	• where practical, natural drainage patterns will be used to reduce the use of ditches or diversion berms • runoff from stockpiles, the mine rock piles and the Coarse PK Pile and the Fine PKC Facility, the ammonium nitrate storage areas, and mine pits piles will be contained within the managed areas of Kennady Lake • all site runoff will be conveyed directly to the WMP or via collection ponds within areas of Kennady Lake, which will act as a control basin for storage of water • deeper basins in the dewatered areas of Kennady Lake will act as collection ponds for natural and site runoff • runoff stored in collection ponds may be pumped to the WMP each year, prior to the onset of winter, to optimize storage for the following year's freshet • runoff from the mine rock piles is designed to remain within the controlled watershed and to take advantage of natural drainages present; till from ongoing pit stripping will be used to cover PAG rock placed within the interior of the mine rock and PK repositories to prevent water from penetrating into that portion storing the reactive rock material • overburden will provide a low permeability barrier that will limit infiltration and encourage water to flow over the surface of the mine rock and coarse PK piles, rather than through them • erosion and sediment control practices (e.g., silt fences, runoff management) will be used as required to limit erosion of topsoil and overburden stockpiles, and corresponding changes in water quality from sediment loading • filter cloth silt fences will be used in natural and enhanced surface drainage courses at the airstrip to remove sediments, and these sediment traps will be maintained as required • erosion protection materials will be used to line downstream natural channels (or engineered channel when required) to limit erosion along the flow paths to the mined-out Tuzo Pit	No Linkage

Table 8.6-1 Potential Pathways for Effects to Water Quality and Fish in Kennady Lake during Construction and Operations (continued)

Project Component/Activity	Effects Pathways	Environmental Design Features and Mitigation	Pathway Assessment
Site Water Management (continued)	• seepage of pore water through, or underneath, incompletely frozen dykes to adjacent watersheds may change water quality in the Kennady Lake watershed, and affect aquatic health and fish	• temporary and permanent dykes will be constructed with a liner keyed into competent frozen ground (saturated inorganic permafrost) or bedrock • internal retention dykes will be constructed with a wide till core to control seepage; any seepage will be collected and pumped back to the source reservoir as required • permafrost will be preserved in foundation soils beneath dykes by constructing structures during the winter when the active layer is frozen • performance of the dykes will be monitored throughout their construction and operating life; to confirm the lower levels remain frozen, temperature monitoring systems will be placed in the mine rock piles as they are being constructed	No Linkage
	• close-circuiting of Areas 2 to 7 may change water quality in Area 8, and affect aquatic health and fish in Area 8	• construction of Dyke A to isolate Areas 2 to 7 from Area 8	Secondary
Construction and Mining Activity during construction and operations	• deposition of dust from fugitive dust sources may change water quality and sediment quality, and affect aquatic health and fish	• regular watering of exposed lake bottoms, roads, the airstrip, and laydown areas will facilitate dust suppression around the site • speed limits will be enforced to assist in reducing dust generation • the compact layout of the surface facilities will limit the area disturbed at construction and reduce traffic around the site • segregation of traffic to reduce interaction of heavy equipment and traffic load (i.e., heavy equipment will be isolated to the mining area, and haulage traffic will be limited to the mine site and mine access road) • personnel arriving at or leaving the site will be transported by bus therefore reducing the amount of traffic between the airstrip and the accommodation complex. • heavy equipment and mine vehicles will undergo regular maintenance of engines, maintain emission guidelines for internal combustion engines, and use low-sulphur diesel fuel • a program of carbon and energy management will be implemented once the generators are commissioned • generator efficiencies and equipment will be tuned for optimum fuel-energy efficiency	Primary
	• air emission and deposition of sulphur dioxide [SO_2], nitrogen oxides [NO_X], particulate matter [PM], and total suspended particulates [TSP] may change water and sediment quality, and affect aquatic health and fish		Primary

Table 8.6-1 Potential Pathways for Effects to Water Quality and Fish in Kennady Lake during Construction and Operations (continued)

Project Component/Activity	Effects Pathways	Environmental Design Features and Mitigation	Pathway Assessment
Construction and Mining Activity during construction and operations (continued)	• increased under-ice noise and vibrations from traffic on the winter road or activity on the ice airstrip may affect fish	• none	Secondary
	• spills within the Project footprint (e.g., petroleum products, reagents, wash-down) may change water and sediment quality in the Kennady Lake watershed, and affect aquatic health, fish habitat and fish	• petroleum products will only be handled by mine personnel who have received appropriate training • an emergency and spill contingency plan will be developed • spill containment supplies will be in designated areas • any spills will be isolated and immediately cleaned up by a trained spill response team consisting of on-site personnel, which will be available for rapid response • mine vehicles and heavy equipment will be maintained to operational standards • all fuel storage tanks will be designed and constructed according to the American Petroleum Institute (API) 650 standard; a lined and dyked containment area around these tanks will be provided to contain any potential fuel spills. The design of the containment area will be based on the requirements of the Canadian Council of the Ministers of Environment (CCME) *Environmental Code of Practice for Above-Ground Storage Tanks Systems Containing Petroleum Products* (CCME 2003), the National Fire Code of Canada, and any other standards that are required. The containment area will be sized to hold 110% of the volume of the largest storage tank and will include a gravel base with a continuous high-density polyethylene liner sheet installed under the tanks and the internal sides of the berm • a fuel unloading pumping module will be installed within a spill containment area adjacent to the fuel storage tank farm • aviation fuel will be stored in self-contained, Underwriters Laboratories Canada (ULC)-rated envirotanks mounted on an elevated pad at the air terminal shelter; aviation fuel for helicopters will be stored in sealed drums inside a lined berm area near the airstrip • to prevent accumulation and/or runoff of de-icing fluids at the airstrip from aircraft de-icing operations, aircraft will be sprayed in a specified area on the strip that will be equipped with swales to collect excess fluid; any affected soil and gravel resulting from spills will be collected and transferred to the landfarm and puddles of de-icing fluid in the swales will be removed by vacuum truck and deposited into waste drums for shipment off-site • waste oil will be collected and stored in the waste oil storage tank and incinerated for heat generation or used with explosives, if it is not shipped off-site for recycling • the grease used in the diamond recovery process on-site will be recycled as much as possible	No Linkage

Table 8.6-1 Potential Pathways for Effects to Water Quality and Fish in Kennady Lake during Construction and Operations (continued)

Project Component/Activity	Effects Pathways	Environmental Design Features and Mitigation	Pathway Assessment
Construction and Mining Activity during construction and operations (continued)	• spills within the Project footprint (e.g., petroleum products, reagents, wash-down) may change water and sediment quality in the Kennady Lake watershed, and affect aquatic health, fish habitat and fish (continued)	• chemicals such as de-icing fluid, acids, solvents, battery acids, and laboratory agents will be collected in lined trays and drums and stored in suitable sealed containers in the waste transfer area • chemicals that cannot be incinerated will be shipped off-site for disposal or recycling • hazardous, non-combustible waste and contaminated materials will be temporarily stored in the waste storage transfer area in sealed steel or plastic, wildlife-resistant drums, and shipped off-site for disposal or recycling • the waste transfer storage area will include a lined and enclosed pad for the collection and subsequent return of hazardous waste to suppliers or to a hazardous waste disposal facility • emulsion materials will be stored at the emulsion plant where spills will be 100% contained within the building • processing of the kimberlite ore will be mechanical, with minimal use of chemicals	No Linkage (continued)

8.6.2.2 Pathways with No Linkage

A pathway may have no linkage if the activity does not occur (e.g., effluent is not released), or if the pathway is removed by environmental design features and mitigation so that the Project results in no detectable (measurable) environmental change and residual effects to water quality and fish in Kennady Lake. The following pathways are anticipated to have no linkage to water quality and fish in Kennady Lake, and will not be carried through the effects assessment.

Impediments to fish passage at stream crossings (e.g., airstrip and roads) may affect fish

A culvert will be installed in the one fish-bearing stream crossed by the airstrip during its construction. This culvert will be designed, sized, and installed using appropriate federal and territorial guidelines (e.g., DFO 1998; Alberta Environment 2001; BC Ministry of Forests 2002; Cott and Moore 2003) to allow passage of fish and to prevent upstream and downstream erosion.

Lakes upstream of the airstrip are known to contain ninespine stickleback and slimy sculpin. Other fish species could move into Stream H1a from Area 8 during operations but this is unlikely. Stream H1a is small (less than 3 metres [m] wide), contains low-quality habitat for spawning, and provides access to lakes with low-quality habitat for fish species other than ninespine stickleback and slimy sculpin. Because the culvert would be properly sized and installed, the airstrip will not pose a barrier to ninespine stickleback (*Pungitius pungitius*), slimy sculpin (*Cottus cognatus*), or other fish species moving upstream or downstream in Stream H1a.

As such, impediments to fish passage at stream crossings within the Kennady Lake watershed (e.g., Stream H1a adjacent to the airstrip) was determined to have no linkage to effects to the fish and fish habitat.

Seepage and runoff from the mine rock piles, Coarse PK Pile, and Fine PKC Facility may change water quality in the Kennady Lake watershed, and affect aquatic health and fish

The key objective of the Water Management Plan during the construction and operations phase of the Project is to minimize the discharge of site water to the downstream environment. During construction and operations, a Water Management Pond (WMP) will be developed in Areas 3 and 5, which will possess a maximum storage capacity of 18.8 million cubic metres (Mm^3). The WMP will collect and store water from the following sources:

- Fine Processed Kimberlite Containment (PKC) Facility (Areas 1 and 2) drainage through filter Dyke L;
- runoff and seepage from the West Mine Rock Pile;
- Area 4 open water drainage (including runoff and seepage from the Coarse Processed Kimberlite [PK] Pile) prior to the construction of Dyke B;
- water pumped from Areas 6 and 7 during dewatering of Kennady Lake;
- open pit dewatering; and
- disturbed and undisturbed site runoff.

The WMP will be the primary reservoir for storage of site water and will supply water to the process plant during mining of the 5034 and Hearne open pits. In addition, the WMP will be the primary source of dust suppression water.

During the operational period, Areas 1 and 2 will be required for deposition of fine PK. A filter dyke (Dyke L) will be constructed to separate these areas from Area 3. During the initial years of operations, fine PK will be deposited into Area 1. The Fine PKC Facility will eventually expand into Area 2 when Area 1 becomes completely inundated with fine PK. At this stage, surface runoff, seepage and liberated process water from Area 1 is expected to report to the WMP via Area 2. As fine PK deposition expands into Area 2, runoff, seepage and process free water from the Fine PKC Facility will report to Area 3 via filter Dyke L. Fine PK deposition will be redirected to the mined out Hearne Pit following the cessation of mining in this pit during 2021. At this time, the Fine PKC Facility will be progressively reclaimed as terrestrial landscape. Subsequently, runoff and seepage from the Fine PKC Facility resulting from precipitation will continue to report to Area 3 via filter Dyke L.

The proposed footprint of the Coarse PK Pile is located immediately east of Area 4. Runoff and seepage from this facility will report to Area 4, where it will initially flow to the WMP when there is an open water connection between Area 3 and 4 in Kennady Lake. Following the completion of Dyke B in August 2019 and dewatering of Area 4, Coarse PK Pile runoff and seepage will report to the Area 4 collection pond and subsequently be pumped to the WMP.

Two facilities will be required to store mine rock during operations at the Project site: West Mine Rock Pile and the South Mine Rock Pile. The West Mine Rock Pile will be constructed within the catchment of Areas 3 and 5 at the watershed divide with Area 6. Seepage and runoff from this facility will report to the WMP. To minimize the amount of seepage reporting to the dewatered Area 6 from the West Mine Rock Pile, Dykes H and I will be constructed along the southern and eastern limits of the facility, respectively. The proposed footprint of the South Mine Rock Pile is located immediately south of Area 6. All runoff and seepage from this facility will be directed to the Area 6 collection pond, where it will be subsequently pumped to the WMP, Area 7 or the mined out Hearne Pit, depending on the timing and where Area 6 water is being directed.

During operations, water from the WMP will not be discharged directly to waters in the Kennady Lake watershed that lie outside of the controlled area boundary (i.e., Area 8, unless the water meets specific water quality criteria). As a consequence, seepage and runoff from Project infrastructure, such as the mine rock and Coarse PK piles and the Fine PKC Facility (including diffusive flux from the mined rock material and blasting residue in porewater), are not expected to result in changes to water quality in downstream waters in the Kennady Lake watershed. Consequently, this pathway was determined to have no linkage to effects to fish.

Construction of site infrastructure may result in sediment releases through the drainage network that will change water and sediment quality, and affect fish habitat and fish

Project infrastructure (e.g., roads, airstrip, buildings) will be constructed using non-acid generating construction rock. Construction will take place during the winter when streams within or adjacent to the Project site are not flowing, or after the spring freshet when flows are generally low. Construction during these periods will minimize the potential for sediment releases. Standard erosion and sediment control measures (e.g., silt curtains, runoff management) will also be used during construction around areas to be disturbed to reduce the release of sediment.

Most of the Project infrastructure will be located in drainage areas within a drainage network that will transfer site runoff to the WMP or collection ponds in the areas within Kennady Lake during operations. Runoff will be transferred from the collection ponds to the WMP, and if necessary, treated in line with flocculent to reduce suspended sediment concentrations.

The WMP is an integral component of the mine development. As the water levels will be drawn down in the WMP to provide site and water storage, it is expected that water quality will be unsuitable to support fish. Thus, subject to receiving *Fisheries Act* Sections 32 and 35 Authorizations, fish will be removed from the WMP. As the WMP would not be suitable for fish, sediment releases through the drainage network to collection ponds and the WMP are not expected to result in changes to fish habitat. Consequently, this pathway was determined to have no linkage to effects to fish.

Erosion of lake-bottom sediments in Area 8 near the outfall may cause changes to water and sediment quality, and affect fish habitat and fish

The potential for erosion of lake-bottom sediments in Area 8 will be minimized during the pumping from Area 7. Constructed channel outfalls or diffusers will be used to reduce the erosive energy of water pumped out of Area 7 into Area 8 during dewatering. Outfalls will be constructed to diffuse the velocity of the pumped discharge. Diffusers, if required, will be placed as close to the surface as possible over the deepest portion of Area 8 to increase the distance between the outfall and the bottom sediments. Although some sediment may be mobilized despite these measures, the extent of this effect is likely to be limited to the zone of turbulence immediately adjacent to the diffuser, and is likely to quickly diminish after sediments in the zone of turbulence are mobilized and become re-deposited farther away from the outfall.

As a result, discharge of water from Area 7 to Area 8 during dewatering is not expected to result in measurable changes to the sediment bed in Area 8. With little disturbance to the sediment bed near the outfall, there will be negligible effects to sediment quality, increases in suspended sediment to the water column or changes to fish habitat. Consequently, this pathway was determined to have no linkage to effects to fish.

Dewatering of Area 7 and pumping to Area 8 may change water quality, and affect aquatic health and fish

Water from Area 7 will be pumped to Area 8 while it meets specific water quality criteria. The projected maximum water flow to Area 8 will be 114,000 cubic metres per day (m^3/d) during these conditions. It is expected that water quality in Area 7 will be consistent with that in Area 8. Any variability in water quality between the two areas will be within the natural range of variability reported for Kennady Lake.

As dewatering of Areas 6 and 7 progresses, suspended sediment concentrations in Areas 6 and 7 will increase. When discharge water quality criteria, which will include criteria for turbidity and total suspended solids (TSS) concentrations are exceeded, discharge from Area 7 to Area 8 will cease. However, the dewatering of Areas 6 and 7 will still be required. At this stage, water from Areas 6 and 7 will be pumped into the south end of Area 5 until the region above the 5034 and Hearne ore bodies in Area 6 and 7 is dry and available for mining.

As a result, discharge of water from Area 7 to Area 8 during dewatering is not expected to result in measurable changes to water and sediment quality in Area 8, and aquatic health relative to baseline conditions. Consequently, this pathway was determined to have no linkage to effects to fish.

Removal of saline groundwater inflows during pit development to the WMP may change water quality in Areas 3 to 7, and affect aquatic health and fish

During the operational period, water reporting to the open pits will be pumped to the WMP, where it will be recycled to the process plant or used for dust suppression. Dewatering of open pits to the WMP will cease when mining is complete in the Hearne Pit in July 2021. Thereafter, the Tuzo Pit will be the only active pit, and water captured in the Tuzo collection pond will be directed to the process plant to supplement process water requirements.

During operations, water from the WMP will not be discharged to waters in the Kennady Lake watershed that lie outside of the controlled area boundary, i.e., Area 8, unless the water meets specific discharge criteria. As a consequence, saline groundwater inflows from the pit development are not expected to result in changes to water quality in downstream waters in the Kennady Lake watershed. Consequently, this pathway was determined to have no linkage to effects to aquatic health and fish.

Blasting and excavation near fish-bearing lakes may result in pressure changes and vibrations, and affect fish

Detonation of explosives in or near water produces post-detonation compressive shock waves that can cause internal damage to the swim bladder and other soft organs of fish (Wright 1982; Wright and Hopky 1998; Godard et al. 2008). The severity of effects is related to the type of explosive, weight and pattern of the charge(s), method of detonation, distance from the fish to the point of detonation, water depth, and the species, size, and life stage of fish. Vibrations from the detonation can also cause damage to eggs incubating in spawning beds close to a blast zone (Wright 1982; Faulkner et al. 2006). Fisheries and Oceans Canada (DFO) Guidelines for the Use of Explosives in or Near Canadian Fisheries Waters (Wright and Hopky 1998) outline procedures to avoid harming fish. According to the guidelines, possible adverse effects on fish will be avoided if pressure changes after detonation are less than 100 kiloPascals (kPa). In addition, peak particle velocities (i.e., vibrations) can increase the mortality of incubating eggs close (i.e., less than 250 m) to the blast zone (Wright 1982; Faulkner et al. 2006). DFO in the Northwest Territories has adopted a more protective approach for the use of explosives around fish-bearing waterbodies, recommending that pressure changes be kept less than 50 kPa.

Fish will continue to reside in nearby lakes during operations (i.e., within Area 8 and watersheds A, B, D and E) but these fish will not be affected by blasting because these lakes are located a considerable distance from the mine pits. For example, assuming a charge weight of 100 kilograms (kg) in confined rock, the minimum setback distance to avoid impacts from pressure changes is 50 m (Wright and Hopky 1998). For a similar charge size, the minimum setback distance to avoid impacts to incubating eggs from increased peak particle velocities (i.e., vibrations in the spawning bed) is 150 m (Wright and Hopky 1998). Even with the more protective approach, and doubling the setback distances, the closest fish-bearing lakes will be at least 750 m from any blasting area, and no effects on fish and eggs in these lakes will be expected to occur.

The effect of pressure changes and vibrations from blasting and excavation on fish is a no linkage pathway for Kennady Lake because all blasting and excavation will occur in the dewatered areas of Kennady Lake where no water or fish will be present. Consequently, this pathway was determined to have no linkage to effects to fish.

Treated effluent discharge from the sewage treatment plant (STP) to the WMP may change water quality in Areas 3 to 7, and affect aquatic health and fish

A modular sewage treatment system to handle a peak load of 432 people will be provided as part of initial construction. Treated effluent will be initially discharged to the WMP of Kennady Lake at an estimated rate of 150 m^3/d and later, during operations, added to the fine PK slurry pipeline. Sewage treatment plant effluent rates during operations are estimated to be 75 m^3/d.

During operations, water from the WMP will not be discharged to waters in the Kennady Lake watershed that lie outside of the controlled area boundary, i.e., Area 8. As a consequence, treated effluent discharge is not expected to result in changes to water quality in downstream waters in the Kennady Lake watershed. Consequently, this pathway was determined to have no linkage to effects to water quality and fish.

Changes to the drainage network due to the Project within the Kennady Lake watershed may change surface water runoff and cause soil erosion, and affect water and sediment quality, fish habitat and fish

Surface water runoff from the Project can affect drainage flows which can alter surface water runoff. Altered runoff can lead to soil erosion, and subsequently affect surface water quality, and fish habitat. The Project will have several environmental design features and mitigation to prevent release of site contact water into the receiving environment. These include the following:

- all runoff will be conveyed to storage areas and collection ponds within areas of Kennady Lake;
- all runoff from the ammonium nitrate storage areas, mine pits and mine rock piles will be contained within the managed areas of Kennady Lake;

- till from ongoing pit stripping will be used to cover potentially acid-generating (PAG) rock placed within the interior of the structure to keep water from penetrating into that portion of the repository;
- erosion and sediment control practices (e.g., silt fences, runoff management) will be used to limit erosion of topsoil and overburden stockpiles, and corresponding changes in water quality from sediment loading;
- filter cloth silt fences will be used in natural and enhanced surface drainage courses at the airstrip to remove sediments, and these sediment traps will be cleaned out as required;
- erosion protection materials will be used to line the downstream natural channels (or engineered channels when required) to limit erosion along the flow paths to the mined-out Tuzo Pit;
- the overburden will provide a low-permeability barrier that will limit infiltration and encourage water to flow over the surface of the mine rock pile, rather than through it;
- storage ponds will be designed to accommodate the total volume of runoff from their contributing catchments under the 1-in-100 wet year freshet event;
- for storage ponds located in the open pits, the required capacity will be designed to hold the maximum predicted daily base case groundwater inflow, in addition to the 1-in-100 wet year freshet event;
- collection ponds may be pumped out on a campaign basis each year prior to the onset of winter to optimize storage for the following year's freshet;
- runoff collection ditches will be designed to be capable of conveying the 1-in-100 year, 24 hour rainfall event;
- seepage through internal water retention dykes will be conveyed to water collection ponds and pumped back to the source reservoirs; and
- where practical, natural drainage patterns will be used to reduce the use of ditches or diversion berms.

Implementation of these environmental design features and mitigation for the management of site water runoff is not expected to result in soil erosion due to modified drainage flows, which would increase suspended sediment transport to receiving waters and changes in water and sediment quality and fish habitat. All site runoff will flow naturally to the dewatered areas of Kennady Lake, which will possess collection ponds in the naturally deep depressions of the lake areas for the storage of water. As fish will have been removed from these areas during the early stages of the Project, this pathway was determined to have no linkage to effects to water quality and fish.

Seepage of pore water through, or underneath, dykes to adjacent watersheds may change water and sediment quality in the Kennady Lake watershed, and affect fish habitat, aquatic health and fish

A series of temporary and permanent dykes will be used to isolate the upper watersheds from Kennady Lake and in most cases, divert their flow to the N watershed. At closure the temporary dykes will be breached to allow the upper watersheds to flow back to Kennady Lake.

The temporary dykes include the following:

- Dyke A – the construction of this retention dyke will be initiated in Year -2 to separate Area 7 from Area 8;
- Dyke E – this water diversion dyke will be constructed prior to Year 1 initially to allow backflow from Lake B1 to Lake N13 in the N watershed. In the latter stages of mine operations this dyke will be a water retention dyke;
- Dyke F – this water diversion dyke will be constructed before Year -1 to raise the water level of Lake D2 to allow backflow from Lake D2 to Lake N17 in the N watershed; and
- Dyke G – this water diversion dyke will be constructed before Year -1 to raise the water level of the E lakes (i.e., Lakes E1 and E2) to allow backflow to Lake N17 in the N watershed.

The permanent dykes are the following:

- Dyke C – this is a water diversion constructed before Year -1 between Lake A3 and the area that will become the Fine PKC Facility. This dyke will divert runoff from the catchment area of Lake A3 and A4 and allow the dewatering of a portion of Area 1 to Lake A3 and redirect this flow to Lake N9; and
- Dyke D – this water retention dyke will be constructed prior to Year 2 to prevent water in Area 2 from flowing north into Lake N7 during the late stages of operations.

Diversion Dykes F and G will be designed to prevent flow to Kennady Lake from the E and D watershed and will not be in contact with water in the water management system. Dykes D and E will separate waters that will be diverted to the N watershed (Lakes N7 and N8) from water in the water management system (e.g., WMP), Dyke C will separate Lake A3 from the Fine PKC Facility and Dyke A will separate Area 8 from the water management system (Area 7). The water in the water management system and in the Fine PKC Facility will be subject to influences from groundwater and porewater seepage, which will be elevated in total dissolved solids, metals and nutrients. The increased concentrations of these parameters could affect water quality of receiving waters in the N watershed and Area 8 if they were able to seep through the permanent or temporary dykes.

Seepage volumes through the perimeter dykes (Dykes A, C, D, E, F and G) around Areas 1 to 7 were explicitly considered in the water balance model. Seepage volumes are expected to be small because these dykes will be constructed with seepage control, which for dykes C, D, E, F and G includes a liner keyed into competent frozen ground (i.e., saturated inorganic permafrost) or bedrock. The liner will be installed from a cut-off trench to the upstream toe of the dyke and the liner will extend up the upstream face of the dyke. The seepage cut-off trench will be excavated and backfilled, extending the base liner into the trench to provide a continuous liner between the seepage cut-off trench at the base of the dyke and the dyke crest. The selected liner is anticipated to be an elastomeric bituminous geomembrane, which provides greater longevity and superior puncture resistance over conventional polyethylene liner.

Dyke A will possess a seepage control measure that includes a soil-bentonite slurry cut-off wall through a till zone placed over the overburden, and the overburden to the bedrock surface. The cut-off wall will be protected by a downstream filter zone and mine rock shell zone. The construction material is anticipated to involved crush rockfill with bentonite or a sand and gravel mix with bentonite.

Seepage of pore water through the dykes will be mitigated by seepage control measures incorporated into the dyke design. As a result, measurable changes to water quality in the raised E and D lakes, Lakes N7, N8 and A3 and Area 8 are not expected. Consequently, this pathway was determined to have no linkage to effects to water quality and fish.

Spills within the Project footprint (e.g., petroleum products, reagents, wash-down) may affect water and sediment quality in the Kennady Lake watershed and result in changes to aquatic health, fish habitat and fish

Spills on-site, and along transportation corridors, can adversely affect surface water quality and fish habitat, and can result in mortality of individual fish. Spills are usually localized, and will be quickly reported and managed. Mitigation identified in the Emergency Response and Spill Contingency Plan (Section 3, Appendix 3.I, Attachment 3.I.1), and other environmental design features (e.g., containment dykes, liners, proper storage conditions) will be in place to limit the frequency and extent of spills that result from Project activities (Table 8.6-1). Chemical spill containment will be incorporated into the plant design, and spill response materials will be available in designated areas where fuel and chemicals are stored.

Employees will be trained in the transportation of dangerous goods, and domestic and recyclable waste dangerous goods will be stored in appropriate containers until shipped off site to an approved facility. Storage facilities for hazardous substances and waste dangerous goods will meet regulatory requirements and will be designed to protect the environment and workers from exposure.

The implementation of emergency response and contingency plans, environmental design features and monitoring programs is expected to result in no detectable change to surface water and sediment quality, and fish habitat and aquatic health relative to baseline conditions. Consequently, this pathway was determined to have no linkage to effects to fish.

8.6.2.3 Secondary Pathways

In some cases, both a source and a pathway exist, but the change caused by the Project is anticipated to result in a minor environmental change, and would have a negligible residual effect on water quality and fish in Kennady Lake relative to baseline or guideline values (e.g., a slight increase in a water quality parameter above Canadian Council of Ministers of the Environment [CCME] guidelines, but would not affect fish health). The following pathways are anticipated to be secondary, or minor, and will not be carried through the effects assessment.

Impingement and entrainment of fish in intake pumps during dewatering may cause injury and mortality to fish

Most fish will be removed from Kennady Lake during the fish salvage conducted before dewatering. The fish salvage will continue during dewatering; however, it is expected that some fish will still be remaining in Kennady Lake during dewatering and that some of these fish could become impinged or entrained in intake pumps. The intake pumps used for dewatering Kennady Lake will be appropriately screened to meet federal requirements to prevent fish entrainment or impingement (DFO 1995). The appropriate screen mesh size will be determined in consultation with DFO for the planned pumping rates to prevent fish from entering the pump during dewatering. This includes the determination of a maximum approach velocity for water at the screen surface to prevent fish from being entrained or impinged on the screen. The intake screen mesh size and dimensions will be influenced by the species found within Kennady Lake, as well as the swimming abilities of these species and the likely age classes of fish present at the water withdrawal location. Fish salvage will also occur in Lake A1 prior to it being partially dewatered to accommodate the Fine PKC Facility. Fish species captured in Lake A1 include Arctic grayling (*Thymallus arcticus*), burbot (*Lota lota*), and round whitefish (*Prosopium cylindraceum*). Forage fish species, such as slimy sculpin and ninespine stickleback, may also be present.

These screens, coupled with the ongoing fish salvage, should limit the number of large-bodied fish impinged on the intake pipe and should limit the fish entrained in the pumps to small-bodied fish (e.g., ninespine stickleback) and newly-hatched young-of-the-year of large-bodied fish (e.g., lake trout). While it is likely that any small fish that become impinged or entrained in the pumps may not survive, the goal of the fish salvage is to remove as many fish from Kennady Lake as possible. The screens will also be regularly maintained throughout the pumping period.

The implementation of environmental design features associated with dewatering, such as fish salvage and screening and maintenance of intake pumps, is expected to reduce fish mortality resulting from impingement or entrainment. Furthermore, the mortality of small species and young life stages are anticipated to be limited to a localized area. Therefore, residual effects to fish from the dewatering of Kennady Lake and Lake A1 are predicted to be negligible.

Release of sediment to Area 8 during the construction of Dyke A may change water and sediment water quality, and affect fish habitat and fish

Dyke A will be constructed in the narrows that separate Areas 7 and 8 in two stages. Initially, a temporary crossing structure will be placed in the narrows to provide access to the airstrip. The temporary dyke will become part of the permanent Dyke A, forming part of the dyke's shell.

During both stages of dyke construction, silt curtains will be used to minimize release of suspended sediments into Area 8. These curtains will be installed downstream of the dyke before construction and will be maintained until construction of the dyke is completed and TSS concentrations between the dyke and silt curtain have been reduced below required levels. With this measure in place, sediment re-suspension in the water column and sedimentation of fish habitat in Area 8 is expected to be minor.

The likelihood of silt curtains reducing the potential for increases in TSS in Area 8 is high because they are a well-established mitigation technique that has been demonstrated to be effective during dyke construction at the Diavik Diamond Mine (Diavik 1998). Use of silt curtains is also planned during construction of dykes for the Meadowbank Gold Project in Nunavut (Cumberland Resources

2005). Some general considerations in the use of silt curtains in dyke construction include:

- engage regulators in the decision process for the design and application of silt curtains;
- provide adequate anchoring of the curtains to maximize effectiveness;
- limit the distance between supports along the length of the curtains;
- tie the support anchors to topographic highs;
- construct wind blocks to limit wind fetch and wave action effects;
- establish the curtains at an appropriate distance from construction activities to maximize their effectiveness and to provide a settlement zone that does not become saturated with TSS;
- use double rows of silt curtains; and
- monitor TSS within and outside of the silt curtain area through construction.

Confidence in this assessment is further increased by the planned construction period, one to two months, and that very little fine sediment exists in the shallow waters at the narrows where the dyke will be built. In the event that TSS concentrations approach monitoring thresholds, construction activities will be curtailed.

The construction of Dyke A is expected to result in a minor change to the water quality through the increase in TSS in Area 8 from the disturbance of the lake bed. The use of silt curtains, and monitoring programs during construction, will minimize the amount of TSS that results in Area 8, which will be localized. Therefore, the residual effects to water and sediment quality, fish habitat and fish are predicted to be negligible.

Alteration of groundwater flows from dewatering Kennady Lake may change surface water levels in nearby lakes, and affect water quantity and quality, fish habitat, and fish

Dewatering of Kennady Lake will increase the hydraulic gradient in the active surface groundwater regime, which may extend 1 to 5 m below the ground surface of the Kennady Lake watershed depending on the topography. The groundwater discharge to the Kennady Lake areas will occur concurrently with the drawdown of the lake and will be a one-time release. The volume of groundwater ingress to the lake areas is expected to be negligible. Surficial groundwater is dilute water that contains substantial proportions of surface lake water and has low chloride concentration of about 100 mg/L or less

(Section 11.6, Subject of Note: Permafrost, Hydrogeology, and Groundwater) depending on the proportion of lake water.

The anticipated effects on the surface groundwater regime will be localized and short-term, and it is expected that dewatering will result in a minor change to the volume of surface groundwater in the Kennady Lake watershed relative to baseline conditions. The residual effects from the alteration of groundwater flows to water quality, fish habitat and fish are predicted to be negligible.

Reduction in upper watershed flow to Area 8 may change surface water levels, and affect surface water quality, fish habitat and fish

Area 8 is the easternmost basin of Kennady Lake and is just upstream of the L watershed. The area is approximately 4 kilometres (km) long, typically less than 500 m wide and contains several small bays and coves. Extensive areas in the northern part of this lake area are less than 4 to 5 m in depth with a mean depth of 3 m, and the deepest portion is located in one small region of the southern part of the lake area (greater than 9 m). The outlet of Kennady Lake to the L watershed is located at the northern end of Area 8.

The outflow channel of Kennady Lake to the downstream L watershed is a shallow, wide channel with a boulder bed and side channels present. Flows to the L watershed are limited to the open water season. In winter, Area 8 is isolated from the L watershed, with the outlet channel completely frozen during ice-covered months. Typically, ice thickness in Area 8 is less than 2.0 m.

With the construction of Dyke A in the early stages of the Project, Area 8 will become isolated from Areas 2 through 7 in Kennady Lake. During the construction and operations phase, Area 8 will receive limited inflows: natural runoff from the Area 8 sub-watershed and the G, H and I sub-watersheds, and dewatering discharge from Area 7.

After the cessation of discharge from Area 7, the reduction in inflows to Area 8 associated with the short-circuiting of the Kennady Lake watershed will result in an estimated annual average water level drop within Area 8 of 0.11 m, which will remain through the operations and closure phases of the Project. Once Kennady Lake is refilled and water quality conditions meet specific criteria, Dyke A will breached and removed to allow for the reconnection of the lake with Area 8.

The water level of Area 8 in the post-closure period is predicted to remain below baseline conditions. A lower water level, estimated to be -0.03 m compared to baseline, will be due to changes in Kennady Lake and the A sub-watershed, which will result in lower average annual discharge to Area 8. The A sub-watershed area will be reduced due to the diversion of Lake A3 to the N watershed and the alteration of the remaining sub-watershed due to the establishment of the Fine PKC Facility.

The average annual water level fluctuation in Area 8, modelled under normal flow conditions (i.e., 1960 to 2005), is 0.38 m. The predicted average annual reduction in water level due to the short-circuiting of Kennady Lake (construction of Dyke A and diversion of the A, B, D and E watersheds) is approximately 0.11 m, which represents approximately 30 percent (%) of the modeled average annual variation in water level under normal flow conditions. As the average depth of Area 8 is approximately 3 m and a maximum depth of up to 8 m, the reduction in water level due to the Project is considered minor.

During operations, Area 8 will still remain connected to the L watershed in open water conditions, although annual flows will be slightly reduced, and will remain isolated during winter conditions as a result of ice development. The predicted decrease in under-ice water levels in Area 8 relative to baseline is approximately 0.10 m, even under dry conditions.

The minor change in depth is not expected to alter water quality in Area 8. Compared to other areas in Kennady Lake, which are slightly deeper in average depth, physicochemical variability, particularly dissolved oxygen (DO) concentrations, are highly variable (see Annex I). Consistent with other areas in Kennady Lake, under-ice DO concentrations decrease rapidly with depth and during open water conditions DO concentrations are typically consistent throughout the water column. These characteristics are expected to remain consistent during the operation of the Project.

The close circuiting of Kennady Lake is anticipated to result in a minor change to water level in Area 8 during construction and operations. However, the small change in littoral area (approximately 2% of the surface area of Area 8) would have a negligible effect on the availability of fish and benthic invertebrate habitat. Changes to water quality, including under-ice DO levels, are expected to be negligible relative to baseline conditions. As a consequence, residual effects to fish habitat and fish (including the availability of overwintering habitat in Area 8) are predicted to be negligible.

Release of sediment during construction of dykes in the A, B, D and E watersheds may change water and sediment quality, and affect fish habitat and fish

During the construction of the water retention and water diversion dykes in the A, B, D and E watersheds, silt curtains will be used to minimize the release of suspended sediment to the receiving waterbodies. These curtains will be located in lake areas adjacent to the dykes. They will be installed before construction of the dykes is initiated and will not be removed until TSS concentrations in water between the dyke and the silt curtains have been reduced below required levels. Water quality monitoring in lake areas outside of the silt curtains will be conducted throughout the construction period. Disturbance associated with the development of the dykes will also be minimized by avoiding construction during the spring freshet when the potential for erosion is highest and when spring spawning species, such as Arctic grayling (*Thymallus arcticus*), are using streams for spawning and migration.

As a result of the mitigation associated with the construction of the dykes, such as the use of silt curtains, avoiding construction activities during the spring freshet, and undertaking water quality monitoring programs during construction, changes to water and sediment quality from elevated suspended sediment associated with construction activities is expected to be minor and confined to the lake area bound by the silt curtains. As a result, residual effects to water quality and fish in the diverted upper watersheds are predicted to be negligible.

Changes to permafrost conditions in the flooded shoreline zone of the raised lakes due to increased water levels may lead to erosion and affect fish habitat

The raising of the lakes in the A, D and E watersheds after the construction of Dykes C, F and G could alter permafrost conditions of the inundated terrain upstream from the dykes. Depending on water depth, permafrost will thaw beneath the inundated terrain, which may increase the extent of the taliks under the raised lakes. The inundated lake margins may be subject to higher erosion potential predominantly from wave action due to the saturation of the inundated surface soil material. The deposition of any disturbed material from these processes is expected to be deposited in close proximity to the shoreline. Surveys prior to the raising of the lakes will identify shoreline habitat that will be more prone to erosional processes when permafrost is lost (e.g., soils types, slope, bedrock) so that shoreline stabilization can be implemented where necessary. As Lakes D2, D3, and E1 will fill gradually changes to the inundated shoreline are also expected to be gradual.

Raised water levels in Lakes D2 and D3, and E2 will revert back to pre-development levels after closure allowing shoreline permafrost conditions to re-establish; however, Lake A3 will be raised permanently. Lowering the water levels in Lakes D2, D3 and E1 will allow permafrost to redevelop, which may lead to alterations in the surface topography (e.g., cracking), leading to increased potential of erosion, gullying and bank slumping along the exposed shoreline. Surveys to monitor the integrity of the lake shore environment during closure will identify these issues and allow for mitigation to be established.

Changes to permafrost along the shoreline of the lakes subject to raising and lowering throughout the life of the Project are predicted to be minor, which may result in erosional processes that may lead to elevated suspended sediment conditions in the nearshore lake areas. With monitoring and mitigation, erosion and sedimentation associated with changes to permafrost conditions in the lakeshore environments are expected to result in minor changes to fish habitat. As a result, residual effects to fish are expected to be negligible.

Release or generation of nutrients, mercury, or other substances into Lakes A3, D2, D3 and E1 from flooded sediments and vegetation may change water quality, and affect aquatic health and fish

Raising of lake levels also has the potential to cause the leaching of minerals and nutrients (i.e., phosphorus and nitrogen) from the soil and vegetation in the area to be inundated. This could cause an initial increase in primary (i.e., phytoplankton) and secondary (i.e., zooplankton and benthic invertebrate) production, and a subsequent increase in growth of fish.

Approximately 22.8 ha of riparian habitat around Lake A3 will be inundated permanently, with 53.1 ha and 6.8 ha of riparian habitat temporarily inundated as a result of raising Lakes D2 and D3, and E1, respectively. The riparian vegetation of the three lakes areas that will be flooded includes scrub birch (Labrador tea tundra and cloudberry low shrub bog), and water sedge (narrow-leaved cottongrass fen) over a low-gradient substrate that has a high proportion of boulder or cobble material. The larger surface area associated with the flooding of Lakes D2 and D3 has a predominance of sedges.

Changes to nutrient dynamics in the flooded lakes will be primarily driven by the inundation of the surrounding riparian vegetation and, to a more limited extent, soil. Nitrogen, phosphorus and carbon are likely to be released to the water column through decompositional processes and sediment-water interactions, but not all forms will be equally bioavailable (Paterson et al. 1997, Thouvenot et al. 2000). Phosphorus, for example, may be released in a non-bioavailable form (i.e., bound to particulates) which can lead to the preferential growth of bacteria over phytoplankton.

Following construction of the dykes, the lakes will fill to their new level through natural drainage. The time required to fill the lakes is predicted to take between one year (i.e., Lake E1) and eleven years (i.e., Lake A3 is predicted to fill in the final year of operations); Lakes D2 and D3 will take three years to fill. The gradual flooding of the riparian habitat associated with the raising of these lakes may result in a surge in nutrient concentrations, particularly in the nearshore region of the lakes. The period of time that the elevated nutrient concentrations will remain in the lakes will be dependent on site-specific conditions, such as the mass of inundated organic material, the hydrological regime (i.e., retention time and flushing rates) and rates of microbiological and biological activity (i.e., low temperatures may reduce the potential for decomposition and assimilation). Once the raised lakes are lowered at the end of operations (i.e., Lakes D2 and D3, and E1), nutrient dynamics are anticipated to return to a condition that is similar to baseline conditions. It is not expected that there will be any long term effect on the nutrient dynamics in these lakes, or in Lake A3, which will remain raised after operations.

The release of metals from the sediment of newly flooded areas is anticipated, either from the suspension of sediment (i.e., particulate metals associated with sediment particles) or during low oxygen conditions at the sediment water interface associated with under-ice conditions in the shallow lakes (i.e., dissolved metals). Total suspended sediment (TSS) concentrations will be elevated during spring freshet inflows through the lakes and as a result of wave action. However, any elevation in the concentration of metals associated with TSS from these sources is anticipated to be temporary. It is not expected that there will be any long term effect on the metals dynamics in these lakes.

Inundation of soils and vegetation surrounding lakes A3, D2 and D3, and E1 can also increase the concentration of methylmercury in fish. Methylmercury is the toxic form of mercury (Bloom 1992) and its availability to aquatic organisms increases when new sources of inorganic mercury are introduced to the water (i.e., inorganic mercury in the soil and vegetation) and microbial activity increases due to increased nutrient additions (Rudd 1995; Bodaly and Kidd 2004). Methylmercury tends to become more concentrated in higher trophic levels, particularly top-predatory fish such as lake trout (Wright and Hamilton 1982; Bodaly et al. 1984; Brouard et al. 1990; Hecky et al. 1987, 1991; Kidd et al. 1995).

There are several physical, chemical, and biological factors that increase the biomagnification of methylmercury in fish in a lake. These factors include the following:

- Small lake size (Bodaly et al. 1993). Smaller lakes tend to have fish with higher mercury concentrations.
- Larger upstream watershed size (Evans 1986).
- Location of the lake lower down in the watershed (McMurtry et al. 1989).
- Low pH and high dissolved organic carbon (McMurtry et al. 1989; Wiener et al. 1990; Driscoll et al. 1994).

- Longer food chain lengths (Cabana et al. 1994; Cabana and Rasmussen 1994; Power et al. 2002). Species connected to the benthic food chain (e.g., round whitefish) have lower mercury concentrations than species connected to the pelagic food chain (e.g., lake trout) (Power et al. 2002).
- Position of the fish at or near the top of the food chain (Kidd et al. 1995; Power et al. 2002).
- Age of the fish (Harris and Bodaly 1998). Larger, mature fish tend to be slower growing than younger fish and use most of their ingested energy for reproduction not growth. Therefore, older fish tend to retain most of the ingested mercury (Bodaly and Kidd 2004).

Mercury concentrations in fish in the raised lakes are not expected to increase high enough to impair the health of the fish or any wildlife that may eat these fish because of the following:

- The amount of inorganic mercury available for methylation will be minimized by preparing the area to be inundated before flooding.
- The number of lake trout, burbot, and northern pike (*Esox lucius*) expected to be present in the raised lakes during mine operations is low.
- Arctic grayling, slimy sculpin, and ninespine stickleback, (i.e., the fish species most likely to persist in the A, D and E watersheds during mining) are planktivores or benthivores and, therefore, are low on the food chain.
- The raised lakes are located in the headwaters of the Kennady Lake watershed.
- Mercury concentrations in non-piscivorous fish typically peak in 4 to 5 years and then return to pre-impoundment concentrations usually within 10 to 15 years after flooding (Schetagne et al. 1997, cited in Legault et al. 2004; Bodaly et al. 1997).

The effects of flooding on the riparian habitats around the small lakes to be raised are expected to be minor because of the following:

- Lake level increases will occur gradually and changes to water quality (i.e., increased turbidity) will be temporary.
- The riparian landscape surrounding Lakes D2, D3, E1, and A3 that will be inundated will be prepared to the extent possible. For example, some vegetation may be considered for removal during the construction of the diversion dykes, and prior to flooding. Surveys of the areas prior to flooding will identify vegetation that can be removed, and areas that should be avoided to minimize land disturbance.

- Shoreline areas that are susceptible to extensive erosion may be armoured by cobble and boulder to reduce erosion and associated resuspension of fine sediments.
- Physico-chemical water quality variations due to flooding are temporary, peak quickly (less than four years) and subside as time passes (Legault et al. 2004).
- Water quality monitoring in the lakes, and shoreline and riparian surveys will be conducted during operations and closure to monitor change and identify any requirement for mitigation.

Naturally low nutrient levels in the surface soils and cold temperatures throughout the year would limit bacterial production, resulting in much lower rates of processes such as decomposition (e.g., releasing nutrients) and methylation compared to warmer waterbodies where large increases in nutrient releases to the water column and mercury accumulation in fish have been documented. Although there is potential for temporary changes to surface water and sediment quality with the raising of lakes A3, D2 and D3, and E1, preparation of the areas to be flooded where necessary, and monitoring will limit the potential for long-term nutrient and metals releases to the lakes and mercury methylation. Changes in water and sediment quality are predicted to be minor relative to baseline conditions. As such, residual effects to fish are anticipated to be negligible.

Removal of bedrock and kimberlite material from the active mining of pits may change groundwater quantity in the Kennady Lake watershed, and affect the water level in small lakes in the watershed

Mining will remove approximately 270 million tonnes (Mt) of rock, primarily from the talik, but also from the deep groundwater system. This mass of rock occupies an approximate volume of 46 Mm^3. With an average porosity of 0.01, the groundwater within this volume is about 0.5 Mm^3. This volume of groundwater will be permanently removed and incorporated into the mine rock and coarse PK piles, the Fine PKC Facility, or managed through the WMP. Pore spaces of the mine rock and coarse and fine PK material used to backfill Hearne Pit and the backfilled portion of 5034 Pit will contain pore water that originates primarily as groundwater. This water will be augmented by fresh water during refilling. Therefore, the groundwater volume removed from the pits will be replaced by groundwater in the backfill material and fresh water. As such, the residual effect to groundwater quantity is expected to be negligible.

Alteration of the groundwater regime from groundwater flows to the mined out pits may change water quality and water quantity in other lakes in the watershed

Dewatering of the Kennady Lake bed and mine pits will induce groundwater to flow toward the pit from all directions. The reduced groundwater pressures in the deep groundwater flow system will cause a small volume of water to flow from Lakes X4 and X6 toward the pit. Lakes X4 and X6 are located outside of the Kennady Lake watershed (Section 11.6, Subject of Note: Permafrost, Hydrogeology, and Groundwater Figure 11.6-2), but are the most hydraulically connected to groundwater below Kennady Lake due to their elevation and proximity. Changes in groundwater discharges to other lakes within the LSA that are hydraulically connected to the deep groundwater through fully penetrating taliks are predicted to be less than those in these two lakes due to their smaller size. The small lakes in the upper watershed of Kennady Lake, with the exception of Area 8, are not considered of sufficient surface area to have talik penetration to the deep groundwater regime. Based on the climatic conditions of the LSA, lakes with a surface area less than 1 km^2 are not expected to have fully penetrating taliks underneath except for some unusually shaped lakes (e.g., those that are long but very narrow) (Section 11.6; Subject of Note: Permafrost, Groundwater and Hydrogeology).

The maximum reduction lake volume for Lakes X4 and X6 through groundwater flows due to dewatering and pit development is predicted to be in the order of 100 m^3/d. The net precipitation to the lake surfaces of X4 and X6 Lakes only, not including the rest of the catchment, is in the order of 2,400 m^3/d. Climatic inputs to the area therefore vastly overwhelm the magnitude of this change to lake volume.

Altered groundwater flow directions and intercepts are anticipated in the LSA surrounding the pit development, but no measureable effects are expected in reducing lake volumes, and therefore water levels, in the small lakes within the Kennady Lake watershed. As such this pathway was determined to have negligible residual effect on water quality.

Impingement and entrainment of fish in potable water intake pumps in Area 8 may cause injury and mortality to fish and affect fish populations

The freshwater intake and pumphouse will be located on the north western shore of Area 8. The intake will consist of vertical filtration wells fitted with vertical turbine pumps that supply water on demand. The intake will be connected to the pumphouse with piping buried under a rock-filled embankment (Section 3). The overlaid embankment will act as a secondary filtration screen, which will prevent fish from becoming entrained.

The implementation of fish screens on the intake and a buried intake under rock fill is anticipated to reduce fish mortality resulting from impingement or entrainment. Mortality of small species and young life stages are anticipated, but will be limited to a localized area and will have a minor influence on fish populations. Therefore, residual effects to fish from the pumping potable water from Area 8 are predicted to be negligible.

Extraction of potable water requirements for the Project may change surface water levels in Area 8, and affect fish habitat

The provision of potable water for the camp and plant will be from Area 8 has the potential to reduce surface water levels and outflows from Area 8. About 60,000 cubic metres per year (m^3/y) of fresh water will be required for potable water during construction. During operations, with a smaller workforce, the potable water required will decrease to about 27,000 m^3/y. The supply volumes are small in comparison to mean daily outflow volumes for median conditions predicted for Area 8 during construction and operations (Table 8.6-2).

Table 8.6-2 Mean Daily Outflow Volumes at the Outlet of Kennady Lake (Stream K5) – Construction and Operations

Condition	Return Period (years)	Snapshot	Monthly Mean Daily Outflow Volume (m^3)					
			May	June	July	August	September	October
Median		baseline	708	65,900	39,300	22,800	13,200	3,070
		construction	779	65,700	86,600	86,500	77,200	4,680
		operations	428	21,900	6,670	4,580	2,460	371

m^3 = cubic metres.

Potable water supply from Area 8 is a small annual supply volume compared to the volume of Area 8 and predicted outflows during construction and operations. The annual requirements of water from Area 8 to meet potable water demand is expected to result in a small change in water level to Area 8, and a minor change to available fish habitat. Consequently, residual effects to fish are expected to be negligible.

Close-circuiting of Areas 2 to 7 may change water quality in Area 8, and affect aquatic health and fish

Water quality in Area 8 during the operations and closure phases will be driven by dewatering of water from Area 7 and drainage flows from the H, I, J and Ke watersheds. Pumped discharge from Area 7 to Area 8 is expected to have similar water quality to Area 8, and will only be discharged if water in Area 8 meets specific discharge water quality criteria.

Concentrations of water quality constituents are predicted to increase slightly in Area 8 over the course of operations and closure, due to evapo-concentration.

The construction of Dyke A will result in a reduction in drainage area reporting to Area 8, thereby increasing the residence time and the rate of evaporation relative to recharge. Consequently, all water quality constituents are predicted to increase to slightly above background conditions by the time Dyke A is breached in Year 21.

The isolation of Area 8 from the upper areas of Kennady Lake will limit inflows to this area to dewatering discharge in the construction and early operations phase from Area 7, and sub-watershed drainage inputs. Minor changes to water quality are anticipated in Area 8 during operations and closure, but these changes are expected to be within the natural range of variability reported for Area 8. As such this pathway was determined to have negligible residual effect on fish.

Increased under-ice noise and vibrations from traffic on winter road or activity on the ice airstrip may affect fish

Trucks travelling on winter roads or aircraft landing on an ice airstrip can cause increased noise levels on lakes. The level at which fish can detect sounds depends on the background noise (Stewart 2001). Fish have been documented to show an avoidance reaction to vessels when the radiated noise levels exceed their threshold of hearing by 30 decibels (dB) or more (ICES 1995). Many factors, including the presence of predators or prey, seasonal or daily variations in physiology, and spawning or migratory activities can make them more or less sensitive to unfamiliar sounds (Schwartz 1985; ICES 1995). Mann et al. (2009) found that anthropogenic (man-made) noise (including helicopters, aircraft landing and takeoff, and ice-road traffic) measured in Kennady Lake raised ambient sound levels by approximately 30 dB; however, this was within the range of natural ambient noise in the lake. Most of the anthropogenic sounds measured were considered to be only detectable by fish species with specialized hearing adaptations, such as lake chub (*Couesius plumbeus*) and suckers (*Catostomidae*) (Mann et al. 2007, 2009).

The low level of truck traffic noise on winter roads or aircraft noise on frozen lakes will have a negligible effect on fish because the noise will be intermittent and sound propagation is limited under ice in shallow water. Fish will also have the ability to move away from the noise; any movements would be expected to be within their normal daily or day-to-day range.

Traffic activity on the winter road, and aircraft landing and taking-off on the ice airstrip on Kennady Lake, which will be used before the permanent airstrip is established, is anticipated to cause under-ice noise and vibrations that will be localized and temporary. As such, disturbances from vehicle activity on the winter road, and aircraft activity prior to the establishment of the on land airstrip, are expected to have negligible residual effects on fish.

8.6.2.4 Primary Pathways for Effects from Construction and Operations

The remaining pathways for water quality and fish in Kennady Lake and its watershed are classified as primary (listed below) and are carried forward as effects statements (Table 8.6-3) to be assessed in the effects analysis sections (Sections 8.7 to 8.12). Potential effects related to permafrost and hydrogeology were determined to possess no linkage or be secondary pathways. Therefore, no pathways related to these disciplines will be carried forward in this key line of inquiry. However, further assessment of Project effects to permafrost, hydrogeology and groundwater is included in the Subject of Note: Permafrost, Groundwater, and Hydrogeology (Section 11.6).

8.6.2.5 Potential Pathways during Closure

Pathways for effects to water quality and fish during closure include direct impacts to fish and fish habitat (e.g., alteration of flows during the refilling of Kennady Lake), and indirect effects to fish through changes in water quality (e.g., change in concentrations of metals or nutrients in Area 8 when Dyke A is breached) (Table 8.6-4). The effects of the Project on fish populations in Kennady Lake and its watershed after Areas 3 to 7 are reconnected to Area 8 are addressed in this section. The discussion regarding the restoration processes of Kennady Lake is addressed in this key line of enquiry, and also more specifically in the Key Line of Inquiry: Long-term Biophysical Effects, Reclamation and Closure (Section 10).

Effects to downstream hydrological conditions, water quality, fish, and fish habitat and after closure are addressed in the Key Line of Inquiry: Downstream Water Effects (Section 9). Section 9 also includes assessment of downstream effects on fish during the refilling of Kennady Lake (i.e., downstream of Kennady Lake and downstream of Lake N11).

Table 8.6-3 Effects Statements for Water Quality and Fish during Construction and Operations

Discipline	Project Activity	Pathway	Effects Statement
Hydrology	Project footprint (e.g., dykes, mine rock and coarse PK piles, Fine PKC Facility, access roads, mine plant, airstrip)	reduction in watershed areas may change flows, water levels, and channel/bank stability in streams and small lakes in the Kennady Lake watershed	Effects of mine rock and coarse PK piles and Fine PKC Facility to flows, water levels and channel/bank stability in streams and smaller lakes in the Kennady Lake watershed
	Dewatering of Kennady Lake	dewatering of Area 7 to Area 8 may change flows, water levels, and channel/bank stability in Area 8	Effects of dewatering Kennady Lake to flows, water levels and channel/bank stability in Area 8
	Isolation and diversion of upper Kennady Lake watersheds	changes in A, B, D and E watershed areas and flow paths may change flows, water levels, and channel/bank stability in the Kennady Lake watershed	Effects of watershed diversions in watersheds A, B, D and E to flows, water levels and channel/bank stability in streams and smaller lakes in the Kennady Lake watershed
		shoreline erosion, re-suspension of sediments and sedimentation may change due to changes in water levels in Lakes A3, D2, D3, and E1	
Water Quality	Construction and Mining Activity during construction and operations	deposition of dust from fugitive dust sources may change to water quality and sediment quality	Effects of the deposition of dust and metals from air emissions to water quality and lake bed sediments in waterbodies within the Kennady Lake watershed
		air emission and deposition of sulphur dioxide [SO_2], nitrogen oxides [NOx], particulate matter [PM], and total suspended particulates [TSP] may change water and sediment quality	Effects of the acidifying air emissions to waterbodies within the Kennady Lake watershed
Aquatic Health	Construction and Mining Activity during construction and operations	deposition of dust in the Kennady Lake watershed may change aquatic health	Effects of air emissions to aquatic health in the Kennady Lake watershed
		deposition of acidifying substances in the Kennady Lake watershed may change aquatic health	
Fish and Fish Habitat	Project footprint (e.g., dykes, mine rock and coarse PK piles, Fine PKC Facility, access roads, mine plant, airstrip)	project development in the Kennady Lake watershed will result in the loss of fish habitat	Effects of Project activities to fish and fish habitat in Kennady Lake, and streams and lakes within the Kennady Lake watershed
	Dewatering of Kennady Lake	dewatering of Kennady Lake and other small lakes may cause mortality and spoiling of fish, temporary loss in productive capacity, and the alteration of flows, water levels, and channel/bank stability in Area 8	
	Isolation and diversion of upper Kennady Lake watersheds	change of flow paths and construction of retention and diversion dykes in the A, B, D and E watersheds may result in loss of stream habitat, alteration of water levels and lake areas, shoreline erosion, re-suspension of sediments and sedimentation, and changes to lower trophic levels, fish communities and migration	
	Construction and Mining Activity during construction and operations	deposition of dust and particulate matter may cause increases in suspended sediment, and changes to aquatic health	

Table 8.6-4 Potential Pathways for Effects to Water Quality and Fish during Closure

Project Component/Activity	Effects Pathways	Environmental Design Features and Mitigation	Pathway Assessment
Reclaimed Project footprint	• development of fish habitat compensation works to account for HADD associated with the Project	• fish habitat compensation developed in consultation with DFO and other regulatory agencies	Primary
	• removal of project infrastructure (e.g., roads, airstrip, dykes, buildings) may change flows, water levels, and channel/bank stability in streams and small lakes in the Kennady Lake watershed, and affect, water quality, fish habitat and fish	• to the extent possible, all disturbed areas will be reclaimed and the surface stabilized • surfaces will be re-graded and till or mine rock will be placed, as appropriate, to prevent dusting and water erosion, and stabilizing, as required, against thermokarst from freeze-thaw processes within the active layer • drainage patterns will be re-established as close to pre-operational conditions as possible, with drainage ditches contoured or backfilled as appropriate to remove any hazards to wildlife	No Linkage
	• the Project may change the long-term hydrology in the Kennady Lake watershed		Primary
Removal of the temporary diversion dykes in the B, D and E watersheds	• reduction of water levels in Lakes D2, D3, and E1 may change to permafrost conditions, and affect fish habitat	• none	Secondary
	• removal of dykes may change flows, water levels, and channel/bank stability in streams and small lakes in the B, D, and E watershed, and affect water quality, fish habitat and fish	• watershed will be reconnected to Kennady Lake along previous connecting streams where possible • any diversion channels will be designed to provide spawning and rearing habitat, and permit fish passage • monitoring of the new shorelines associated with the reduced lake levels	Primary
	• removal of the temporary dykes for the realignment of diverted B, D, and E watersheds to Kennady Lake may release sediment and change water and sediment quality, and affect fish habitat and fish	• watershed will be reconnected to Kennady Lake along previous connecting streams, but where necessary cobble and boulder placement will be used to reduce erosion potential • place erosion protection materials and processes over the natural downstream channels to limit erosion along the flow path to Kennady Lake • silt curtains will be placed upstream and downstream of the dykes to control the release of suspended sediments during their deconstruction/breaching • water levels in lakes will be drawn down by pumping or siphoning water to Kennady Lake prior to removal of dykes • dykes will be removed during low- or no-flow periods to allow work to be completed “in the dry”	Secondary
Removal of the temporary diversion dykes in the B, D and E watersheds (continued)	• removal of diversions and temporary dykes in B, D, and E watersheds may result in changes to fish migration	• watershed will be reconnected to Kennady Lake along previous connecting streams where possible • any diversion channels will be designed to provide spawning and rearing habitat, and permit fish passage • fish salvage will occur where appropriate prior to breaching and removing the dykes and constructed diversion channels	Primary

Table 8.6-4 Potential Pathways for Effects to Water Quality and Fish during Closure

Project Component/Activity	Effects Pathways	Environmental Design Features and Mitigation	Pathway Assessment
Refilling of Kennady Lake	• refilling dewatered areas of Kennady Lake may alter permafrost conditions, and affect fish habitat	• areas in Kennady Lake will not be completely dewatered for the duration of operations. Refilling of Areas 6 and 7 will be commenced in Year 6 when mining of 5034 is complete. Dewatering of Area 4 will start in Year 4	No Linkage
	• release of groundwater into the refilled Tuzo Pit may change groundwater quality in the pit, and affect water quality and fish in Kennady Lake	• Tuzo Pit will be refilled with surface water from Area 3 and 5 to minimize groundwater inflow.	Secondary
	• pumping water from Lake N11 to Kennady Lake to supplement refilling may change water and sediment quality in Kennady Lake, and affect aquatic health and fish	• use of supplemental inflow from Lake N11 using a pipeline and pumping system to divert water directly to Area 3 • water quality of supplemental inflow will be similar to water quality of Kennady Lake prior to dewatering	Secondary
	• realignment of B, D, and E watersheds for the refilling Kennady Lake may result in effects to fish	• exclusion measures will be used to limit the initial migration of large-bodied fish from the B, D, and E watersheds into Kennady Lake during refilling once the dykes have been removed	Primary
	• erosion of lake-bottom sediments in Area 3 from the pump discharge during the refilling of Kennady Lake may change water quality, and affect fish habitat and fish	• designing outfalls/diffusers so that they sit high in the water column and actively disperse piped discharge to prevent erosion of the lake-bed sediment • Areas 3 and 5 will remain part of the closed-circuited system until the lake is filled and water quality meets criteria for reconnection with Area 8	No Linkage
	• continued isolation of Area 8 during refilling and recovery period may change surface water flows, water levels in Area 8, and affect and water quality, fish habitat and fish	• refilling of Kennady Lake will be supplemented by pumping from Lake N11 to reduce the re-fill period to approximately 8 years	Primary
	• co-mingling of water in Tuzo Pit with water in Areas 3 to 7 during refilling may change water quality in Kennady Lake, and delay ecosystem recovery	• none	Primary
Refilling of Kennady Lake	• release or generation of mercury, nutrients, or other substances into Areas 3 to 7 from flooded sediments and vegetation during refilling of Kennady Lake may change water quality	• none	Primary
	• release of saline water from the Tuzo Pit to surface waters of Kennady Lake may change water quality	• none	Primary

Table 8.6-4 Potential Pathways for Effects to Water Quality and Fish during Closure

Project Component/Activity	Effects Pathways	Environmental Design Features and Mitigation	Pathway Assessment
Breaching Dyke A to reconnect Kennady Lake with Area 8	• release of sediment into Areas 7 and 8 during the removal of Dyke A may change water and sediment quality, and affect fish habitat and fish	• silt curtains will be placed upstream and downstream of the construction area to control the release of suspended sediments	Secondary
	• underwater noise and vibrations during the breaching and removal of Dyke A may affect fish	• use of machinery instead of explosives to reduce underwater noise and vibration • if explosives are required, DFO will be consulted, and their use will be in accordance with applicable standards and guidelines	Secondary
	• changes in B, D, and E watershed areas and flow paths may result in alteration of flows, water levels, and channel/bank stability in the Kennady Lake watershed, which can affect water and sediment quality, fish habitat and fish	• monitoring of the new shorelines associated with the reduced lake levels	Primary
	• changes to water levels in Lakes D2, D3, and E1 may lead to shoreline erosion, re-suspension of sediments and sedimentation, and affect water quality, fish habitat and fish		Primary
	• reconnection of Areas 3 to 7 to Area 8 may change water flows and water levels in Area 8, and affect fish habitat and fish	• breaching and removal activities will be limited to daylight hours to limit effects to fish and expected to be completed in one month • breaching and removal activities will be completed using heavy machinery, such as long-armed backhoes, to limit effects to fish, with explosives used only if necessary	Secondary
	• reconnection of Areas 3 to 7 with Area 8 may change water quality in Area 8, and affect aquatic health and fish	• Dyke A will be breached and removed when water quality in Kennady Lake meets specific criteria	Primary
	• removal of Dyke A will change fish migration through the Kennady Lake watershed	• none	Secondary

Table 8.6-4 Potential Pathways for Effects to Water Quality and Fish during Closure

Project Component/Activity	Effects Pathways	Environmental Design Features and Mitigation	Pathway Assessment
Mine rock and Coarse PK piles	• seepage from the mine rock and coarse PK piles may change water quality, and affect aquatic health and fish	• at closure, the mine rock piles will be re-shaped and a 1 m layer of NAG mine rock will placed on the outer surface of the pile to prevent erosion. • PAG rock will comprise only a small proportion of the overall mine rock tonnage and will be sequestered within the mine rock storage facilities. • the thickness of the cover layer is predicted to be sufficient so that the active freeze-thaw layer remains within the non-reactive mine rock. • the Coarse PK Pile, adjacent to Area 4, will be shaped and covered with a layer of mine rock of a minimum of 1 m to limit surface erosion. Permafrost conditions are anticipated to be established in the pile by the end of mine life. • runoff from the Coarse PK Pile and mine rock piles will be managed to mitigate downstream effects on flows, water levels and channel bank stability. Perimeter ditches will collect facility runoff, intercept upstream runoff and convey it to a discharge point. Natural receiving channels that convey water to Kennady Lake will be armoured to prevent erosion if necessary, or engineered channels will be constructed.	Primary
	• alteration of drainage patterns to Kennady Lake due to the mine rock and coarse PK piles may change water flows, water levels, and channel/bank stability in streams and small lakes, and can affect water and sediment quality, fish habitat and fish		No Linkage
Fine PKC Facility	• seepage through filter dyke L may change water quality in Kennady Lake, and affect aquatic health and fish	• At closure, the Fine PKC Facility (Areas 1 and 2) will be graded and 1 to 2 m of NAG mine rock will be placed on the outer surface of the pile to prevent erosion. • The final shaping of the facility will be designed to limit ponding of water over the mine rock • Thermistors will be installed within the mine rock piles to monitor the progression of permafrost development. • Permafrost development in the Fine PKC Facility and underlying talik is expected to occur over time. • Thermistors will be installed in the Fine PKC Facility to monitor the formation of permafrost in the solids. • Runoff from the Fine PKC Facility will be managed to mitigate downstream effects on flows, water levels and channel bank stability. Perimeter ditches will collect facility runoff, intercept upstream runoff and convey it to a discharge point. Natural receiving channels that convey water to Kennady Lake will be armoured to prevent erosion if necessary, or engineered channels will be constructed.	Primary
	• alteration of drainage patterns to Kennady Lake from the Fine PKC Facility may change water flows, water levels, and channel/bank stability in streams and small lakes, and affect water and sediment quality and fish		No Linkage

Table 8.6-4 Potential Pathways for Effects to Water Quality and Fish during Closure

Project Component/Activity	Effects Pathways	Environmental Design Features and Mitigation	Pathway Assessment
Partial backfilling of Hearne Pit with fine processed kimberlite	• seepage from backfilled PK material in pits may change water quality in Kennady Lake, and affect aquatic health and fish	• Hearne pit will be partially backfilled with fine PK after Year 7 • the backfilled pit will be 120 m deep • runoff water, pit water, and decant water from the fine PK will cause a high TDS water layer above the settled fine PK in the pit • the volume of high TDS water overlying the fine PK will allow for an accelerated refilling at closure and promote the development of a chemocline above the settled fine PK	Primary
Fish restocking to re-establish fish community structure	• restocking Kennady Lake with fish may change brood-stock fish population and affect genetics or parasites of fish in Kennady Lake	• maintain an annual sustainable harvest rate from each potential brood stock lake to reduce potential for fish mortality and maintain trophic stability • stocking of Kennady Lake with fish from lakes within the same watershed as Kennady Lake (i.e., the Kirk Lake watershed) will maintain similar genetic make-up and minimize susceptibility to disease and maximize adaptability to new environment • conduct pathology examinations of fish in potential source lakes to reduce the potential of transferring diseased or parasite-infested fish to Kennady Lake	Secondary

8.6.2.6 No Linkage Pathways

The following pathways are anticipated to have no linkage to water quality and fish in Kennady Lake during the closure phase, and will not be carried through the effects assessment. The following section lists all of the potential pathways that are classified with no linkage, and provides an explanation for the classification.

Removal of Project infrastructure (e.g., roads, airstrip, dykes, buildings) may change flows, water levels, and channel/bank stability in streams and small lakes in the Kennady Lake watershed, and affect water and sediment quality, fish habitat and fish

Mining is scheduled to end in Year 11, after which Project infrastructure removal will begin. This process is expected to take two years, and will require the demolition and removal of plant operations facilities (e.g., processing plant, power plant), storage facilities (e.g., explosive storage, fuel storage tanks), buildings, the airstrip, and roads.

To the extent possible, all disturbed areas will be reclaimed and the surface stabilized. This will include re-grading and placing till or mine rock, as appropriate to prevent dust generation and water erosion, and stabilizing, as required, against thermokarst from freeze-thaw processes within the active layer. Drainage patterns will also be re-established as close to pre-operational conditions as possible, with drainage ditches contoured or backfilled as appropriate to remove any hazards to wildlife.

Erosion will be controlled principally by keeping slope angles of constructed facilities at less than the angle of repose or by rock armouring, as appropriate. Where feasible, long-term sediment control will be achieved by re-vegetation. Rock armouring will be done where re-vegetation is not possible and erosion control is required. The rock will be obtained by screening suitably sized inert material from the mine rock stockpile.

The removal of infrastructure from the Project is not anticipated to have a measurable influence on surface hydrology and bank/channel integrity within the Kennady Lake watershed. As such, drainage through the reclaimed areas of the Project is not expected to result in measurable changes to water and sediment quality in Kennady Lake. Consequently, this pathway was determined to have no linkage to effects to fish.

Refilling dewatered areas of Kennady Lake may change permafrost conditions, and affect fish habitat

A talik exists under most of Kennady Lake. During construction and operations, Areas 4, 6 and 7 of Kennady Lake will be dewatered for varying periods of time and exposed to cold air temperatures. This may result in the decrease in the extent of the talik under Kennady Lake and formation of permafrost in the dewatered lake-bed. The mean annual soil temperature in the dewatered lake-bed is estimated to cool after draining to approximately -2 to -3°C.

Based on the current Project schedule, Areas 4, 6 and 7 of Kennady Lake will be dewatered at stages during operations for extended periods while the pits are mined (i.e., up to a maximum of six years). Permafrost-related processes, such as frost cracking and thermoerosion may occur within the dewatered lake-bed. Frost cracking over the exposed lake-bed surface will also result in formation of a polygon landscape and thin ice wedges in the cracks. The exposed saturated material on the relatively flat slopes of the lake-bed surface will have sufficient time for pore water pressure dissipation and it is unlikely that major slope instability within the dewatered lake-bed will result. However, there may be a potential for a local slope failure/deformation in steeper slopes around the perimeter of the dewatered areas.

A talik is expected to reform under Kennady Lake after refilling. Disturbance of the lake-bed and any resulting earth processes that resulted during exposure of the lake bed following dewatering would be promptly levelled under the wave action after refilling in the shallow portions of Kennady Lake. In areas with deep water, the levelling of the bottom topography will occur more slowly, mainly by gravitational processes, but would return to pre-existing talik conditions.

The alteration of lake-bed topography due to changes in permafrost conditions within the areas of Kennady Lake is expected to have no measurable influence on the re-establishment of fish habitat [where it would be expected] after refilling. Consequently, this pathway was determined to have no linkage to effects to fish.

Erosion of lake-bottom sediments in Area 3 from the pump discharge point during the refilling of Kennady Lake may change water quality, and affect fish habitat and fish

The potential for erosion of lake-bottom sediments in Area 3 will be minimized during the pumping from Lake N11. Constructed channel outfalls or diffusers will be used to reduce the erosive energy of water pumped into Area 3 to supplement the natural refilling of Kennady Lake. It is anticipated that supplemental pumping from Lake N11 will be required for approximately 8 years for Kennady Lake to refill. The average annual volume of supplemental water required from Lake N11 will be 3.7 Mm^3.

Outfalls will be constructed in Area 3 to diffuse the velocity of the pumped discharge. Diffusers, if required, will be placed as close to the surface as possible over the deepest portion of Area 3 to increase the distance between the outfall and the bottom sediments. Although some sediment may be mobilized despite these measures, the extent of this effect is likely to be limited to the zone of turbulence immediately adjacent to the diffuser, and is likely to quickly diminish after sediments in the zone of turbulence are mobilized and become re-deposited farther away from the outfall.

As a result, discharge of water from Lake N11 to Area 3 during refilling is not expected to result in measurable changes to water and sediment quality or fish habitat in Area 3. Consequently, this pathway was determined to have no linkage to effects to fish.

Alteration of drainage patterns to Kennady Lake due to the mine rock and coarse PK piles may change water flows, water levels, and channel/bank stability in streams and small lakes, and affect water and sediment quality, fish habitat and fish

Runoff from the mine rock and coarse PK piles will be managed to mitigate downstream effects on flows, water levels and channel bank stability.

Mine rock will be placed in two designated mine rock piles during operations, which will be constructed in Areas 5 and 6: the South Mine Rock Pile final pile crest will be at a surface elevation of approximately 515 masl, giving the pile a maximum height of about 90 m, and the West Mine Rock Pile will have a final crest elevation of 474 masl and a height of 70 m. Both piles will be developed with 2.4H:1V overall side slopes, which provide stability. Flatter side slopes will be constructed when the final slope is exposed to the shoreline. Progressive reclamation of the mine rock piles, which will include contouring and re-grading, will start as early as Year 5 for the South Mine Rock Pile and Year 7 for the West Mine Rock Pile. The piles will not be covered or vegetated, consistent with the approaches in place at the Ekati Diamond Mine and Diavik Diamond Mine. Runoff from these piles will be directed to Areas 5 and 6.

The Coarse PK Pile is located on land adjacent to Area 4. The Coarse PK Pile will be progressively reclaimed during mine operations, and will be shaped and covered with a layer of mine rock of a minimum of 1 m to limit erosion and dust production. Runoff from this pile will be directed to Area 4.

Runoff rates from the South and West Mine Rock and Coarse PK Piles are expected to be equivalent to those from undisturbed surfaces after final mine rock and coarse PK placement is completed. Drainage courses from the piles to Kennady Lake will be monitored and evaluated to determine if flow rates exceed the capacity of natural channels. Alternatively, natural channels may be armoured to prevent erosion, or engineered channels may be used.

The alteration of drainage patterns in the Kennady Lake watershed from the construction of the mine rock and coarse PK piles is expected to have no measurable influence on water flows, water levels, and channel/bank stability in drainage streams to Kennady Lake. As a result, changes to water and sediment quality are not anticipated and this pathway was determined to have no linkage to effects to water quality or fish once Kennady Lake is reconnected with the upper watersheds and Area 8.

Alteration of drainage patterns to Kennady Lake from the Fine PKC Facility may change water flows, water levels, and channel/bank stability in streams and small lakes, and affect water quality, fish habitat and fish

Runoff from the Fine PKC Facility will be managed to mitigate downstream effects on flows, water levels and channel bank stability.

The Fine PKC Facility in Areas 1 and 2 will be progressively reclaimed during mine operations, as fine PK will be placed in the bottom of the mined-out Hearne Pit during the latter stages of operations. As the Area 1 portion of the facility becomes filled during the initial years of operations, it will be covered with a layer of coarse PK to prevent the fine PK from being windblown. This will allow subsequent vehicle traffic and placement of approximately a 1 to 2 m thick layer of NAG mine rock. The facility will be graded so that any surface runoff will flow towards Area 3.

The Area 2 portion of the Fine PKC Facility will be reclaimed in a similar fashion. Any remaining water impounded within Area 2 behind Dyke L will be backfilled with coarse PK or mine rock to provide runoff drainage patterns flowing into Area 3. As above, the closure scenario also involves a NAG mine rock covered terrain. For both Area 1 and Area 2, the final geometry of the cover layer will be graded to limit ponding of water over the mine rock covered areas.

Runoff rates from the Fine PKC Facility are expected to be less than those from undisturbed areas while they are being constructed, and equivalent to those from undisturbed surfaces after final mine rock placement is completed.

Drainage channels from these areas to Kennady Lake will be evaluated to ensure that flow rates do not exceed the capacity for stability in the drainage channels. These channels may be armoured to prevent erosion.

The alteration of drainage patterns in the Kennady Lake watershed from the construction of Fine PKC Facility is expected to have no measurable influence on water flows, water levels, and channel/bank stability in drainage streams to Kennady Lake. As a result, changes to water and sediment quality are not anticipated and this pathway was determined to have no linkage to effects to water quality and fish once Kennady Lake is reconnected with the upper watersheds and Area 8.

8.6.2.7 Secondary Pathways

The following pathways are anticipated to be secondary, or minor, and will not be carried through the effects assessment. The following section lists all of the potential pathways that are classified as minor, and provides an explanation for the classification.

Reduction of water levels in Lakes D2, D3 and E1 may change permafrost conditions, and affect fish habitat

At closure, the temporary dykes will be removed and the raised lakes that formed upstream of the diversion dykes will be allowed to drain back to pre-disturbance water levels to initiate the refilling of Kennady Lake. The background permafrost conditions will return to the drained shoreline areas, potentially resulting in the development of permafrost-related earth processes, such as frost cracking and thermoerosion. These alterations to the exposed shoreline may reduce the re-establishment of vegetation and increase erosion potential that may lead to localized fish habitat changes through increased suspended solids and sedimentation in the nearshore zone of the lakes. These changes are anticipated to be short-term.

The removal of the temporary dykes in the realignment of the D and E watersheds and lowering of water levels in lakes D2 and D3, and E1 will modify the permafrost conditions in the exposed shoreline areas. Increases in TSS and sedimentation in the nearshore zone of these lakes are anticipated, but will be localized and have a minor influence on shallow fish habitat. As a result, the residual effects to the fish are predicted to be negligible.

Removal of the temporary dykes for the realignment of diverted B, D and E watersheds to Kennady Lake may release sediment and change water and sediment quality, and affect fish habitat and fish

At the end of operations, diversion Dykes E, F, and G will be breached. Prior to breaching the dykes, the water levels in the raised lakes will be drawn down through pumping or siphoning. Silt curtains will also be installed within the drawn down lakes and downstream of the dykes before breaching activities are initiated. The silt curtains will minimize the release of suspended sediment to downstream channels. These curtains will remain in place until TSS concentrations between the dyke and the silt curtains have been reduced below required levels. Disturbance associated with the development of the dykes will also be minimized by avoiding construction during the spring freshet when the potential for erosion is highest.

Environmental design features and mitigation, such as silt curtains, restricting breaching activities to low or no-flow periods, and undertaking monitoring during breaching activities, will limit sediment resuspension and sedimentation. As a result, localized, minor changes to water and sediment quality are expected. Residual effects of dyke construction to fish and fish habitat in the diverted upper watersheds are predicted to be negligible.

Despite the realignment of the B, D and E watersheds to Kennady Lake, fish exclusion measures within the downstream channels will impede large-bodied fish migration from the upper watersheds into Kennady Lake until Kennady Lake is reconnected to Area 8.

Release of groundwater into the refilled Tuzo Pit may change groundwater quality in the pit, and affect water quality and fish in Kennady Lake

Flooding of the Tuzo Pit basin (Tuzo Pit and unfilled portion of the 5034 Pit) with fresh water will alter hydraulic gradients until new pressure and chemical equilibriums are established, which are predicted to take more than 1,000 years. The water quality within the talik that will reform directly under the refilled Kennady Lake will initially be more dilute due to fresh water from the pit flowing into the talik groundwater system. This will be expected to be a long-term effect.

Flooding of the backfilled and empty pit will be done in a controlled manner. Once the pits are refilled, groundwater, with a higher salinity and density than fresh water, may seep into the pit. The ingress of groundwater will be slow and as pit filling continues, density stratification will develop where the lower-density fresh water will float on top of the higher-density saline water. The hydrogeology modelling (Section 11.6) indicates that fluid density gradients will create very little flux and that reaching new equilibrium conditions with baseline groundwater chemistry will take a very long time. As a neutral hydraulic gradient is expected between the groundwater and refilled Tuzo Pit basin, it is expected that there will be no active movement of groundwater into Tuzo Pit.

The alteration to surface and deep groundwater regimes associated with Tuzo Pit and the development of a density gradient within Tuzo Pit is expected to have a negligible influence on groundwater quality in the pit, and surface water quality in Kennady Lake. The strong density gradients and potential for chemocline development will isolate the elevated TDS associated with deep groundwater in the deeper zones of the pit. Therefore, residual effects to fish after the reconnection of Kennady Lake to the upper watersheds and Area 8 are expected to be negligible.

The long-term stability of the saline water at the bottom of the Tuzo Pit basin was considered to be a primary effects pathway.

Pumping water from Lake N11 to Kennady Lake to supplement refilling may change water and sediment quality in Kennady Lake, and affect aquatic health, and fish

At the end of mine life, the water elevations in all water storage areas within Area 1 to 7 will be lowered to 417.0 m by siphoning the water from Areas 3 and 5, Area 6 and Area 7 to the mined-out Tuzo Pit. It is estimated that the total volume of water required to raise the water elevation in the entire lake area, including Areas 1 to 7 and the mined-out pits, to the original Kennady Lake elevation of 420.7 m will be 56.0 Mm^3. To reduce the time required to refill Kennady Lake, the closure Water Management Plan requires annual supplemental pumping of water from Lake N11 to Area 3. The average annual volume of water that can be pumped from Lake N11 has been estimated to be 3.7 Mm^3 per year, which represents no more than 20% of the normal annual flow from Lake N11. The required filling time is estimated to be approximately eight years of both pumping from Lake N11 and natural surface runoff accumulation. Natural surface runoff flows to Kennady Lake are much smaller in volume, such that it would take about 15 to 16 years to fill the lake using natural inflow alone. Groundwater inflow rates to the open pits will be small.

The water quality of the water pumped from Lake N11 to supplement the Kennady Lake refilling will be consistent with that measured in Kennady Lake during existing conditions. Any variability in water quality of the flows from Lake N11 will be within the natural range of variability reported for Kennady Lake.

The water quality in Kennady Lake at closure will possess a higher total dissolved solids concentration than the diverted inflows from Lake N11. The process of supplementing the natural refilling from watershed inflows will provide dilution potential to Kennady Lake.

During refilling, Kennady Lake will remain close circuited. Pumping water from Lake N11 to Kennady Lake to supplement refilling is expected to have a measurable influence on water quality because it will result in dilution of the water retained in Area 3, and Kennady Lake. This change is positive and as a result, residual effects to water quality from the pumping of supplemental water from Lake N11 are predicted to be negligible. Prior to the reconnection of Kennady Lake to Area 8, there will not be fish in the Areas 3 through 7.

The long-term water quality of Kennady Lake after refilling and effects to fish as a result of the Project is a primary effects pathway.

Release of sediment into Areas 7 and 8 during the removal of Dyke A may change water and sediment quality, and affect fish habitat and fish

Suspended sediment concentrations in Area 8 and the refilled areas of Kennady Lake will be minimized by the use of silt curtains. Using appropriate design criteria, silt curtains would be installed upstream and downstream of the dyke before breaching Dyke A, and would be maintained until the entire dyke is removed and habitat underneath the dyke has been replaced. With this environmental design feature in place, sediment re-suspension and sedimentation in Areas 7 and 8 are anticipated to result in minor changes to water quality and fish habitat, which will be localized and temporary. As such residual effects to fish in Area 8 will be negligible.

Underwater noise and vibrations during the breaching and removal of Dyke A may affect fish

The noise and vibration disturbance from removing Dyke A in Area 8 will have a negligible effect on fish, as Dyke A will be breached and removed using heavy machinery, such as long-armed backhoes. Only if necessary will explosives be used.

Underwater noise will be generated by the removal of boulders and any crushing of rock or concrete by heavy machinery to facilitate the dyke breaching. However, noise levels and vibrations from these sources are expected to be low. Mann et al. (2009) found that activities associated with diamond exploration, such as under-water drilling (46 dB higher than ambient noise levels), helicopter hovering (60 dB higher than ambient), and walking on ice (30 dB higher than ambient) all produced noise in Kennady Lake greater than ambient at a control site. However, all anthropogenic (man-made) noises fell within the range of natural background noise (44 dB to greater than the 105 dB spectrum level in the

200 to 300 hertz [Hz] band) in Kennady Lake. Most of the anthropogenic sounds measured were considered to be only detectable by fish species with specialized hearing adaptations, such as chub and suckers (Mann et al. 2009). There is the potential impact that anthropogenic noise of this type may mask natural sounds for these species (Mann et al. 2009).

As a result, lake chub are likely to be the only fish species present in Area 8 able to hear noises generated by excavation of Dyke A. The masking of natural sounds could potentially make lake chub more susceptible to predation or reduce their feeding efficiency. However, this will have a negligible effect on lake chub in Area 8 because the breaching and removal of Dyke A will not be continuous (i.e., only occur during the day shift) and disturbance duration is not expected to extend beyond one month. Fish will also have the ability to move away from the noise and continue to seek cover in the boulders along the shoreline. The abundance of predators (i.e., lake trout, burbot, and northern pike) in Area 8 at closure is also likely to be lower than pre-disturbance conditions.

Noise disturbance as a result of the breaching and removal of Dyke A will be limited to fish present in Area 8, because fish are not expected in Kennady Lake upstream of the dyke before its removal. The disturbance to fish in Area 8 is anticipated to be minor, while being localized to the construction area and limited to the period of time to complete the breaching and removal activities. Consequently, residual effects to fish in Area 8 will be negligible.

Reconnection of Areas 3 to 7 with Area 8 may change water flows and water levels in Area 8, and affect fish habitat and fish

When Kennady Lake and Area 8 are reconnected, water levels in Area 8 will increase slightly from the operations and closure period, i.e., an annual average water level increase of approximately 0.08 m. This predicted water level in the post-closure phase is approximately 0.03 m below baseline conditions, due to changes in Kennady Lake and the A sub-watershed. This minor change in water level is within the natural variability of the Area 8, and as a result, changes to fish habitat relative to baseline conditions are anticipated to be minor. Residual effects to fish in Area 8 are predicted to be negligible.

Removal of Dyke A will change fish migration through the Kennady Lake watershed

Once Kennady Lake is refilled and water quality conditions meet specific criteria, Dyke A will be breached and removed to allow for the reconnection of the lake with Area 8. It is expected that after removal of Dyke A, migrant fish will be enter the refilled portions of Kennady Lake from Area 8, which is expected to contain residual populations of lake chub, slimy sculpin, ninespine stickleback and burbot. Fish from the watershed downstream of Area 8, such as Arctic grayling, will also be able to migrate into Kennady Lake. Habitat under Dyke A will be replaced with similar large boulders, and the width and average depth of the narrows between Areas 7 and 8 will be similar to what currently exists in the lake (70 m and 2.5 m, respectively). As a result, fish will be able to migrate through the narrows between Areas 7 and 8 as they were before the Project. Consequently, residual effects to fish will be negligible.

Restocking Kennady Lake with fish from other local lakes may change brood-stock fish population in the Kennady Lake watershed and affect genetics or parasites of fish in Kennady Lake

After water quality in the refilled Kennady Lake is suitable for aquatic life, and a self-sustaining low trophic community has established, including round whitefish, benthic invertebrates, phytoplankton, and zooplankton, lake trout may be transplanted into Kennady Lake from other lake sourced. Potential donor lakes for lake trout for stocking Kennady Lake would be Lake 410 or Kirk Lake, which would maximize the likelihood of transferring fish with similar genetic composition as the lake trout in the Kennady Lake watershed. Stocking success is increased if the source population has genetic traits that have adapted it to similar habitat present in the lake to be stocked (Powell and Carl 2004).

A re-stocking plan for Kennady Lake will be required to include genetic analyses of lake trout in Kennady Lake before drawdown and from lake trout in candidate donor lakes to determine which lakes would provide the closest genetic match to lake trout in Kennady Lake. Genetic analyses of progeny from transplanted fish in Kennady Lake will also be conducted.

Fish will not be considered for transfer from any donor lake where the condition of lake trout is poor (e.g., low weight to length ratio, evidence of heavy parasite loading). This will ensure that potentially diseased or parasitized fish are not transferred to Kennady Lake.

Restocking Kennady Lake with fish from other lakes within the LSA is expected to result in minor changes to the genetic makeup of the lake trout population relative to baseline conditions. As a result of the upper watershed diversion and fish salvage prior to operations, lake trout would have been completely removed from Kennady Lake upstream of Area 8, and the assumption has been made that Area 8 would not support a self-sustaining population of lake trout during the mine operation. Lake trout that migrate to Kennady Lake after reconnection with the upper watershed and Area 8 (e.g., from Lake I1 and other lakes) may possess slightly different genetics from lake trout that were established in Kennady Lake prior to salvage, primarily because of the length of time between the initial fish salvage, isolation and reconnection of Kennady Lake (i.e., approximately 20 years). As a consequence, restocking of Kennady Lake with lake trout after reconnection with the upper watershed and Area 8 is predicted to result in negligible residual effects to fish.

Restocking Kennady Lake with fish to establish the fish community structure to aid in the recovery of the aquatic ecosystem in Kennady Lake is discussed in Section 8.11.

8.6.2.8 Primary Pathways for Effects from Closure

The remaining pathways for water quality and fish in Kennady Lake and its watershed during closure are classified as primary and are carried forward as effects statements (Table 8.6-5) to be assessed in the effects analysis sections (Sections 8.7 to 8.12).

Table 8.6-5 Effects Statements for Water Quality and Fish during Closure

Discipline	Project Activity	Pathway	Effects Statement
Hydrology	reclaimed Project footprint	the Project may change the long-term change hydrology in the Kennady Lake watershed	Long-term effects of mine development to hydrology of Kennady Lake
	removal of the temporary diversion dykes in the B, D, and E watersheds	removal of dykes may change flows, water levels, and channel/bank stability in streams and small lakes in the B, D, and E watersheds, changes to water levels in Lakes D2, D3, and E1 may lead to shoreline erosion, re-suspension of sediments and sedimentation	Effects of temporary dyke removal to flows, water levels and channel/bank stability in Kennady Lake
	refilling of Kennady Lake	continued isolation of Area 8 during refilling and recovery period may change surface water flows, water levels and water quality in Area 8, which may affect fish and fish habitat	Effects of diversion of flows, water levels and channel/bank stability in Area 8
			Effects of refilling activities on flows, water levels and channel/bank stability in Areas 3, 4, 5, 6 and 7
Water Quality	refilling of Kennady Lake	co-mingling of water in Tuzo Pit with water in Areas 3 to 7 during refilling may change water quality in Kennady Lake, and delay ecosystem recovery	Long-term effects of changes to pit water quality on the stability of meromictic conditions in the Tuzo Pit basin
		release or generation of mercury, nutrients, or other substances into Areas 3 to 7 from flooded sediments and vegetation during refilling of Kennady Lake may change water quality	Effects of Project activities to water quality in Kennady Lake and Area 8 during and after refilling
		release of saline water from the Tuzo Pit to surface waters of Kennady Lake may change water quality	
	breaching Dyke A to reconnect Kennady Lake with Area 8	reconnection of Areas 3 to 7 with Area 8 may change water quality in Area 8	
	mine rock and coarse PK piles	seepage and runoff from the mine rock and coarse PK piles may change water quality in Kennady Lake after refilling	
	Fine PKC facility	seepage through filter dyke from the Fine PKC Facility after refilling may change water quality in Kennady Lake	
	full or partial backfilling of Hearne Pit with processed kimberlite	seepage from backfilled PK material in pits may change water quality in Kennady Lake	
Aquatic Health	breaching Dyke A to reconnect Kennady Lake with Area 8	altered water quality in Kennady Lake and Area 8 resulting in changes to aquatic health to waterbodies within the Kennady Lake watershed	Effects of water quality changes to aquatic health in waterbodies within the Kennady Lake watershed

Table 8.6-5 Effects Statements for Water Quality and Fish during Closure (continued)

Discipline	Project Activity	Pathway	Effects Statement
Fish and Fish Habitat	reclaimed Project Footprint	development of fish habitat compensation works to account for HADD associated with the Project	Effects of Project closure and post-closure activities to fish and fish habitat in Kennady Lake, and streams and lakes within the Kennady Lake watershed
	removal of the temporary diversion dykes in the B, D and E watersheds	changes to flow paths, water levels and lake areas in the B, D and E watersheds may change lower trophic levels, fish communities and migration	
	refilling of Kennady Lake	continued isolation of Area 8 during refilling may affect fish populations	
	post-closure activities	changes to water quality in Area 8 may change lower trophic communities, fish habitat, and fish communities	
		changes to aquatic health may affect fish populations and abundance	

8.7 EFFECTS TO WATER QUANTITY

The pathway analysis presented in Section 8.6 considered potential pathways for effects to hydrology in Kennady Lake and the Kennady Lake watershed. A summary of the primary pathways by which changes to water quantity could occur during construction and operations is presented in Table 8.7-1, and during closure in Table 8.7-2.

Section 8.7.1 provides an overview of the methodology used to develop the hydrology predictions within Kennady Lake and the Kennady Lake watershed during construction and operations, followed by a discussion of the results of the effects analysis in Section 8.7.3.

Table 8.7-1 Valid Pathways for Effects to Water Quantity in the Kennady Lake Watershed during Construction and Operations

Project Activity	Pathway	Effects Statement	Effects Addressed
Project footprint (e.g., dykes, mine pits, mine rock and coarse PK piles, Fine PKC Facility, access roads, mine plant, airstrip)	reduction in watershed areas may change flows, water levels, and channel/bank stability in streams and small lakes in the Kennady Lake watershed	Effects of mine rock and coarse PK piles and Fine PKC Facility to flows, water levels and channel/bank stability in streams and smaller lakes in the Kennady Lake watershed	Section 8.7.3.1
Dewatering of Kennady Lake	dewatering of Area 7 to Area 8 may change flows, water levels, and channel/bank stability in Area 8	Effects of dewatering Kennady Lake to flows, water levels and channel/bank stability in Area 8	Section 8.7.3.2
Isolation and diversion of upper Kennady Lake watersheds	changes in A, B, D and E watershed areas and flow paths may change flows, water levels, and channel/bank stability in the Kennady Lake watershed	Effects of watershed diversions in watersheds A, B, D and E to flows, water levels and channel/bank stability in streams and smaller lakes in the Kennady Lake watershed	Section 8.7.3.3
	shoreline erosion, re-suspension of sediments and sedimentation may change due to changes in water levels in Lakes A3, D2, D3, and E1		

PKC = processed kimberlite containment.

Table 8.7-2 Valid Pathways for Effects to Water Quantity in the Kennady Lake Watershed during Closure

Project Activity	Pathway	Effects Statement	Effects Addressed
Refilling of Kennady Lake	continued isolation of Area 8 during refilling and recovery period may change surface water flows, water levels and water quality in Area 8, which may affect fish and fish habitat	Effects of refilling activities on flows, water levels and channel/bank stability in Areas 3, 4, 5, 6, and 7	Section 8.7.4.1
		Effects of diversion of flows, water levels and channel/bank stability in Area 8	Section 8.7.4.2
Removal of the temporary diversion dykes in the B, D and E watersheds	removal of dykes may change flows, water levels, and channel/bank stability in streams and small lakes in the B, D, and E watersheds, changes to water levels in Lakes D2, D3, and E1 may lead to shoreline erosion, re-suspension of sediments and sedimentation	Effects of temporary dyke removal to flows, water levels and channel/bank stability in Kennady Lake	Section 8.7.4.3
Reclaimed Project footprint	the Project may change the long-term change hydrology in the Kennady Lake watershed	Long-term effects of mine development to hydrology of Kennady Lake	Section 8.7.4.4

Section 8.7.2 provides an overview of the methodology used to develop the hydrology predictions within Kennady Lake and the Kennady Lake watershed during closure, followed by a discussion of effects analysis results in Section 8.7.4.

8.7.1 Effects Analysis Methods – Construction and Operations

8.7.1.1 Water Balance Model

A water balance model was set up using GoldSim™ software on a daily time step for the period of 1950 to 2005. This time period was selected to allow use of the long-term climate data derived for the site. The Kennady Lake watershed was divided into watersheds, including Kennady Lake, its tributaries, and land area adjacent to the lake.

The water balance for each watershed considered rainfall and snowmelt runoff, inflow from upstream watersheds, changes in lake storage, lake evaporation, and outflow to downstream watersheds. The model incorporated runoff coefficients from land surfaces, lake outlet stage-discharge rating curves, and degree-day models for snowmelt and spring ice melt in outlet channels. These parameters were used to calibrate the model using site-specific data collected in 2004 and 2005.

The baseline water balance model described in Annex H was modified to model the effects on Kennady Lake during construction and operations. The following changes were made to the water balance model:

- Areas 2, 3, 4, 5, 6 and 7 were isolated from Area 8 of Kennady Lake, due to the presence of Dyke A during construction and operations;
- runoff from watershed A, upstream of the Lake A3 outlet, was permanently diverted out of the Kennady Lake watershed due to the presence of Dyke C during Operations;
- watershed A, in Area 1 downstream of the Lake A3 outlet, was treated as land area due to the establishment of the Fine PKC Facility during Operations;
- runoff from watershed B was diverted out of the Kennady Lake watershed due to the presence of temporary Dyke E during Operations;
- runoff from watershed D, upstream of the Lake D2 outlet, was diverted out of the Kennady Lake watershed due to the presence of temporary Dyke F during Operations; and
- runoff from watershed E, upstream of the Lake E1 outlet, was diverted out of the Kennady Lake watershed due to the presence of temporary Dyke G during Operations.

During Construction, dewatering will discharge approximately half the volume in Areas 2, 3, 4, 5, 6 and 7 of Kennady Lake to Lake N11 and to Area 8 of Kennady Lake. Dewatering discharges to Area 8 will be managed to prevent downstream erosion or geomorphological changes. The Dewatering model was set up such that:

- pumping began on June 1 of each year;
- the pumping rate was limited to ensure that the total of natural and diverted discharge will not exceed the 2-year (median) maximum daily flow rate at Area 8 (114,000 m^3/d) and will not exceed 500,000 m^3/d at the Lake N11 outlet, and that no pumping occurred when natural flows exceeded that rate;
- water was pumped from Kennady Lake Areas 2, 3, 4, 5, 6 and 7 until half the initial volume remains (about 17.6 Mm^3); and
- runoff from Kennady Lake Areas 2, 3, 4, 5, 6 and 7 and their tributaries was accounted for in the model.

During Operations, Areas 2, 3, 4, 5, 6 and 7 of Kennady Lake will continue to be separated from Area 8, and the volume remaining in Kennady Lake will be kept constant by pumping any excess capacity in the Water Management Pond

(WMP, Areas 3 and 5) to Lake N11, subject to the same discharge limits. Inflows to Area 8 will be limited to natural runoff from its adjacent watersheds (i.e., Ke, H, I and J watersheds).

8.7.1.2 Analysis

For each modelling scenario, the time series of temperature and precipitation was imposed on the water balance model for the entire 56-year modelling period. The resulting time series of flows at key nodes, including Area 8, were subject to frequency analysis to determine median flows and those for 5-, 10-, 20-, 50- and 100-year wet and dry conditions. Values were calculated for monthly mean daily outflow volumes as well as representative flows including 1-, 7-, and 14-day peak flows and 30-, 60-, and 90-day low flows. These simulated discharges are presented in figures and tables.

Effects on Kennady Lake tributary watersheds were evaluated by quantifying changes to watershed areas and using water balance components to determine the corresponding changes to mean annual water yields and lake water surface elevations.

Effects on channel and bank stability were evaluated qualitatively by identifying changes relative to baseline and the corresponding monitoring and mitigation methods to be applied.

8.7.2 Effects Analysis Methods – Closure

8.7.2.1 Water Balance Model

The baseline water balance model referred to in Section 8.7.1.1, and described in Annex H (Climate and Hydrology Baseline), was modified to represent changes to Area 8 of Kennady Lake and downstream watersheds during closure and refilling.

To model the effects on Kennady Lake and downstream watersheds at closure, the following changes were made to the water balance model:

- Areas 2, 3, 4, 5, 6 and 7 were isolated from Area 8 of Kennady Lake; and
- operational diversions of watersheds B, D and E were removed and runoff to Areas 3 to 7 of Kennady Lake was restored.

Two refilling scenarios were modelled, to evaluate the Base Case scenario and one alternative:

- The Base Case scenario involved refilling Kennady Lake with runoff from the reconnected Kennady Lake watershed with supplemental diversion from Lake N11 to Kennady Lake Areas 3, 4, 5, 6 and 7 to reduce the refill time.
- The No Pumping scenario involved refilling Kennady Lake only with runoff from the Kennady Lake watershed, with no diversions from the adjacent watershed.

The Base Case is intended to represent conditions during refilling, including the effects of planned mitigation (pumped diversion from Lake N11). The No Pumping scenario is intended to demonstrate the positive effect of the mitigation provided in the Base Case scenario.

The refilling approach involved diverting water from Lake N11 to refill Kennady Lake, while leaving enough flow to prevent adverse downstream effects in the N watershed (i.e., Lake N11). The diversion criterion was to allow flow to be diverted for refilling while maintaining a minimum Lake N11 outflow equal to the 5-year dry flow condition (refer to Section 9.10). The model was set up as follows:

- diversion occurred within a 6-week period centred in June and July;
- if the annual flow from Lake N11 was greater than the 5-year dry flow, the difference in volume was diverted over the 6-week period; and
- if the annual flow was less than the 5-year dry flow, no water was diverted.

The No Pumping scenario was identical to the baseline water balance model, except Area 8 was separated from the other areas of Kennady Lake.

8.7.2.2 Monte Carlo Simulation

The water balance model was used in conjunction with a Monte Carlo simulation to develop probability-based estimates of the refill times for each of the two scenarios. Output from the water balance model was used to develop probability distributions that generate inflows into the Monte Carlo simulation. These outputs included annual water yield from Lake N11 and the Areas 3 to 7 of Kennady Lake. Refilling was modelled in stages that considered pit and lake refilling.

Annual water yields at Kennady Lake and Lake N11 were arranged statistically in bins, showing that each data set was normally distributed (normal distribution using a mean and a standard deviation). Statistical parameters were approximated in Microsoft Excel. The normal distributions both fit the data well and were available for use with the GoldSim software used for the water balance model.

The Monte Carlo simulation was performed for the Base Case scenario as well as for the No Pumping scenario. Inflows to the model were set up as probability distributions of annual volumes, which were sampled each year to obtain annual values. The entire system was simulated 2,500 times (realizations), generating multiple numbers of refilling times and allowing probabilities to be assigned.

The Monte Carlo simulation for the Base Case scenario sampled the water yield distributions for the natural Kennady Lake watershed, the dry pit and lake areas, and the Lake N11 outflow distribution each year. The Monte Carlo simulation for the No Pumping scenario considered only runoff from the natural Kennady Lake watershed, as well as dry pit and lake areas.

8.7.2.3 Analysis

The analysis approach for closure is identical to that described in Section 8.7.1.2.

8.7.3 Effects Analysis Results – Construction and Operations

8.7.3.1 Effect of Project footprint (dykes, mine pits, mine rock and Coarse PK piles, Fine PKC Facility, access roads, mine plant and airstrip) on Flows, Water Levels and Channel/Bank Stability in Streams and Smaller Lakes in the Kennady Lake Watershed

8.7.3.1.1 Project Activities

Project Surface Infrastructure

Project surface infrastructure, aside from the Fine PKC Facility, Coarse PK Pile, South Mine Rock and West Mine Rock piles and watershed diversions, includes the camp and plant site, processing facilities, sewage treatment plant, explosives management facilities, airstrip and site roads.

The camp site will include an accommodations complex, administration offices, maintenance complex, warehouse, power plant and storage facilities for oil, fuel and de-icing fluid. The plant will include processing facilities for crushing, screening, concentration, diamond recovery and disposal of fine and coarse PK. The camp, plant and sewage treatment plant will be located in Area 6 and Area 7.

Explosives management facilities will include explosives magazines, ammonium nitrate storage and an emulsion plant. These will be located in Area 1, to the east of the Fine PKC Facility.

The Airstrip will be located across Kennady Lake from the camp and plant facilities, in Area 7 and Area 8. It will be accessed via a causeway on top of Dyke A. The airstrip will include an aviation fuel storage tank incorporating spill prevention features and mobile de-icing equipment.

Site service and dedicated haul roads will be constructed throughout the Kennady Lake watershed to provide land access to mine infrastructure. These will be developed using compacted granular fill over general fill material. Road grades will generally be limited to 8%, and will provide for two 4 metre (m) wide lanes with 1 m wide shoulders, except for roads to outlying portions of the mine, which may be provided with one 4 m wide lane with 0.5 m shoulders.

Mine Rock Piles

The South Mine Rock Pile, with an ultimate footprint area of 0.778 square kilometres (km^2), will be developed starting in Year -2 on the south side of Kennady Lake. This will occupy portions of the bed of Area 6 and local tributary watersheds Kc and F.

The West Mine Rock Pile, with an ultimate footprint area of 0.789 km^2, will be developed starting in Year 3 on the west side of Kennady Lake. This will occupy portions of the bed of Kennady Lake Area 5 and local tributary watershed Ka.

Water from the mine rock piles will be managed to remain within the mine closed-circuited area and will be conveyed by constructed ditches or by natural drainage paths, where appropriate, to the WMP (Areas 3 and 5).

Coarse PK Pile

The Coarse PK Pile, with an ultimate footprint area of 0.323 km^2, will be developed starting in Year 1 on land in Area 4. During the latter part of Operations, coarse PK will be used as reclamation cover for the Fine PKC Facility or placed in open pits.

Fine PKC Facility

The Fine PKC Facility, with an ultimate footprint area of 1.554 km^2, will be developed starting in Year -1 on the northeast side of Kennady Lake. This will occupy portions of the bed of Area 2 and local tributary watersheds Ka and A (Area 1). In Year 1 and 2, fine PK will be deposited in Area 1, followed by deposition in Area 2 in Years 3 to 8. After that time, fine PK will be deposited in the mined-out Hearne Pit. The Fine PKC Facility will ultimately be capped with coarse PK and mine rock.

8.7.3.1.2 Residual Effects

Project Surface Infrastructure

Plant and Camp

The camp and plant areas will have a footprint of approximately 0.333 km^2, and will be located primarily in Watersheds Kb (0.261 km^2) and Kd (0.047 km^2), with a small footprint in the upland area of Watershed I (0.024 km^2 or 3% of the watershed area of 0.746 km^2 Watershed I). Water flows will be managed within these areas, with natural drainage patterns used, where practical, to minimize the use of ditches or diversion berms. Runoff will be conveyed to the WMP (Areas 3 and 5).

Airstrip

The airstrip will be located about 1 km southeast of the plant site on the opposite side of Kennady Lake, in watersheds Kd, Ke, and H. It will have a total surface area of 0.15 km^2. Runoff from about 50% of the airstrip (eastern portion) will be conveyed to Area 8 via natural drainage paths. Runoff from the remainder (western portion) will be conveyed to Area 8 via natural and enhanced drainage paths. Sediment traps (e.g., filter cloth silt fences) will be installed to intercept sediment and will be cleaned out as required.

Explosives Management

Explosives management facilities have a footprint of approximately 0.025 km^2, and will be located in Watersheds Ka (0.023 km^2), Kb (0.019 km^2) and A (0.006 km^2). Water flows will be managed within these areas, with natural drainage patterns used, where practical, to minimize the use of ditches or diversion berms. Runoff will be conveyed to the WMP.

Access Roads

Runoff from access roads within the mine closed-circuited area will be conveyed to the WMP using natural drainage patterns, where practical, to minimize the use of ditches or diversion berms. Watercourse crossings will be constructed using culverts or rock drains to prevent upstream ponding and flows across the road surface.

A summary of effects on flows, water levels, and channel/bank stability is provided below:

- Effects on flows:
  - Tributaries to Areas 2 to 7 of Kennady Lake that include Project infrastructure and are not assessed elsewhere include watersheds A, Ka, Kb and Kd. All runoff from these watersheds will be conveyed to the WMP by the site water management system.
  - Tributaries to Area 8 that include Project infrastructure and are not assessed elsewhere include watersheds H, I, and Ke. All infrastructure within these watersheds will be free-draining and no measurable effect on the quantity of inflow to Area 8 of Kennady Lake is anticipated.
- Effects on water levels:
  - No measurable hydrological effects are anticipated on any waterbodies due to the Project infrastructure discussed in this section.
- Effects on channel/bank stability:
  - No effects on natural channel or bank stability are anticipated, as no natural lakes will be affected, and constructed ditches will incorporate erosion and sediment control measures.

Mine Rock Piles

The South Mine Rock Pile will be located in Area 6 of Kennady Lake, which is located within the closed-circuit site water management system. Besides land areas, the South Mine Rock Pile footprint of 0.778 km^2 will cover the existing Lake F1 outlet channel and a portion of the bed of Kennady Lake. Watersheds and basins affected, and the associated area of the South Mine Rock Pile, are summarized below and in Table 8.7-3:

- Area 6 of Kennady Lake: The South Mine Rock Pile will occupy 0.506 km^2 of the 1.778 km^2 land and lake area of Area 6.
- Watershed Kc: The South Mine Rock Pile will occupy 0.254 km^2 of the 1.695 km^2 land area in watershed Kc. All of the area occupied by the mine rock pile drains directly to Kennady Lake under baseline conditions, with no defined waterbodies.
- Watershed F: The South Mine Rock Pile will occupy 0.018 km^2 of the 0.300 km^2 watershed F. This includes the lower portion of the Lake F1 outlet channel, which drains directly to Kennady Lake under baseline conditions. Lake F1 (0.039 km^2) will not be disturbed, and its outflow will be diverted around the South Mine Rock Pile via a constructed

diversion channel or natural watercourses with appropriate erosion control measures.

The West Mine Rock Pile will be located in Area 5 of Kennady Lake, which is located within the closed-circuit site water management system. Besides land areas, the South Mine Rock Pile footprint of 0.789 km^2 will cover the existing Lake Ka1 and its outlet channel, and a portion of the bed of Kennady Lake. Watersheds and basins affected, and the associated area of the South Mine Rock Pile, are summarized below and in Table 8.7-3:

- Area 5 of Kennady Lake: The West Mine Rock Pile will occupy 0.348 km^2 of the 2.448 km^2 watershed associated with the WMP (Areas 3 and 5).
- Watershed Ka: The West Mine Rock Pile will occupy 0.441 km^2 of the 1.695 km^2 Ka watershed area that drains to Kennady Lake. Some of this area drains directly to Kennady Lake under baseline conditions, with the remainder draining through Lake Ka1 (0.009 km^2) and its outlet channel. Lake Ka1 and its outlet channel will be completely covered by the West Mine Rock Pile and upstream flow will be diverted to Kennady Lake via a constructed diversion channel or natural watercourses with appropriate erosion control measures.

Mine rock will also be used to cap the Fine PKC Facility and the Coarse PK Pile, and effects are addressed in the discussion of those facilities in the following, sub-sections.

Table 8.7-3 Effects of Mine Rock Piles on Watershed Areas

Mine Rock Pile	Watershed/ Lake Area	Description	Watershed Area/ Lake Area (km^2)	Lake Area (%)
South	Kennady Lake Area 6	existing	1.778	100
		construction and operations	1.272	100[a]
	Kc	existing	1.695	0.0
		construction and operations	1.441	0.0
	F	existing	0.300	13.0
		construction and operations	0.282	13.8
West	Kennady Lake Area 3 and 5	existing	2.448	100
		construction and operations	2.100	100[b]
	Ka	existing	2.237	0.4
		construction and operations	1.796	0.0

(a) This portion of Kennady Lake will be dewatered during construction and operations.

(b) This portion of Kennady Lake will be partially dewatered and refilled during construction and operations.

km^2 = square kilometres; % = percent.

During construction and operations, it is estimated that direct precipitation to the mine rock piles will collect and freeze in interstices in the stored mine rock and that the mean annual water yield from the mine rock pile will be about 116 mm, or about half of that for natural vegetated land surfaces.

A summary of effects on flows, water levels and channel/bank stability is provided below:

- Effects on flows:
  - The mine rock piles will be located entirely within the mine closed-circuited area and all drainage will be managed as part of the closed-circuit site water management system.
- Effects on water levels:
  - Lake F1 will not be affected by the South Mine Rock Pile. A small portion (6%) of the tributary area to its outlet channel, downstream of Lake F1, will be occupied by the South Mine Rock Pile
  - Lake Ka1 and its outlet channel will be covered by the West Mine Rock Pile.
- Effects on channel/bank stability:
  - No effects on natural channel or bank stability are anticipated, because runoff around the mine rock pile perimeters and in the diverted Lake F1 outlet channel will be managed to prevent channel erosion.

Coarse PK Pile

The Coarse PK Pile will be located in Area 4 of Kennady Lake, which is located within the closed-circuit site water management system. Besides land areas, the Coarse PK Pile footprint of 0.323 km^2 will cover Lake Kb4 and its outlet channel, and a portion of the bed of Kennady Lake. Watersheds and lake areas affected, and the associated area of the Coarse PK Pile, are summarized below and in Table 8.7-4:

- Area 4 of Kennady Lake: The Coarse PK Pile will occupy 0.006 km^2 of the 0.762 km^2 Area 4 of Kennady Lake.
- Watershed Kb: The Coarse PK Pile will occupy 0.316 km^2 of the 1.375 km^2 Kb watershed area that drains to Kennady Lake. Some of this area drains directly to Kennady Lake under baseline conditions, with the remainder draining through Lake Kb4 (0.010 km^2) and its outlet channel. Lake Kb4 and its outlet channel will be completely covered by the Coarse PK Pile and flow from upstream will be diverted to Kennady Lake via a constructed diversion channel or natural watercourses with appropriate erosion control measures.

Table 8.7-4 Effects of Coarse PK Pile on Area 4

Watershed/ Lake Area	Description	Watershed/ Lake Area (km^2)	% Lake Area
Kennady Lake Area 4	baseline area	0.762	100.0
	Coarse PK Pile footprint	0.006	100.0
	area unaffected by Coarse PK Pile footprint	0.756	100.0
Watershed Kb	baseline area	1.375	4.1
	Coarse PK Pile footprint	0.316	3.1
	area unaffected by Coarse PK Pile footprint	1.059	4.4

km^2 = square kilometres; % = percent; PK = processed kimberlite.

A summary of effects on flows, water levels, and channel/bank stability is provided below:

- Effects on flows:
  - All runoff from the Coarse PK Pile will be located entirely within the mine closed-circuited area and all drainage will be managed as part of the closed-circuit site water management system.
- Effects on water levels:
  - Construction and operation of the Coarse PK Pile will result in the permanent loss of Lake Kb4 as a waterbody, with a lake area of approximately 0.010 km^2.
- Effects on channel/bank stability:
  - No effects on natural channel or bank stability are anticipated, due to construction of the Coarse PK Pile. Runoff from the facilities and upstream areas will be managed with internal and perimeter ditches to prevent channel erosion.

Fine PKC Facility

The Fine PKC Facility will be located in Areas 1 and 2 of Kennady Lake, which are located within the closed-circuit site water management system. Besides land areas, the Fine PKC Facility footprint of 1.554 km^2 will cover Lake A1 and its outlet channel, Lake A2 and its outlet channel, and a portion of the bed of Kennady Lake (Area 2). Watersheds and lake areas affected, and the associated footprint area of the Fine PKC Facility, are summarized below and in Table 8.7-5:

- Area 2 of Kennady Lake: The Fine PKC Facility will occupy 0.584 km^2 of Area 2 (0.626 km^2). Dyke L will occupy an additional 0.042 km^2 of Area 2 of Kennady Lake. The lake area of Area 2 will be completely filled.

- Watershed Ka: The Fine PKC Facility will occupy 0.100 km^2 of the 2.237 km^2 land area in watershed Ka. All of the area occupied by the Fine PKC Facility drains directly to Kennady Lake under baseline conditions, with no defined waterbodies. Dykes D, E and L will occupy an additional 0.028 km^2 of land area in watershed Ka.
- Watershed A: The Fine PKC Facility will occupy 0.492 km^2 of the 1.593 km^2 land area in watershed A, and will also completely cover Lakes A1, A2, A5 and A7, with a total lake area of 0.378 km^2, for a total footprint of 0.870 km^2. Dyke C will occupy an additional 0.019 km^2 of land area and 0.001 km^2 of lake area in Watershed A. The upper watershed, including Lake A3, will be diverted to the N lakes watershed, and this is discussed in Section 8.7.3.3.

Seepage water from the Fine PKC Facility will flow towards Area 2, where it will seep through the permeable Dyke L into the WMP. This will include runoff from undisturbed portions of the Area 2 (Watershed Ka) upland.

Table 8.7-5 Effects of Fine PKC Facility on Area 1 and Area 2

Watershed/ Lake Area	Description	Watershed/Lake Area (km^2)	% Lake Area
Kennady Lake Area 2	baseline area	0.626	100.0
	Fine PKC Facility footprint	0.584	100.0
	Dyke L footprint	0.042	100.0
	area unaffected by Fine PKC Facility footprint	0.000	100.0
Watershed Ka	baseline area	2.246	0.4
	Fine PKC Facility footprint	0.100	0.0
	Dyke D, E and L footprint	0.028	0.0
	area unaffected by Fine PKC Facility footprint	2.118	0.4
Watershed A	baseline area	2.237	28.8
	Fine PKC Facility footprint	0.870	43.4
	Dyke C footprint	0.020	5.0
	area unaffected by Fine PKC Facility footprint	0.840	28.7
	area diverted to L watershed	0.507	5.0

km^2 = square kilometres; % = percent; PKC = processed kimberlite containment.

A summary of effects on flows, water levels, and channel/bank stability is provided below:

- Effects on flows:
  - All runoff from the Fine PKC Facility will be located entirely within the mine closed-circuited area and all drainage will be managed as part of the closed-circuit site water management system.
- Effects on water levels:
  - Construction and operation of the Fine PKC Facility will result in the permanent loss of Kennady Lake Area 2 as a waterbody, with a lake area of approximately 0.626 km^2. It will also result in the permanent loss of lakes A1, A2, A5 and A7 and outlet channels, with a total lake area loss of approximately 0.379 km^2.
- Effects on channel/bank stability:
  - No effects on natural channel or bank stability are anticipated, due to construction of the Fine PKC Facility. Runoff from the facilities and upstream areas will be managed with internal and perimeter ditches to prevent channel erosion.

8.7.3.2 Effects of Dewatering of Kennady Lake to Flows, Water Levels and Channel/Bank Stability in Area 8

8.7.3.2.1 Project Activities

Kennady Lake Areas 2, 3, 4, 5, 6, and 7 will be partially or completely dewatered at stages during the construction and operation of the Project to allow mine pit development on the lake-bed. Key steps in this activity will include:

- Dyke A will be constructed across the narrows between Area 7 and Area 8;
- Areas 2 to 5 will be dewatered to Lake N11 through active pumping from Area 3, and Areas 6 and 7 will be dewatered to Area 8 through active pumping from Area 7. It is estimated that at a minimum 2 m drawdown will be achieved before bottom sediments have a significant impact on water quality. Active pumping from Area 7 will cease when the water quality in Area 7 approaches specific water quality criteria for discharge;
- Dewatering will expose sills on the lakebed. Dyke H will be constructed on the sill between Area 5 and Area 6, and Dyke J will be constructed on the sill between Area 4 and Area 6. These will separate Areas 2 to 5 from Areas 6 and 7, and allow Areas 3 and 5 to then serve as the WMP for the Project;

- The remaining water from Areas 6 and 7 will be dewatered to Area 5 of the WMP, to allow mining of the 5034 and Hearne pits. A pervious dyke may be constructed within Area 5 if required to control TSS concentrations in the WMP. As groundwater will be pumped to the WMP, active pumped discharge from Area 3 will continue as long as the water quality in Area 3 meets specific water quality criteria for discharge;
- Between Year 4 and Year 5, Dyke B will be constructed to separate Area 3 and Area 4 of Kennady Lake. Area 4 will then be dewatered to the WMP between Year 5 and 6 to allow mining of the Tuzo Pit;
- In Year 6, Dyke K will be constructed to its final height between Area 6 and Area 7 of Kennady Lake.

A summary of the Kennady Lake dewatering schedule is provided in Table 8.7-6. During the dewatering period, discharges will be limited so that flows at the outlet of Kennady Lake (stream K5) do not exceed the 1 in 2 year flood value of 114,000 m^3/d. During operations, natural flows from Areas 2 to 7 will no longer flow into Area 8 due to the construction of Dyke A, but runoff from undisturbed areas within the Area 8 watershed will still flow to Area 8.

Table 8.7-6 Kennady Lake Areas 2 to 7 Dewatering Schedule

Period	Kennady Lake Area	Project Activity	Water Surface Elevation at End of Period (masl)
Baseline	Areas 2 to 7	None.	420.7
Year -2 to Year -1	Areas 2, 3, 4 and 5	Dewater to Lake N11.	~418.7
	Areas 6 and 7	Dewater while meeting TSS criteria to Area 8; remaining water decanted to Area 5.	<414.5
Year 1 to Year 4	Areas 2, 3, 4 and 5	Annual discharge from Area 3 to Lake N11.	~418.7
	Areas 6 and 7	Maintain as dewatered.	<414.5
Year 5 to Year 6	Areas 2, 3 and 5	Operate as closed system, unless water quality permits discharge to Lake N11.	~420.7
	Area 4	Dewater to WMP (Areas 3 and 5) to allow mining.	405.0
	Areas 6 and 7	Maintain as dewatered.	<414.5
Year 6 to Year 8	Areas 2, 3 and 5	Allow to fill to ~2 m above original lake elevation. Allow overflow to Area 6 mined-out pits.	~422.1
	Area 4	Maintain.	405.0
	Area 6	Maintain. East portion allowed to refill after mining of Hearne Pit is complete.	404.0
	Area 7	Dyke off Area 7 and allow to refill.	<419.8
Year 9 to Year 11	Areas 2, 3 and 5	Maintain at ~2 m above original lake elevation.	~422.6
	Area 4	Maintain.	405.0
	Area 6	Maintain, with continued filling of east portion.	404.0
	Area 7	Allow to refill.	~420.7
End of Project	Areas 3 to 7	Begin flooding Tuzo Pit with water from Areas 3, 6 and 7. Begin supplemental pumping refill of Areas 2 to 7.	n/a

masl = metres above sea level; ~ = approximately; < = less than.

8.7.3.2.2 Residual Effects

Dewatering of Areas 2 to 7 will reduce the quantity of water in these lake areas to water stored in the WMP (Areas 3 and 5) and in local depression storages (collection ponds). All water in Areas 2 to 7 will be in the mine closed-circuit area and will be managed by the Project.

Dyke A will prevent water from flowing from Area 8 into Area 7 during construction and operations. Area 8 will be preserved as a free-draining waterbody throughout this period, though its hydrological regime will be changed.

During dewatering, discharges from Area 7 of Kennady Lake will be limited to ensure that 2-year flood conditions (1 in 2 year maximum daily discharge) are not exceeded within Area 8 or its outlet channel. During dewatering, no direct discharge will occur if snowmelt or rainfall runoff cause water levels to exceed the 2-year flood water level in Area 8.

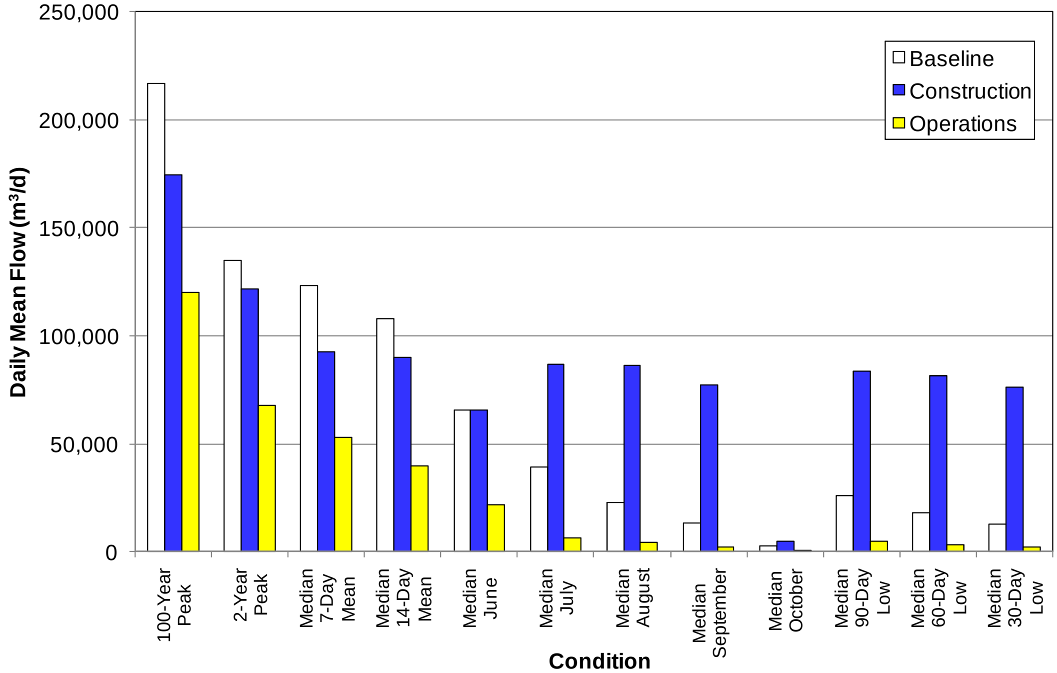
Diffusers will be used to dissipate the energy of water pumped into Area 8 during the dewatering. These diffusers will be placed as close to the surface as possible to increase the distance between the outfall and the bottom sediments. Although some sediment may be mobilized despite these measures, the extent of this effect is likely to be limited to the zone of turbulence immediately adjacent to the diffuser, and is likely to quickly diminish after sediments in the zone of turbulence are mobilized and become re-deposited further away from the outfall.

Discharges from Area 8 and water levels in Area 8 were modeled for dewatering during construction and operations. Project effects on Area 8 during construction and operations are shown in Figure 8.7-1 and Figure 8.7-2, and summarized in Table 8.7-7 to Table 8.7-10.

Construction: The water balance results for Area 8 show that monthly mean flows will be approximately equal to baseline during the natural high water month of June, and will be greater than baseline during the natural low water months of July to September. The 100-year and 2-year flood discharges will be lower than baseline due to the reduction in upstream drainage area and low pumping capacity relative to the natural flood discharges. Under median conditions, low flows will increase during construction.

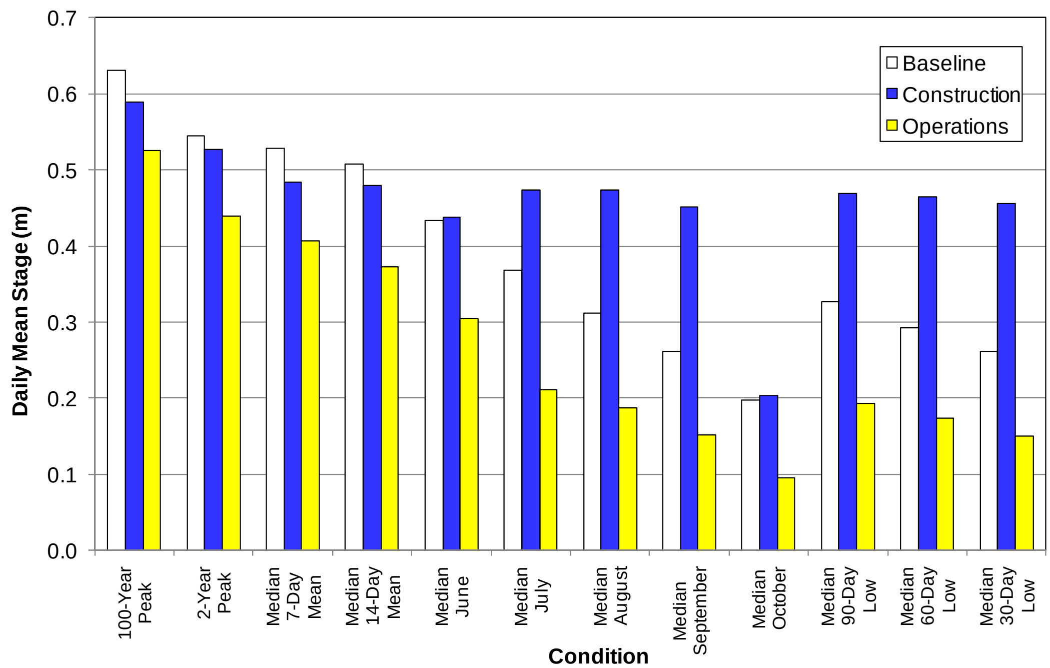
Operations: The water balance results for Area 8 show that when pumped discharge from Area 7 ceases, flows will be reduced from baseline. Results for the month of November are not shown because conditions during construction and operations for that month are expected to be similar to baseline, due to frozen conditions.

Figure 8.7-1 Comparison of Effects on the Outlet of Kennady Lake (Stream K5) Discharges during Construction and Operations



m^3/d = cubic metres per day.

Figure 8.7-2 Comparison of Effects on the Outlet of Kennady Lake (Stream K5) Water Level during Construction and Operations



m = metres.

Table 8.7-7 Mean Daily Outflow Volumes at the Outlet of Kennady Lake (Stream K5) – Construction and Operations

Condition	Return Period (years)	Snapshot	Monthly Mean Daily Outflow Volume (m^3)				
			June	July	August	September	October
Wet	100	baseline	121,000	86,500	59,600	68,600	13,500
		construction	91,500	92,800	93,300	90,800	18,400
		operations	35,500	19,600	14,700	16,900	2,030
	10	baseline	97,600	61,900	38,100	29,200	6,640
		construction	83,800	89,600	89,700	88,100	10,200
		operations	30,700	12,000	8,680	6,620	967
Median	2	baseline	65,900	39,300	22,800	13,200	3,070
		construction	65,700	86,600	86,500	77,200	4,680
		operations	21,900	6,670	4,580	2,460	371
Dry	10	baseline	36,900	23,100	13,900	6,880	1,430
		construction	41,000	85,500	85,400	57,300	1,880
		operations	12,000	3,570	2,310	892	91
	100	baseline	12,900	12,000	9,420	4,910	878
		construction	6,470	84,900	84,800	43,800	1,270
		operations	2,380	1,880	1,390	496	18

m^3 = cubic metres.

Table 8.7-8 Representative Discharges at the Outlet of Kennady Lake (Stream K5) – Construction and Operations

Condition	Return Period (years)	Snapshot	Peak Daily Q (m^3/s)	7-Day Mean Peak Q (m^3/d)	14-Day Mean Peak Q (m^3/d)	30-Day Low Flow Q (m^3/d)	60-Day Low Flow Q (m^3/d)	90-Day Low Flow Q (m^3/d)
Wet	100	baseline	2.51	192,000	167,000	48,900	52,500	59,000
		construction	2.02	103,000	96,900	91,800	90,100	89,200
		operations	1.39	85,200	61,000	10,500	14,100	13,300
	10	baseline	2.14	166,000	145,000	26,200	32,300	41,000
		construction	1.68	97,600	93,100	88,100	87,500	87,700
		operations	1.11	71,700	52,600	5,070	7,200	8,450
Median	2	baseline	1.56	123,000	108,000	12,800	18,300	26,000
		construction	1.41	92,600	89,900	76,100	81,400	83,800
		operations	0.78	52,900	39,900	2,100	3,390	4,830
Dry	10	baseline	0.798	64,600	59,900	6,990	10,900	16,000
		construction	1.24	89,400	88,000	56,700	71,800	77,500
		operations	0.46	31,100	23,700	900	1,820	2,720
	100	baseline	0.0013	1,680	9,110	4,760	7,480	10,500
		construction	1.16	88,100	87,200	42,300	64,000	72,200
		operations	0.21	10,800	7,400	473	1,260	1,680

m^3/s = cubic metres per second; m^3/d = cubic metres per day; Q = discharge

Table 8.7-9 Mean Daily Water Levels at the Outlet of Kennady Lake (Stream K5) – Construction and Operations

Condition	Return Period (years)	Snapshot	Monthly Mean Stage (m)				
			June	July	August	September	October
Wet	100	baseline	0.531	0.471	0.425	0.443	0.315
		construction	0.497	0.492	0.492	0.490	0.291
		operations	0.367	0.297	0.267	0.283	0.166
	10	baseline	0.498	0.430	0.370	0.341	0.256
		construction	0.479	0.484	0.484	0.483	0.254
		operations	0.348	0.257	0.231	0.214	0.137
Median	2	baseline	0.433	0.368	0.311	0.262	0.197
		construction	0.438	0.474	0.474	0.452	0.204
		operations	0.304	0.210	0.187	0.152	0.096
Dry	10	baseline	0.361	0.312	0.270	0.217	0.156
		construction	0.392	0.472	0.472	0.392	0.163
		operations	0.250	0.174	0.153	0.113	0.059
	100	baseline	0.299	0.269	0.246	0.197	0.136
		construction	0.356	0.472	0.472	0.343	0.139
		operations	0.203	0.149	0.133	0.095	0.039

m^3 = cubic metres.

Table 8.7-10 Representative Water Levels at the Outlet of Kennady Lake (Stream K5) – Construction and Operations

Condition	Return Period (years)	Snapshot	Peak Daily Stage (m)	7-Day Mean Peak Stage (m)	14-Day Mean Peak Stage (m)	30-Day Low Flow Stage (m)	60-Day Low Flow Stage (m)	90-Day Low Flow Stage (m)
Wet	100	baseline	0.631	0.607	0.582	0.397	0.406	0.421
		construction	0.590	0.501	0.491	0.483	0.480	0.479
		operations	0.525	0.472	0.425	0.246	0.270	0.265
	10	baseline	0.600	0.581	0.557	0.327	0.349	0.376
		construction	0.557	0.492	0.485	0.477	0.476	0.476
		operations	0.490	0.447	0.406	0.197	0.219	0.230
Median	2	baseline	0.544	0.529	0.508	0.262	0.293	0.327
		construction	0.527	0.484	0.480	0.456	0.465	0.470
		operations	0.439	0.407	0.373	0.150	0.174	0.194
Dry	10	baseline	0.442	0.433	0.423	0.217	0.249	0.281
		construction	0.507	0.479	0.477	0.416	0.448	0.458
		operations	0.373	0.345	0.317	0.115	0.143	0.162
	100	baseline	0.060	0.140	0.236	0.193	0.222	0.246
		construction	0.496	0.477	0.475	0.380	0.432	0.448
		operations	0.290	0.249	0.221	0.094	0.128	0.140

m = metre.

A summary of effects on flows, water levels, and channel/bank stability is provided below:

- Effects on flows:
  - Construction of dyke A across the narrows will reduce the outflow from Area 7 into Area 8 to zero. All discharges from Area 7 to Area 8 during construction and operations will be by direct discharge during dewatering.
  - During dewatering, flows from Area 8 will generally be increased and the duration of the flood period will be extended through September; however, flows will be limited so that dewatering does not cause the total flow to exceed the 2-year flood discharge.
  - During Operations, when dewatering has ceased, flows from Area 8 will be reduced from baseline, because only the local tributary area (Watersheds I, J and Ke) will contribute runoff to Area 8.

- Effects on water levels:
  - Water levels in Areas 3 to 7 will be managed to allow mining and changes water levels will follow the schedule presented in Table 8.7-6.
  - Changes to water levels in Area 8 will correspond to changes in flows. For median conditions, the greatest changes in June to October mean monthly stage are expected to occur in September during construction (+0.190 m) and July for operations (-0.158 m).

- Effects on channel/bank stability:
  - No effects on channel stability in the Kennady Lake watershed are anticipated, as all dewatering flows will be pumped via pipeline to receiving waterbodies or pumped to receiving streams rather than conveyed by natural channels. No effects on bank stability are anticipated, due to the drop in water levels. Exposed lake-bed areas may be subject to erosion by runoff, depending on the type of substrate present. However, all water within Areas 3 to 7 will be managed to prevent the release of water to the natural receiving environment if TSS concentrations exceed specific water quality criteria.
  - Water levels in Area 8 and discharges from its outlet channel will be maintained below baseline 1 in 2 year flood levels throughout construction and operations, except where natural exceedences occur while pumped diversions are suspended. No adverse effects on channel or bank stability are anticipated.

8.7.3.3 Effect of Watershed Diversion in Watersheds A, B, D and E on Flows, Water Levels and Channel/Bank Stability in Streams and Smaller Lakes in the Kennady Lake Watershed

8.7.3.3.1 Project Activities

To reduce the amount of natural runoff into the dewatered Areas 2 to 7 of Kennady Lake, and the amount of water that must be managed by the site water management system, several upstream tributary watersheds will be diverted to the adjacent N watershed during operations. These diversions will remain in place until the start of Kennady Lake refilling.

Watershed A above Lake A2 will be diverted to Lake N9. Permanent Dyke C will be constructed across the existing Lake A3 outlet to Lake A2. The mean water level in Lake A3 will be raised by approximately 3.5 m. The new outlet channel from Lake A3 to Lake N9 will be approximately 150 m long at a bed slope of 2.6%. All diversion channels will be designed and constructed to prevent erosion and sedimentation and to incorporate lessons learned from the Ekati Diamond Mine (Jones et al. 2003).

Watershed B will be diverted to Lake N8. Temporary Dyke E will be constructed across the existing Lake B1 outlet to Kennady Lake. The mean water level in Lake B1 will not be raised, because the natural water surface is approximately 1.3 m above that in Lake N8. The new outlet channel from Lake B1 to Lake N8 will be approximately 275 m long at a bed slope of 0.5%.

Watershed D above Lake D1 will be diverted to Lake N14. Temporary Dyke F will be constructed across the existing Lake D2 outlet. The mean water level in Lake D2 will be raised by approximately 2.8 m and the mean water level in Lake D3 will be raised by approximately 1.6 m, as the area between the two lakes is flooded and they form a continuous waterbody. The new outlet channel from Lake D2/D3 to Lake N14 will be approximately 120 m long at a bed slope of 1.4%. Lake D1 is located downstream of the saddle dyke and will receive runoff from the local watershed only during the diversion period.

Watershed E will also be diverted to Lake N14. Temporary Dyke G will be constructed across the existing Lake E1 outlet. The mean water level in Lake E1 will be raised by approximately 0.8 m. The new outlet channel from Lake E1 to Lake N14 will be approximately 25 m long at a bed slope of 3.4%.

8.7.3.3.2 Residual Effects

Diversion of watersheds A, B, D and E will reduce the amount of runoff from undisturbed areas that must be managed by the site water management system.

Natural streams immediately downstream of the saddle dykes will be dry while the watershed diversions are in place, and flows to receiving streams will increase. The water level within the diverted lakes will also increase. A summary of hydrological changes to Lakes A3, B1, D2, D3 and E1 is provided in Table 8.7-11.

Table 8.7-11 Hydrological Effects on the Outflows from the A, B, D and E Watersheds during Operations

Lake	Condition	Local Lake Parameters			Watershed Parameters				
		Surface Area	Perimeter	Maximum Depth	Watershed Area	Lake Surface Area		Mean Annual Water Yield	
		(ha)	(m)	(m)	(km^2)	(km^2)	(%)	(mm)	(m^3)
A3[(a)]	Baseline	23.77	2,360	12.4	0.839	0.241	28.7	162	136,000
	Diverted	46.55	3,470	15.9	0.839	0.466	55.5	98	82,500
B1	Baseline	8.21	2,340	4.1	1.269	0.174	13.7	198	251,000
	Diverted	8.21	2,340	4.1	1.269	0.174	13.7	198	251,000
D1	Baseline	1.88	780	(b)	4.497	1.027	22.8	175	788,000
	Diverted	1.88	780	(b)	0.349	0.019	5.4	210	73,300
D2	Baseline	12.53	2,320	1.0	4.148	1.008	24.3	172	713,000
	Diverted	103.00	6,460	3.8	4.148	1.447	34.9	155	645,000
D3	Baseline	38.37	4,070	3.0	2.957	0.839	28.4	163	481,000
	Diverted	(c)	(c)	4.6	(c)	(c)	(c)	(c)	(c)
E1	Baseline	20.24	2,780	3.9	1.225	0.244	19.9	182	223,000
	Diverted	26.98	3,150	4.7	1.225	0.311	25.4	173	212,000

(a) Lake A4, with a pre-diversion lake area of 0.35 ha and an unknown depth, will also be inundated when Lake A3 is raised.

(b) Maximum depth unknown; no change anticipated due to Project.

(c) Included in values provided for raised Lake D2.

km^2 = square kilometre; % = percent; m = metre; mm = millimetre.

Diversion outlet structures will be designed and managed to provide an outflow rating curve that approximates the natural outflow rating curve, to the extent possible, during construction and operations. Because of the increase in proportion of lake water surface area for raised lakes, greater evaporative losses are expected and the mean annual water yield from the diverted portion of Lake A3 watershed will be reduced from 136,000 to 82,500 m^3 (a reduction of 39%), the mean annual water yield from the diverted portion of the D watershed will be reduced from 788,000 to 718,300 m^3 (a reduction of 10% from the watershed above the Lake D2 outlet and 9% from the entire watershed), and the mean annual water yield from the diverted portion of the E watershed will be reduced from 223,000 to 212,000 m^3 (a reduction of 5%). The D watershed below the Dyke F at the Lake D2 outlet will not be disturbed. The mean annual water yield from the local watershed is expected to be the same as baseline, though the inflow from Lake D2 will be interrupted while the diversion is in place. This will increase the residence time of water in the lake and reduce lake outflows.

The increase in lake storage in the Lake A3 watershed will be about 1,100,000 m^3, due to the increase in the water surface elevation of Lake A3. This volume is about 10 times the mean annual water yield from the diverted watershed, meaning that, for mean conditions, there will be no outflow from the diverted watershed as Lake A3 fills until the eleventh year of Operations. However, if water is transferred to Lake A3 during Area 1 dewatering, the time until outflow occurs would be reduced.

The increase in lake storage in the D2/D3 lakes watershed will be about 1,400,000 m^3, due to the increase in the water surface elevation of Lakes D2 and D3. This volume is about twice the mean annual water yield from the diverted watershed, meaning that, for mean conditions, there will be no outflow from the diverted watershed as these lakes fill until the third year of operations.

The increase in lake storage in the E1 watershed will be about 110,000 m^3, due to the increase in the water surface elevation of Lake E1. This volume is about half the mean annual water yield from the diverted watershed, meaning that, for mean conditions, outflow from the raised Lake E1 should commence in the first year of operations.

Raising of the water levels in Lakes A3, D2, D3 and E1 will create new shorelines at higher elevations than the existing shorelines. This will expose new soils, often on steeper slopes than the existing shorelines, to wave erosion and potential instability due to permafrost disturbance. A recent regulatory application (MHBL 2005) included a review of historical research and six case studies of lakes being raised in northern environments. Annual shoreline erosion for these case studies ranged from 0.14 m^3/m to 1.08 m^3/m, and a best estimate of 0.23 m^3/m was suggested for the lake that was the subject of the regulatory application. This lake had a fetch length of approximately 1 km, similar to those at Lakes A3, D2/D3 and E1, and shorelines comprising deposits of fine marine sediments including clay fractions.

Table 8.7-12 shows the approximate lengths of new shoreline that will be established at each raised lake, broken down by soil units corresponding to those described in Annex D (Bedrock Geology, Terrain, Soil and Permafrost Baseline). Surficial soils have the following Associations:

- Lobster Lake (moraine veneer, with till >1 m thick);
- Wolverine Lake (moraine veneer, with till <1 m thick);

- Sled Lake (shallow to deep bog and mixed fen and bog peat);
- Dragon Lake (shallow to deep fen peat); and
- Goodspeed (shallow organic soils derived from sedge, cottongrass, willow, birch and alder species.

Table 8.7-12 shows that of a total new shoreline length of 13 km:

- 3.7 km has a water erosion risk rating of Low;
- 5.7 km has a water erosion risk rating of Low (Moderate);
- 2.4 km has a water erosion risk rating of Low (High); and
- 0.4 km has a water erosion risk rating of Moderate.

The remaining 0.8 km of dyke face will be armoured appropriately to prevent erosion. These water erosion risk ratings were developed to assess the risk of erosion from flowing water, based on rainfall intensity, soil erodibility and terrain slope and length, so they are not directly applicable to erosion due to wave action at shorelines. However, they are indicative of the greater erosion resistance of organic soils (i.e., Dragon, Sled and Goodspeed Lake Associations) and morainal soils (i.e., Wolverine and Lobster Lake Associations) relative to more fine-grained lacustrine soils that are not present in the area. Approximately 8.1 km of the new shoreline will comprise morainal soils, and 4.1 km will comprise organic soils.

Furthermore, morainal soils, as described in Section D5.3.1.2 of Annex D, contain coarse fractions up to boulder size. These are erosion-resistant due to the natural armouring that occurs with these larger sized soil fractions; the fine fractions are eroded away and coarser fractions are left behind. The sand and larger fractions of morainal soils have high settling velocities relative to silts and clays, and are unlikely to contribute to persistent or non-localized increases in TSS concentrations.

Bog and fen peat soils are typically associated with low-slope terrain that is less susceptible to wave erosion and would similarly not contribute silt and clay sediment fractions that would result in elevated TSS concentrations.

Table 8.7-12 Characteristics of New Shorelines at Lakes A3, D2/D3 and E1

Lake	Shoreline Length (m)	Soil Unit	Description (From Table D6.3-3)	Erosion Risk (from Annex D Table D6.3-5)[a]
A3	180	W1u	Wolverine Lake Association dominant; minor inclusions of Bedrock and Sled Lake, Dragon Lake, and Goodspeed Lake unit, landforms are undulating in the W1u unit associations	M
	2,570	WS1	Wolverine Lake and Sled Lake associations are co-dominant; minor inclusions of Dragon Lake and Goodspeed Lake associations; the landform is undulating to hummocky with bog forms in the WS1 unit	L (M)
	370	SD1	Sled Lake and Dragon Lake associations co-dominant; minor inclusions of Goodspeed Lake Association; landforms are polygonal peat plateau, northern peat plateau and lowland polygon bogs, with level to gently inclined forms	L
	350	Dyke Face		n/a
	3,470	Total		
D2/D3	350	W2	Wolverine Lake Association dominant; inclusions of Sled Lake Association; minor inclusions of Bedrock, and of Goodspeed Lake and Dragon Lake associations; the landform is undulating to hummocky in the W2 unit	L (H)
	70	WS1u	See WS1 above	L (M)
	1,570	WS2u	Wolverine Lake and Sled Lake associations are co-dominant; inclusions of the Dragon Lake Association occur; landforms are undulating in the WS2u unit, with subdominant bog forms (plateau and polygonal)	L (M)
	310	S3u	Sled Lake Association dominant; inclusions of the Wolverine and Dragon Lake associations; landforms are polygonal peat plateau, northern peat plateau and lowland polygon bogs, with undulating upland in the S3u unit	L (M)
	510	SD1	See SD1 above	L
	110	SD2	the Sled Lake and Dragon Lake associations are co-dominant; inclusions of Wolverine Lake Association; landforms are polygonal peat plateau, northern peat plateau and lowland polygon bogs	L (M)
	230	Dyke Face		n/a
	3,150	Total		
E1	230	W1u	See W1u above	M
	990	W2	See W2 above	L (H)
	1,080	W3	Wolverine Lake Association dominant; inclusions of Sled Lake and Dragon Lake associations occur; the landform is undulating to hummocky, with inclusions of Bog and Fen forms	L (H)
	360	WS1	See WS1 above	L (M)
	730	WS2u	See WS2u above	L (M)
	1,440	SD1	See SD1 above	L
	1,380	D3	Dragon Lake Association dominant; inclusions of the Sled Lake Association; landforms are complexes of bog and fen forms, including horizontal and lowland polygon fens, with polygonal peat plateau, northern peat plateau and lowland polygon bogs	L
	250	Dyke Face		n/a
	6,460	Total		

[a] L = Low, L (M) = Low (Moderate), L (H) = Low (High), M = Moderate. The ratings Low (Moderate) and Low (High) indicate that there are some areas of soil complexes in which one of the soil components has a rating higher than Low. Generally, the Medium and High ratings apply to Wolverine Lake soils that occur on hummocky topography with slopes in the 6 to 15% or higher slope categories.

It is possible that shoreline erosion rates at the Project could be similar to those predicted for Tail Lake (MHBL 2005). However, the armouring action of morainal materials and the rapid settling of its coarse fractions from the water column, along with the location of organic soils in low-gradient locations, mean that increases in TSS concentrations during the lake level increases are expected to be low. It is expected that the lakes with the largest changes in elevation (A3 and D2/D3) will take three or more years to fill to an elevation that will result in discharge to the N watershed, leaving time to observe shoreline and TSS conditions and assess the need for specific mitigation.

A detailed survey of future shoreline areas to identify areas of significant erosion potential on a finer spatial scale will be performed during construction to establish a monitoring program baseline. The monitoring program will include visual inspection of shoreline characteristics and periodic TSS monitoring. Should areas of significant erosion be identified during construction and operations, mitigation measures, including placement of rock armour material to arrest erosion, will be undertaken.

A summary of effects on flows, water levels and channel/bank stability is provided below:

- Effects on flows:
  - Annual outflows from raised lakes (i.e., Lakes A3, D2/D3 and E1) will be reduced somewhat from baseline due to increased evaporation from the lake water surfaces. The annual outflow from Lake D1 into Kennady Lake will be greatly reduced, because of the upstream diversion. The annual outflow from Lake B1 will be unchanged.
  - Constructed diversion channels will convey water from the diverted areas to receiving waterbodies in the N watershed, once water surface elevations have increased to the spill elevation. The general shapes of the annual hydrographs in these diversion channels will be similar to that of the natural lake outflows, though peak and annual flows will be reduced due to increased evaporative losses.

- Effects on water levels:
  - The nominal water level of Lake A3 will increase by 3.5 m, the nominal water level of Lake D2 will increase by 1.6 m, the nominal water level of Lake D3 will increase by 2.8 m, and the nominal water level of Lake E1 will increase by 0.8 m. The nominal water level of Lake B1 will not be affected.
  - Annual variation in water levels in the raised lakes will be similar to pre-diversion values.

- Effects on channel/bank stability:
  - Diversions will consist of constructed channels designed to prevent erosion and to maintain stability in permafrost.
  - Raised lakes will be subject to erosion as new shorelines are established. Natural armoring of the 8.1 km of morainal soils is expected to limit erosion in these areas and persistent TSS generation is expected to be limited as coarse materials settle out on the lakebed near to where they are mobilized. Low slopes in new shoreline areas with organic (peat) soils are expected to minimize erosion and generation of TSS. A monitoring and mitigation program will be incorporated in an adaptive management plan for shoreline erosion.

8.7.4 Effects Analysis Results – Closure

8.7.4.1 Effect of Refilling Activities on Flows, Water Levels and Channel/Bank Stability in Areas 3, 4, 5, 6, and 7

8.7.4.1.1 Activity Description

Kennady Lake refilling will use natural runoff from Areas 2, 3, 4, 5, 6 and 7, including upstream tributary watersheds, plus a diversion of flow from Lake N11 to shorten the refill time.

Pumping of water from Lake N11 will be restricted to years where the annual runoff volume upstream of the N11 lake outlet will be greater than the 5-year dry annual runoff volume, to be protective of fisheries resources (refer to Section 9.10.4.1). This estimate will be based on measurements of snowpack and lake water surface elevation. When this criterion is met, the difference will be pumped to Area 3 of Kennady Lake. The diversion will occur within a 6-week period, centered between June and July. The difference between the 2-year median and 5-year dry annual runoff volume upstream of the Lake N11 outlet is estimated to be 3,715,000 m^3, or 88,550 m^3/d, over a 6-week period.

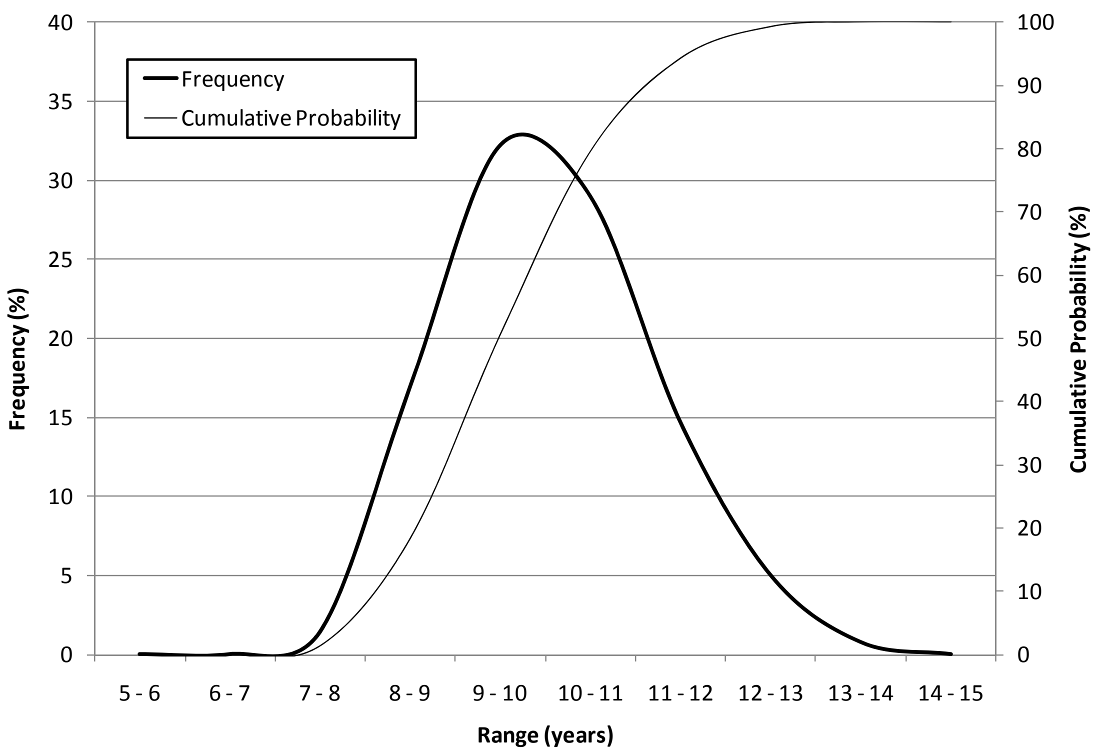
8.7.4.1.2 Residual Effects

To increase the rate of refilling and decrease the refilling time, flow will be diverted from Lake N11 to Area 3 of Kennady Lake.

The water balance model was used in conjunction with a Monte Carlo simulation to evaluate the probabilities of durations for Kennady Lake refilling. The simulations were based on a total lake refilling volume of 63.6 Mm^3, including mine pits and voids in mine rock placed below the final lake water level. The median refilling time for the Base Case scenario is about 8 to 9 years.

Detailed results for the Base Case scenario were placed in ranges along with the corresponding frequency of occurrence and cumulative probability. Results are presented in Figure 8.7-3 and Table 8.7-13. Corresponding lake water levels with time are shown in Figure 8.7-4 and Table 8.7-14. The median time to refill the mine pits is just over seven years, after which the lake proper will refill.

Figure 8.7-3 Kennady Lake Refilling Time Frequency and Cumulative Probability for Base Case Scenario



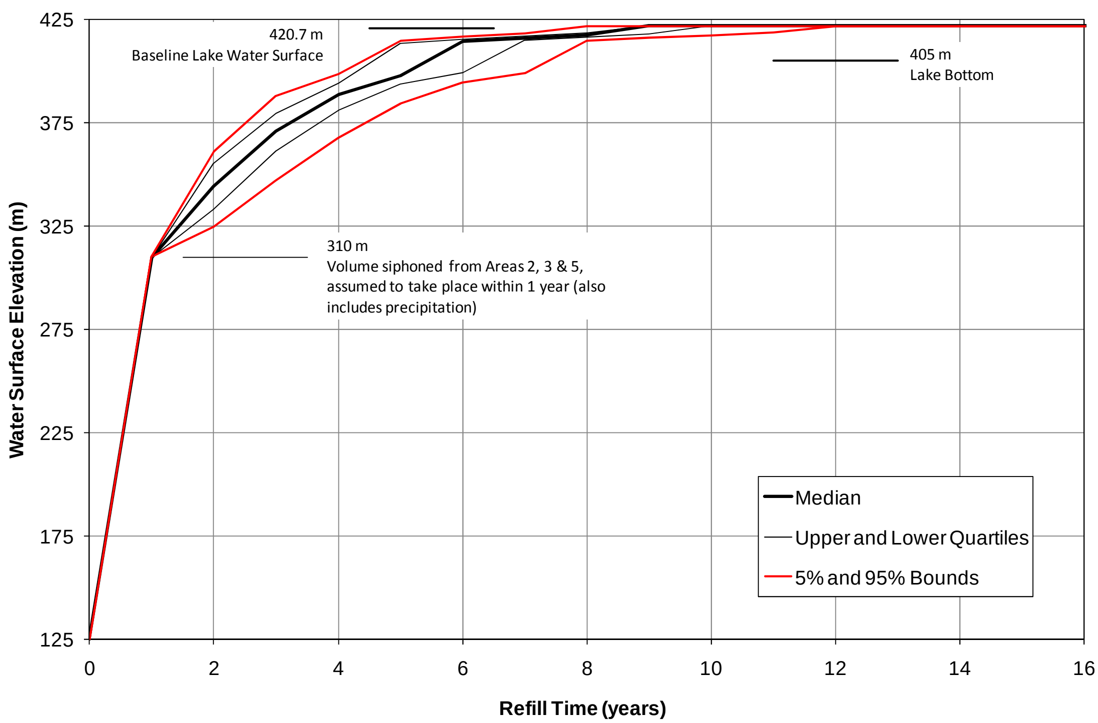
% = percent.

Table 8.7-13 Kennady Lake Refilling Time Frequency and Cumulative Probability for Base Case Scenario

Range (years)	Base Case Scenario		Range (years)	Base Case Scenario	
	Frequency (%)	Cumulative Probability (%)		Frequency (%)	Cumulative Probability (%)
5 to 6	0.00	0.00	10 to 11	29.00	79.56
6 to 7	0.00	0.00	11 to 12	14.68	94.24
7 to 8	1.40	1.40	12 to 13	5.00	99.24
8 to 9	16.92	18.32	13 to 14	0.76	100.00
9 to 10	32.24	50.56	14 to 15	0.00	100.00

% = percent.

Figure 8.7-4 Kennady Lake Water Levels with Time during Refilling – Base Case



m = metre.

Table 8.7-14 Kennady Lake Water Levels with Time during Refilling – Base Case, Median Conditions

Lake Depth (m)	Water Level (m)	Refilling Time (Years)
0	405.00	5.4
5	410.00	5.7
10	415.00	6.5
15	420.00	8.6
15.7	420.70	9.0

m = metre.

Areas of potential erosion during Kennady Lake refilling include direct discharge points and areas of unprotected sediment that are subject to wave action as the lake water level rises. The outfall of the pipeline in Area 3 from Lake N11 will be armoured to prevent local erosion, as will potentially erodible flow paths to lower elevations in the dewatered lake-bed and the Tuzo and Hearne mine pits. No water will be released downstream into Area 8 until the water level is equal to the water level in the upstream basins (about 420.7 m) and water quality in Area 7 meets specific water quality criteria. At that time, the shoreline will be at its naturally armoured baseline location and suspended sediment from prior wave action will have settled from the water column.

A summary of effects on flows, water levels, and channel/bank stability is provided below:

- Effects on flows:
  - During closure, all flow from Kennady Lake Areas 3, 4, 5, 6 and 7 tributary watersheds will contribute to lake refilling. Diversion of water from Lake N11 to Kennady Lake during refilling will reduce the median refilling time from 17 years to approximately 8 or 9 years.
- Effects on water levels:
  - Water levels in Kennady Lake will rise during refilling as a function of the cumulative inflow less lake evaporation.
- Effects on channel/bank stability:
  - The diversion pipeline outfall will be armoured to prevent erosion. No water will be released downstream from Kennady Lake Areas 3, 4, 5, 6 and 7 into Area 8 until the upstream water level is equal to that in Area 8 (and water quality in Area 7 meets specific water quality criteria). Water levels in the upstream Areas will not exceed the naturally armoured shoreline elevation. Therefore, no effects on channel or bank stability are anticipated.

8.7.4.2 Effect of Diversion on Flows, Water Levels and Channel/Bank Stability in Area 8

8.7.4.2.1 Activity Description

Refilling activities are described in detail in Section 8.7.4.1.1. During refilling, hydrological conditions at Area 8 will be similar to those during Operations. The only difference will be that potable water demand will likely be considerably reduced, but this will not have a significant effect on the water balance for the watershed.

8.7.4.2.2 Residual Effects

Discharges and water levels and associated residual effects during closure will be identical to those presented for operations in Section 8.7.3.2.2.

8.7.4.3 Effects of Temporary Dyke Removal to Flows, Water Levels and Channel/Bank Stability in Kennady Lake

8.7.4.3.1 Activity Description

During Closure, the temporary dykes involved in diversions of Lakes B1, D2/D3 and E1 to the N watershed will be removed to restore drainage of the upstream watersheds to Kennady Lake. Lake water levels will be drawn down to baseline levels prior to removal of the dykes. Lake outlets will be reconstructed to restore the baseline lake water level regime.

8.7.4.3.2 Residual Effects

Lake drawdown activities will require the transfer of approximately 1,400,000 m^3 of water from Lake D2/D3 (equal to approximately twice the natural annual water yield) and 110,000 m^3 of water from Lake E1 (equal to about half of the natural annual water yield) to Kennady Lake. This drawdown will be accomplished by pumping and/or siphoning flow over the dykes at the existing lake outlets. Flows in the natural outlet channels will be limited to the 2-year flood discharge, and dewatering could be accomplished in one year by maintaining this flow for an extended duration. Piping may be extended to discharge at armoured aprons on the shore of Kennady Lake if more rapid drawdown over a shorter duration is desired.

Lake B1 will not need to be drawn down, but the operational diversion will be decommissioned by constructing a permanent earthfill plug. Other operational diversions will be above the range of restored water levels and will not need to be blocked.

Temporary dykes at the natural lake outlets will be breached and the outlets restored to provide non-erodible control sections that restore the baseline water level and flow regimes of Lakes B1, D2, D3 and E1.

Baseline shorelines will be restored and it is expected that they will remain stable. Baseline water level and flow regimes in the lake outlet channels are expected to result in stable channels with natural rates of erosion. Shorelines will be monitored during and after the drawdown period for evidence of erosion or altered shoreline instability, including TSS monitoring in lakes. Mitigation in the form of armouring to prevent progressive erosion will be provided if required.

A summary of effects on flows, water levels, and channel/bank stability is provided below:

- Effects on flows:
  - Elevated flow rates during the drawdown of Lakes D2, D3 and E1 will be managed to ensure that flows do not exceed the baseline 2-year flood discharge.
  - During closure, natural flow regimes will be established in the outlet channels of Lakes B1, D2, D3 and E1.
- Effects on water levels:
  - The baseline lake water level regime in Lakes D2, D3 and E1 will be restored.
  - The baseline lake water level regime in Lake B1, maintained through construction and operations, will be maintained.
- Effects on channel/bank stability:
  - Drawdown flows will be managed to prevent erosion and instability in lake outlet channels.
  - Restoration of baseline lake outlet channel regimes will preserve channel stability with natural rates of erosion;
  - Restored baseline lake shorelines are expected to remain stable.

8.7.4.4 Long-term Effects of Mine Development on Hydrology of Kennady Lake

8.7.4.4.1 Activity Description

After Closure, the connection between Areas 3 to 7 and Area 8 of Kennady Lake will be restored, allowing unregulated downstream flow. Some changes to the land and water surfaces in the Kennady Lake watershed will remain, resulting in permanent reductions in the upstream watershed area and the proportion of lake area in the watershed.

8.7.4.4.2 Residual Effects

Changes to the Kennady Lake watershed will have a negligible effect on the post-closure (after refilling of Kennady Lake and removal of Dyke A) hydrological regime in the closure phase of the Project. Dyke A will be removed and all operational diversions within the watershed will be removed. Residual changes to the watershed will include:

- A net decrease in the total watershed area of Kennady Lake (from 32.46 km^2 to 31.62 km^2), due to the permanent diversion of the Lake A3 watershed to the adjacent N watershed.
- A net increase in the total land area (from 21.17 km^2 to 21.92 km^2) in the Kennady Lake watershed, due to the infilling of portions of Kennady Lake and some tributary lakes, partially offset by losses of land due to pit development.
- A net decrease in the total water surface area of Kennady Lake tributaries (from 3.14 km^2 to 2.51 km^2), due to the permanent diversion of Lake A3 to the adjacent N watershed, and infilling of Lakes A1 and A2, and some smaller tributary lakes by mine rock piles, the Coarse PK Pile and the Fine PKC facility. This will slightly increase the water yield of the Kennady Lake watershed, due to decreased lake evaporation.
- A net decrease in the water surface area of Kennady Lake (from 8.15 km^2 to 7.19 km^2), because the infill by the Fine PKC Facility, the Coarse PK Pile and the South Mine Rock and the West Mine Rock Piles will be greater than the removal of land area during excavation of the 5034, Tuzo and Hearne mine pits. This will change the area-elevation-storage relationship of Kennady Lake and cause less attenuation of flood flows.

A summary of changes to the land and lake areas within the Kennady Lake watershed is shown in Table 8.7-15.

Table 8.7-15 Post-closure Changes to Kennady Lake Watershed Land and Lake Areas

Area Description	Total Watershed (km^2)	Total Land (km^2)	Total Lake (km^2)	Kennady Lake (km^2)	Tributary Lake (km^2)	Lake Proportion (%)
Baseline Kennady Lake Watershed	**32.463**	**21.170**	**11.293**	**8.149**	**3.144**	**34.8%**
Diverted A3 Watershed	-0.839	-0.597	-0.241	-	-0.241	-
Kennady Lake less Lake A3 Watershed	**31.624**	**20.573**	**11.052**	**8.149**	**2.903**	**34.9%**
Infill - Mine Rock Covered Fine / Coarse PK	-	0.955	-0.955	-0.584	-0.371	-
Infill - Mine Rock Covered Coarse PK	-	0.016	-0.016	-0.006	-0.009	-
Infill - West Mine Rock Pile	-	0.348	-0.348	-0.339	-0.009	-
Infill - South Mine Rock Pile	-	0.506	-0.506	-0.506	-	-
Land Cut - 5034 Pit and Benches	-	-0.266	0.266	0.266	-	-
Land Cut - Tuzo Pit and Benches	-	-0.173	0.173	0.173	-	-
Land Cut - Hearne	-	-0.037	0.037	0.037	-	-
Kennady Lake Post-Closure	**31.624**	**21.922**	**9.703**	**7.190**	**2.513**	**30.7%**
Change	-0.839	0.752	-1.590	-0.959	-0.631	-

km^2 = square kilometres; PKC = processed kimberlite containment; % = percent; “-“ = not applicable.

The reduced lake area will affect lake evaporation and evapotranspiration within the watershed and the annual outflow from Kennady Lake, while the increased land area will increase runoff to the lake. A water balance was completed using results from the baseline model simulation at the outlet of Area 8 (K5 Outlet). These calculations show that the mean annual water yield will increase by 8.9% at post-closure, from approximately 147 mm to 160 mm. Because the post-closure watershed area will be reduced by the permanent diversion of the Lake A3 watershed, the increase in mean annual discharge from Kennady Lake will increase by only 6.1%, from 4,760 cubic decametres (dam^3) to 5,050 dam^3.

Due to the post-closure decrease in Kennady Lake surface area by 11.8%, the runoff of a given quantity of water into the lake will result in a proportionally greater increase in lake water level. This would be offset somewhat by void spaces in the South and West Mine Rock piles, which will have a porosity of 23% and cover approximately 0.85 km^2. Changes to the Kennady Lake surface area will slightly increase post-closure flood peak discharges and water levels.

8.8 EFFECTS TO WATER QUALITY

The pathway analysis presented in Section 8.6 considered potential pathways for the Gahcho Kué Project (Project) activities to affect water quality in Kennady Lake and its watershed, including tributaries and small lakes. The implementation of environmental design features and mitigation into the Project eliminated potential pathways and reduced the number of potential effects that were carried forward to the detailed effect analysis. A summary of the valid pathways by which changes to water quality in Kennady Lake and the Kennady Lake watershed could occur during construction and operations is presented in Table 8.8-1.

Table 8.8-1 Effects to Water Quality in Kennady Lake and Streams and Smaller Lakes in the Kennady Lake Watershed – Construction and Operation

Project Component	Pathway	Effects Statement	Effects Addressed
Construction and mining activity during construction and operations	deposition of dust from fugitive dust sources may change to water quality and sediment quality	Effects of the deposition of dust and metals from air emissions to water quality and lake bed sediments in waterbodies within the Kennady Lake watershed	Section 8.8.3.1
	air emission and deposition of sulphur dioxide, nitrogen oxides, particulate matter, and total suspended particulates may change water and sediment quality	Effects of acidifying air emissions to waterbodies within the Kennady Lake watershed	Section 8.8.3.2

A summary of the valid pathways by which changes to water quality in Kennady Lake and its watershed, including tributaries and small lakes, could occur during closure is presented in Table 8.8-2.

Table 8.8-2 Valid Pathways for Effects to Water Quality in Kennady Lake and the Kennady Lake Watershed – Closure

Project Component	Pathway	Effects Statement	Effects Addressed
Refilling of Kennady Lake	release or generation of mercury, nutrients, or other substances into Areas 3 to 7 from flooded sediments and vegetation during refilling of Kennady Lake may change water quality	Effects of Project activities to water quality in Kennady Lake and Area 8 during and after refilling	Section 8.8.4.1
	release of saline water from the Tuzo Pit basin to surface waters of Kennady Lake may change water quality		
Breaching Dyke A to reconnect Kennady Lake with Area 8	reconnection of Areas 3 to 7 with Area 8 may change water quality in Area 8		
Mine rock and Coarse PK piles	seepage and runoff from the mine rock and Coarse PK piles may change water quality in Kennady Lake after refilling		
Fine PKC Facility	seepage through filter dyke from the Fine PKC Facility after refilling may change water quality in Kennady Lake		
Refilling of Kennady Lake	co-mingling of water in Tuzo Pit with water in Areas 3 to 7 during refilling may change water quality in Kennady Lake, and delay ecosystem recovery	Long-term effects of changes to pit water quality on the stability of meromictic conditions in the Tuzo Pit basin	Section 8.8.4.2

PK = processed kimberlite; PKC = processed kimberlite containment.

Sections 8.8.1 and 8.8.2 provide an overview of the methodology used to analyze the effects to water quality in the Kennady Lake and its watershed during construction and operation, and closure, respectively. The discussion of analysis results for construction and operations is provided in Section 8.8.3, and in Section 8.8.4 for closure.

8.8.1 Effects Analysis Methods – Construction and Operation

8.8.1.1 Deposition of Dust and Metals from Air Emissions to Water Quality and Lake Bed Sediments in Waterbodies within the Kennady Lake Watershed

8.8.1.1.1 Introduction

Windborne dust from Project facilities and exposed lake bed sediments, and air emissions from Project facilities may result in increased deposition of dust and associated metals in the surrounding area. The deposited dust may enter surface waters, particularly during spring freshet, and could result in increased concentrations of suspended sediments and associated metals in lake water.

This section evaluates potential changes in the concentrations of suspended sediments and metals from Project-related atmospheric deposition for lakes in the Kennady Lake watershed. Sections 8.8.1.1.2 and 8.8.1.1.3 describe the assessment approach and the study area, respectively. Section 8.8.1.1.4 summarizes the assessment methods. Section 8.8.3.1.1 provides the results of the analysis for baseline conditions, and during construction and operations.

8.8.1.1.2 Assessment Approach

A simple mass balance calculation was used to predict changes in total suspended solids (TSS) and metal concentrations in lake water from deposition on the lake surface and within the watershed, for selected lakes in the Kennady Lake watershed. Changes in TSS and metal concentrations were calculated based on total suspended particulate (TSP) deposition rate and individual metal deposition rates, respectively, as predicted by air quality dispersion modelling (Section 11.4 Subject of Note [SON]: Air Quality). The calculation was performed for baseline conditions and using maximum deposition rates during construction and operations. Predicted TSS concentrations are evaluated in Section 8.10 (Effects to Fish and Fish Habitat); predicted metal concentrations were compared to chronic water quality guidelines for the protection of aquatic life (CCME 1999) and background concentrations.

The approach used for this evaluation is highly conservative for the following reasons:

- It is based on air quality modelling, which incorporates conservative assumptions for emissions of dust and metals; in particular, modelling of dust emissions from roads did not account for reductions due to precipitation during summer or snow cover during winter (Section 11.4: Air Quality, Appendix 11.4.II).
- Predicted annual deposition rates were based on the maximum of the daily road dust emissions during summer and winter.
- No retention of particulates or metals was assumed in lake catchment areas.
- Settling of suspended sediments in lakes was not incorporated.
- Geochemistry data used to estimate metal concentrations in dust included a large proportion of concentrations below the analytical detection limit for cadmium, mercury, selenium, and silver.

Concentrations of these metals were set at the detection limit for air quality and deposition modelling.

As a result of these factors, predicted changes in TSS and metal concentrations in local lakes are considered to be conservative estimates of the maximum potential changes that could occur during construction and operations.

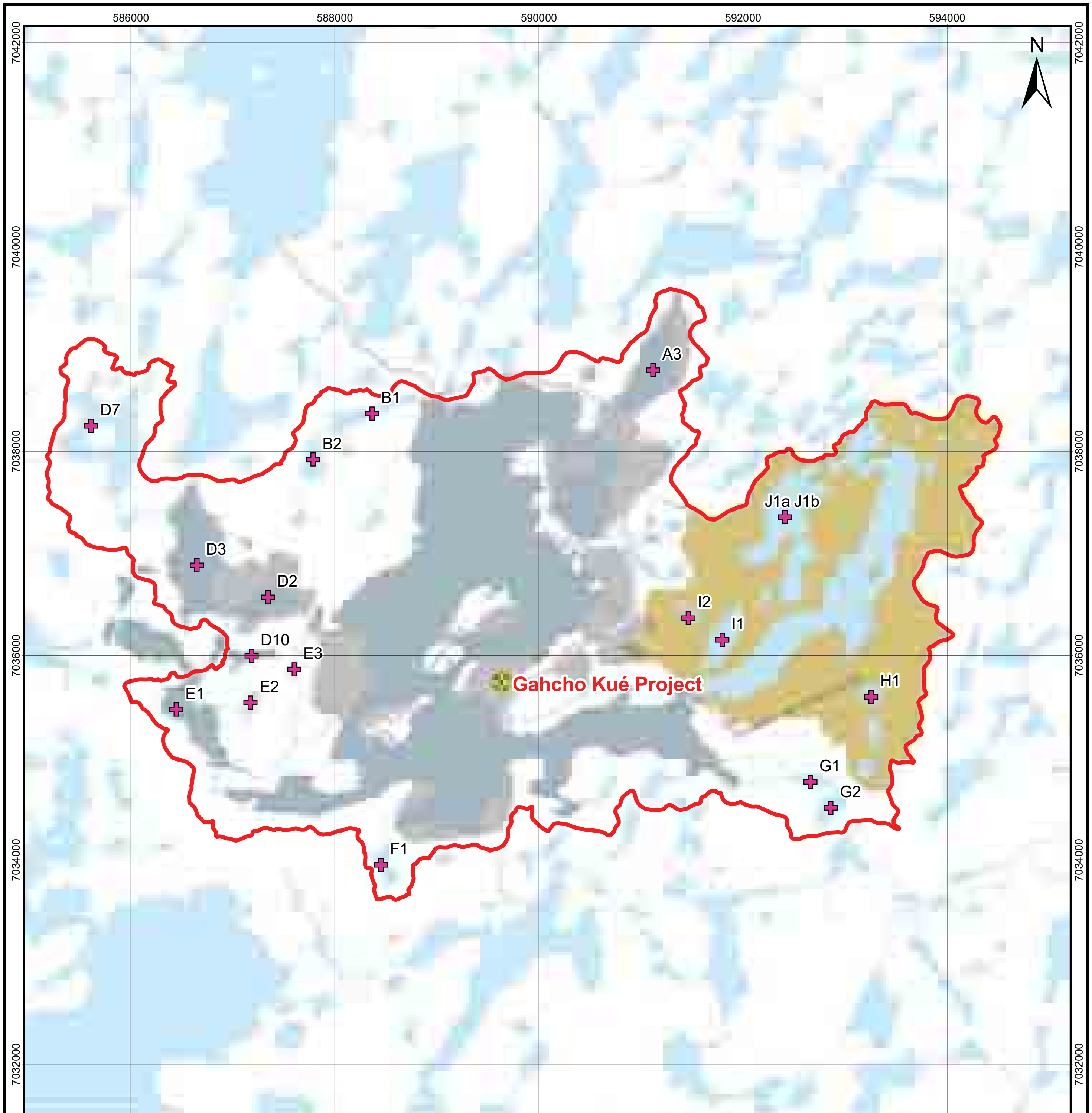
8.8.1.1.3 Study Area

The effects of atmospheric deposition of dust and metals were evaluated for 19 lakes within the Kennady Lake watershed (Figure 8.8-1). These lakes were selected on the basis of available water quality data and position relative to the Project footprint. Lakes that had available data and were located outside the Project footprint were included in the analysis. Lakes within the Project footprint were included if they were expected to remain largely undisturbed during construction and operations, and were not surrounded by Project infrastructure. Lakes excluded from the analysis are expected to be lost or modified during operations.

8.8.1.1.4 Assessment Methods

Modelled Parameters

Parameters included in the analysis and respective water quality guidelines are shown in Table 8.8-3. Parameters included a suite of metals and TSS, selected based on availability of chemistry data for particulate materials expected to contribute to dust released from roads and Project facilities.



LEGEND

- Gahcho Kué Project
- Assessed Lake
- Project Footprint
- Watercourse
- Waterbody

Watershed Boundary

- Kennady Lake Watershed

Subwatershed Boundary

- Subwatershed Ke

NOTES

Base data source: National Topographic Base Data (NTDB) 1:50,000

GAHCHO KUÉ PROJECT

Lakes in the Kennady Lake Watershed Assessed for Annual Deposition of Dust and Metals

PROJECTION: UTM Zone 12	DATUM: NAD83
Scale: 1:55,000 (1,000 500 0 1,000 Metres)	
FILE No: KLOI-08-003-GIS	DATE: December 16, 2010
JOB NO: 09-1365-1004	REVISION NO: 1
OFFICE: GOLD-CAL	DRAWN: SK
CHECK: JF	

Figure 8.8-1

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Table 8.8-3 Parameters Used to Evaluate Changes from Atmospheric Deposition of Dust and Metals in the Kennady Lake Watershed, and Water Quality Guidelines

Parameter	Chronic Aquatic Life Guideline[(a)] (mg/L)
Aluminum	0.1
Antimony	-
Arsenic	0.005
Barium	-
Beryllium	-
Boron	1.5
Cadmium	0.000039
Chromium	0.001
Cobalt	-
Copper	0.002
Iron	0.3
Lead	0.002
Manganese	-
Mercury	0.000026
Molybdenum	0.73
Nickel	0.065
Selenium	0.001
Silver	0.0001
Strontium	0.049
Uranium	-
Vanadium	-
Zinc	0.03
Total suspended solids	-

Source: CCME 1999.

mg/L = milligrams per litre; - = no data.

Mass Balance Calculation

Sources of metals and solids loading to lakes from atmospheric deposition are as follows:

- direct deposition on the lake surface;
- deposition to impervious surfaces within the watershed and subsequent runoff;
- deposition to pervious surfaces within the watershed followed by soil-water partitioning and subsequent runoff; and
- soil erosion and subsequent runoff from pervious surfaces.

A simple mass balance calculation was used to predict changes in TSS and metal concentrations for the selected lakes in the Kennady Lake watershed under baseline conditions, and during construction and operations. The calculation was based on the conservative assumption that the watershed consisted only of impervious surfaces and therefore all deposited material entered the lake. As noted above, this represents an upper-bound prediction, corresponding to the maximum potential change in concentrations of metals and TSS in lake water.

Hydrology and Lake Morphometry Data

Lake morphometry data and hydrology data are provided in Table 8.8-4. Mean annual water yield for lakes within the Kennady Lake watershed was calculated using the water balance model described in the Climate and Hydrology Baseline (Annex H).

Table 8.8-4 Hydrology and Morphometry Data for Lakes Included in the Evaluation of Atmospheric Deposition of Dust and Metals

Lake ID[a]	Site Name/ Original Identifier	Easting[b]	Northing[b]	Gross Catchment Area (km^2)	Lake Catchment Area (km^2)	Annual Water Yield (mm/y)	Net Annual Inflow (m^3/s)
30	Area 8	589341	7037350	7.56	4.33	143	0.0343
3	A3	591122	7038798	0.83	0.83	159	0.0042
5	B1	588368	7038371	1.27	0.17	195	0.0078
6	B2	587791	7037922	0.81	0.09	197	0.0051
11	D2	587349	7036574	4.15	0.95	169	0.0222
12	D3	586649	7036886	2.96	1.68	160	0.0150
13	D7	585613	7038252	1.41	1.41	157	0.0070
10	D10	587186	7036000	0.19	0.19	170	0.0010
14	E1	586448	7035474	1.23	0.23	182	0.0071
15	E2	587176	7035542	0.43	0.03	208	0.0028
16	E3	587605	7035867	0.04	0.01	167	0.0002
17	F1	588454	7033953	0.27	0.04	189	0.0016
18	G1	592663	7034766	0.66	0.09	195	0.0041
19	G2	592862	7034512	0.35	0.06	186	0.0021
20	H1	593258	7035599	0.78	0.08	196	0.0048
21	I1	591801	7036158	0.73	0.53	179	0.0041
22	I2	591468	7036370	0.25	0.02	206	0.0016
23	J1a	592415	7037357	1.65	0.53	161	0.0084
24	J1b	592415	7037357	1.23	1.23	155	0.0060

[a] Identifier used on map showing waterbody locations (Figure 8.8-1).

[b] Universal Transverse Mercator (UTM) co-ordinates, north American datum (NAD83), Zone 12.

km^2 = square kilometre; mm/y = millimetres per year; m^3/s = cubic metres per second.

Air Modelling

Change in metal deposition was estimated from air dispersion modelling for the Baseline and Application cases described in the Subject of Note: Air Quality (Section 11.4). The modelling results represent the highest predicted emissions near each lake and are therefore considered to be highly conservative. Total change in deposition for each parameter was estimated as a sum of both wet and dry deposition.

The modelled results do not include background emissions and represent only the change in deposition related to the Project. Emissions from other developments included only those from the De Beers Snap Lake Mine, because all other sources of emissions are located too far from the Project.

Emissions of metals and dust were modelled based on erosion sources (i.e. fugitive dust from lake beds) and Project-related industrial sources (i.e., power generators and vehicle traffic). A full list of emission sources included in the model is provided in the Air Quality SON (Section 11.4).

Data Sources

Background concentrations of metals and TSS were estimated from water quality data collected in the Kennady Lake watershed between 1995 and 2005 by various studies, and additional baseline water quality sampling in the Local Study Area by Golder in 2010 (Annex I, Addendum II, 2010 Additional Water Quality Information) (Table 8.8-5).

Available metal concentration data for each lake were pooled to calculate summary statistics for background concentrations. Data for which the detection limit was above the guideline were not included. Data below the detection limit were replaced with half the detection limit.

Table 8.8-5 Water Quality Studies Used to Characterize Background Metal Concentrations in the Kennady Lake Watershed (1995 to 2010)

Report Author(s)	Year Published	Report Title
Jacques Whitford Environment Ltd.	1998	Water Quality Assessment of Kennady Lake, 1998 Final Report. Project No. BCV50016 Submitted to Monopros Ltd., Yellowknife, NWT (Jacques Whitford 1998)
Jacques Whitford Environment Ltd.	1999	Results of Water Sampling Program For Kennady Lake, July 1999 Survey. Project No. 50091. Submitted to Monopros Ltd., Yellowknife, NWT (Jacques Whitford 1999a)
Jacques Whitford Environment Ltd.	2002	Baseline Limnology Program (2001), Gahcho Kué (Kennady Lake). Project No. ABC50254. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (Jacques Whitford 2002a)
Jacques Whitford Environment Ltd.	2002	Data Compilation (1995-2001) and Trends Analysis Gahcho Kué (Kennady Lake). Project No. ABC50310. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (Jacques Whitford 2002b)
Jacques Whitford Environment Ltd.	2003	Gahcho Kué (Kennady Lake) Limnological Survey of Potentially Affected Bodies of Water (2002). Project No. NTY71008. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (Jacques Whitford 2003a)
Jacques Whitford Environment Ltd.	2003	Baseline Limnology Program (2002), Gahcho Kué (Kennady Lake). Project No. NTY71008. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (Jacques Whitford 2003b)
Jacques Whitford Environment Ltd.	2004	Baseline Limnology Program (2003), Gahcho Kué (Kennady Lake). Project No. NTY71037. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (Jacques Whitford 2004)
Golder Associates Ltd.	2010	Annex I, Addendum II, 2010 Additional Water Quality Information
AMEC Earth & Environmental	n/a	Gahcho Kué Surface Water Quality Field Program (Unpublished Data) (AMEC 2004a)
AMEC Earth & Environmental	n/a	Gahcho Kué Surface Water Quality Field Program (Unpublished Data) (AMEC 2005a)

n/a = not applicable (not published).

8.8.1.2 Acidifying Air Emissions to Waterbodies within the Kennady Lake Watershed

8.8.1.2.1 Introduction

Mining activities have the potential to affect aquatic ecosystems through the release of air emissions that result in increased deposition rates of sulphate (SO_4^{2-}) and nitrate (NO_3^-). Deposition of SO_4^{2-} and NO_3^- can lead to a reduction in pH in acid-sensitive lakes, which in turn might alter other aspects of water chemistry (e.g., the solubility of aluminum), ultimately resulting in adverse effects on aquatic life.

This section evaluates the potential for acidification of local surface waters from Project-related air emissions. Sections 8.8.1.2.2 and 8.8.1.2.3 summarize the assessment approach and study area, respectively. Section 8.8.1.2.4 summarizes the assessment methods. Section 8.8.3.2.1 provides the results of the analysis for baseline conditions, and peak emissions during construction and operations.

8.8.1.2.2 Assessment Approach

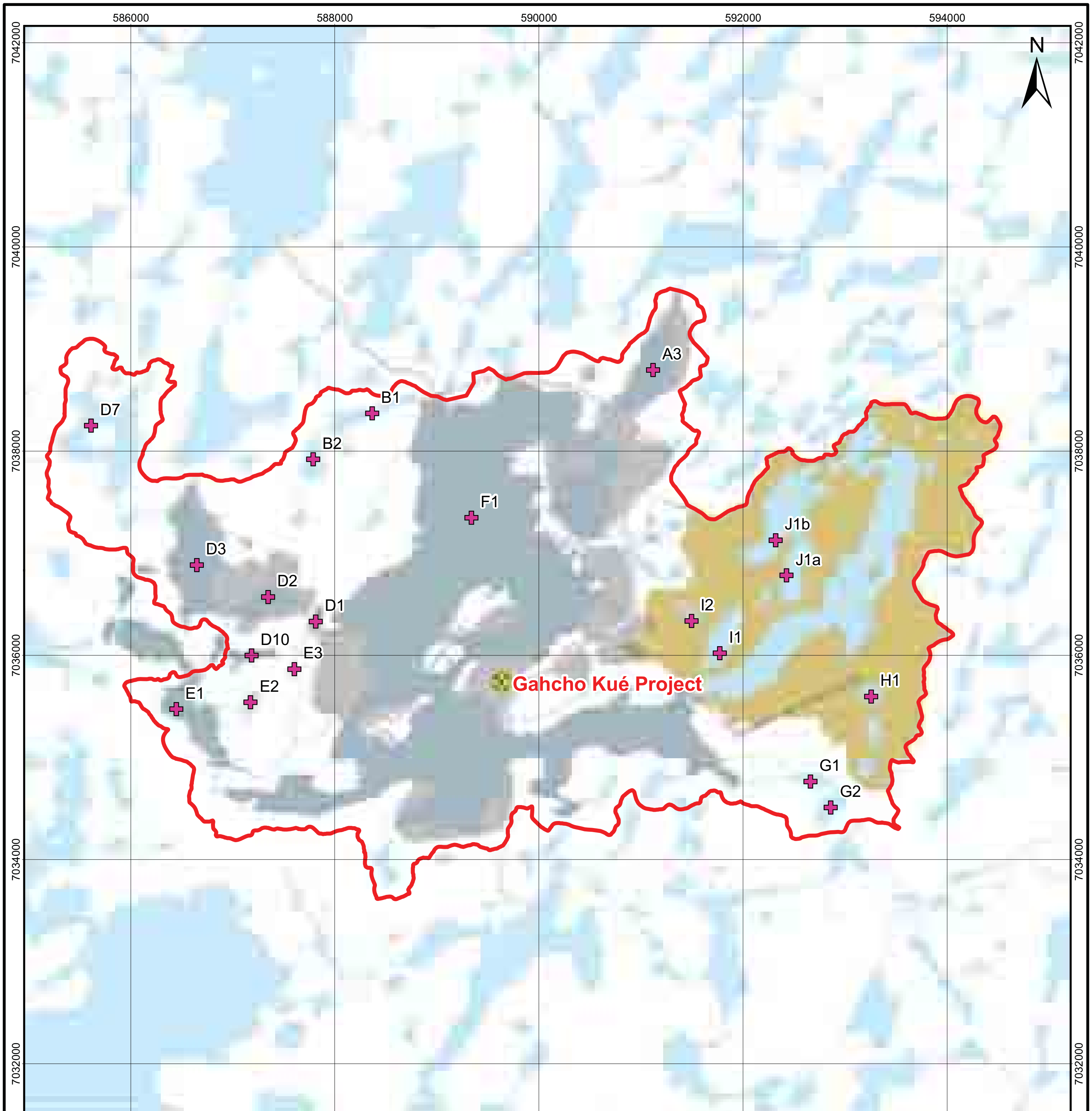
The effects of Project-related SO_4^{2-} and NO_3^- deposition on nearby surface waters were evaluated by comparing modelled acid deposition rates to lake-specific critical loads. Acid deposition was expressed the Potential Acid Input (PAI). The critical load is an estimate of the amount of acidifying input above which a change in pH corresponding to adverse effects to aquatic life may occur. A PAI value above the critical load was considered an indication that a lake's buffering capacity may be exceeded, with a subsequent drop in pH below a specified threshold value.

PAI is usually calculated as the sum of SO_4^{2-} and NO_3^- deposition minus base cation deposition, as estimated by air dispersion modelling. This calculation includes deposition from all sources and is therefore referred to as the gross PAI. The gross PAI is commonly used to evaluate the effects of acid deposition on terrestrial ecosystems. A more refined estimate of the PAI was used in this assessment to evaluate aquatic effects, by incorporating retention of a portion of deposited nitrogen by the terrestrial ecosystem. The retained portion does not contribute to surface water acidification. The resulting PAI is referred to as the net PAI.

The net PAI does not incorporate the mitigating effect of base cation deposition. In the Steady-State Water Chemistry (SSWC) model (Henriksen and Posch 2001) used to estimate critical loads, the base cation component of the critical load is assumed to represent the current base cation flux to the waterbody from all sources, including base cation deposition from the atmosphere. Therefore, accounting for the neutralizing effect of base cation deposition, as done when using the gross PAI, would result in double-counting of base cations.

8.8.1.2.3 Study Area

The effects of acidifying emissions were assessed for 19 lakes in the Kennady Lake watershed (Figure 8.8-2). Although water quality data are available for a number of additional small lakes in the study area, they were not included in the evaluation because they are located within the Project footprint and will either be lost or modified during operations.



LEGEND

- Gahcho Kué Project
- Assessed Lake
- Project Footprint
- Watercourse
- Waterbody

Watershed Boundary

- Kennady Lake Watershed

Subwatershed Boundary

- Subwatershed Ke

NOTES

Base data source: National Topographic Base Data (NTDB) 1:50,000

GAHCHO KUÉ PROJECT

Lakes in the Kennady Lake Watershed Surveyed for Effects of Acid Deposition

PROJECTION: UTM Zone 12	DATUM: NAD83	
Scale: 1:55,000 (1,000 500 0 1,000 Metres)		
FILE No: KLOI-08-002-GIS		DATE: December 16, 2010
JOB NO: 09-1365-1004	REVISION NO: 1	
OFFICE: GOLD-CAL	DRAWN: SK	CHECK: JF

Figure 8.8-2

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8.8.1.2.4 Assessment Methods

Indicators of Acid Sensitivity

The sensitivity of surface waters to acid deposition can be evaluated based on alkalinity or acid neutralizing capacity (ANC). These terms are now used interchangeably and refer to the capacity of water to neutralize strong inorganic acids (Wetzel 2001). The term “alkalinity” is typically used when acid neutralizing capacity is estimated using titration, whereas “ANC” is usually used when it is calculated. Alkalinity is frequently expressed in units of mg/L as calcium carbonate ($CaCO_3$), assuming that alkalinity results only from calcium carbonate and bicarbonate, which may or may not be applicable to a given lake. Therefore, the clearest expression of alkalinity is in terms of microequivalents per litre (µeq/L) or milliequivalents per litre (meq/L). For comparative purposes, alkalinity of 1 mg/L as $CaCO_3$ = 20 µeq/L, or 50 mg/L as $CaCO_3$ = 1 meq/L.

Saffran and Trew (1996) presented a scale of lake sensitivity to acidification based on alkalinity/ANC (Table 8.8-6).

Table 8.8-6 Acid Sensitivity Scale for Lakes Based on Alkalinity/ANC

Acid Sensitivity	Alkalinity/ANC	
	(mg/L as $CaCO_3$)	(µeq/L)
high	0 to 10	0 to 200
moderate	>10 to 20	>200 to 400
low	>20 to 40	>400 to 800
least	>40	>800

Source: Saffran and Trew (1996).

mg/L = milligrams per litre; $CaCO_3$ = calcium carbonate; µeq/L = microequivalents per litre;
> = greater than.

Acid sensitive lakes are situated in areas where soils have little or no capacity to reduce the acidity of the atmospheric deposition. Soil chemistry (i.e., particle size, texture, soil pH, cation exchange capacity), soil depth, drainage, vegetation cover and type, bedrock geology and topographic relief are all factors that determine the sensitivity of the drainage basin to acid deposition (Lucas and Cowell 1984; Holowaychuk and Fessenden 1987; Sullivan 2000). Surface waters that are sensitive to acidification usually have the following characteristics, as summarized by Sullivan (2000):

- They are dilute, with low concentrations of major ions (i.e., specific conductance is less than 25 microSiemens per centimetre (µS/cm).
- Alkalinity/ANC are low (i.e., less than 10 mg/L as $CaCO_3$ or less than 200 µeq/L).

- Base cation concentrations are low (i.e., in relatively pristine areas, the combined concentration of calcium, magnesium, potassium and sodium in sensitive waters is generally less than 50 to 100 µeq/L).
- Organic acid concentrations are low (i.e., dissolved organic carbon [DOC] concentration is generally less than 3 to 5 mg/L).
- The pH is low (i.e., less than 6).
- Physical characteristics are as follows:
  - elevation is moderate to high;
  - lakes are located in areas of high relief;
  - lakes are subject to severe, short-term changes in hydrology;
  - there is minimal contact between drainage waters and soils or geologic material that may contribute weathering products to solution; and
  - sensitive lakes may have small drainage basins that derive much of their hydrologic input as direct precipitation to the lake surface.

Calculation of Critical Loads

General Application

The assessment approach was based on the application of critical loads according to the SSWC model. Critical loads of acidity can be used to evaluate the likelihood of lake acidification (Henriksen et al. 1992; Kämäri et al. 1992a, 1992b, 1992c; Posch et al. 1992; Rihm 1995; RMCC 1990; WHO 1994). The critical load has been defined in general terms as “a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge” (Nilsson and Grennfelt 1988). For evaluating the effects of acid deposition, the critical load can be thought of as an estimate of the amount of acidic deposition below which no significant harmful effects occur to a specified component of a lake’s ecosystem (e.g., a valued fish species) (Sullivan 2000).

The calculation of critical loads is based on a dose-response relationship between ANC and an aquatic organism considered important to the ecosystem. Many studies have shown that the effects of acidification on aquatic organisms are better correlated with ANC than with pH (as reviewed by Sullivan 2000) because pH measurements are sensitive to carbon dioxide (CO_2) effects (Stumm and Morgan 1981).

The following formula was used to calculate the critical load for each lake included in the analysis (Henriksen et al. 1992):

$$CL = ([BC^*]_0 - [ANC]_{lim}) \times Q$$

where:

CL = critical load (keq/ha/y);

$[BC^*]_0$ = pre-industrial non-marine base cation concentration (keq/L), assumed to correspond to the current values in lakes near the Project, because they are considered unaffected by acidification at the present;

$[ANC]_{lim}$ = critical value for acid neutralizing capacity (20 µeq/L = 2×10^{-8} keq/L) based on observed effects to brown trout (*Salmo trutta*), a European species; and

Q = mean annual runoff to the lake (L/ha/y).

Data used to calculate critical loads and resulting critical loads of acidity are provided in Table 8.8-7. Additional details related to the input data for calculating critical loads are provided in subsequent sections.

Table 8.8-7 Critical Loads of Acidity for the 19 Local Lakes Included in the Assessment

Lake ID[(a)]	Site Name/ Original Identifier	Easting[(b)]	Northing[(b)]	Distance[(c)] (km)	Direction[(c)]	Base Cations (µeq/L)	Annual Water Yield (mm/y)	Critical Load (keq/ha/y)
30	Area 8	589341	7037350	1	ESE	175	143	0.221
3	A3	591122	7038798	3	N	150	159	0.206
5	B1	588368	7038371	3	NW	130	195	0.215
6	B2	587791	7037922	3	WNW	262	197	0.477
11	D2	587349	7036574	3	W	131	169	0.188
12	D3	586649	7036886	4	W	89	160	0.110
13	D7	585613	7038252	6	WNW	185	157	0.259
10	D10	587186	7036000	4	W	191	170	0.291
14	E1	586448	7035474	4	W	168	182	0.269
15	E2	587176	7035542	4	W	478	208	0.952
16	E3	587605	7035867	3	W	251	167	0.386
17	F1	589341	7037350	2	NW	118	189	0.185
18	G1	592663	7034766	2	SE	242	195	0.434
19	G2	592862	7034512	3	SE	136	186	0.216
20	H1	593258	7035599	3	ESE	156	196	0.267
21	I1	591775	7036022	1	E	159	179	0.248
22	I2	591497	7036337	1	ENE	273	206	0.522
23	J1a	592428	7036785	2	ENE	633	161	0.988
24	J1b	592322	7037130	2	ENE	67	155	0.073

(a) Identifier used on map showing lake location (Figure 8.8-2).

(b) Universal transverse Mercator (UTM) co-ordinates; north American datum (NAD83), Zone 12.

(c) Distance and direction relative to the Project.

km = kilometre; µeq/L = microequivalents per litre; mm/y = millimetres per year; keq/ha/y = kiloequivalents per hectare per year.

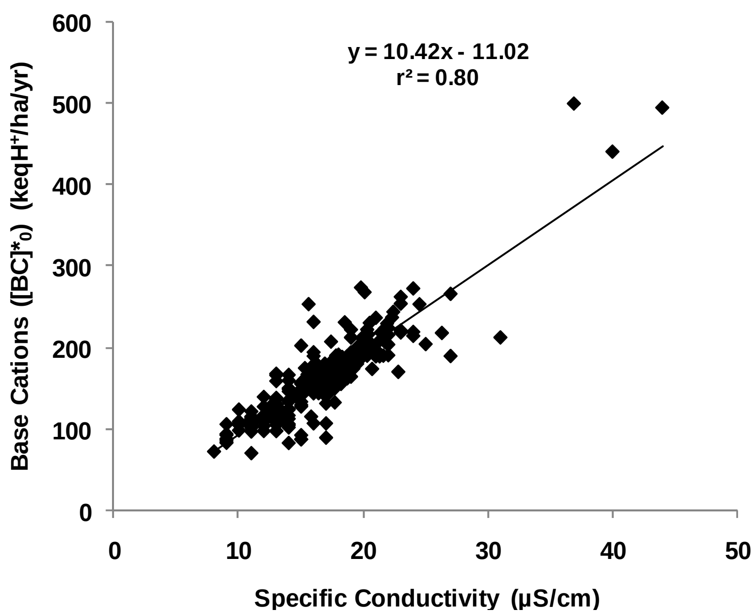
Base Cation Concentration

Henriksen and Posch (2001) and Henriksen et al. (2002) converted the present day base cation flux (i.e., the $[BC^*]_0$ term in the critical load equation) to a pre-acidification flux for European lakes and Ontario lakes, respectively. The procedure applied here assumed that the conditions before construction of the Project were representative of pre-industrial conditions.

The average concentration of each base cation was calculated for each lake based on available data shown in Table 8.8-8. This table also presents average concentrations of other indicators of acid sensitivity or modifying factors, such as pH, specific conductivity, total dissolved solids, alkalinity, dissolved organic carbon, colour, nitrate+nitrite, and sulphate.

Only field water quality measurements were available for three lakes in the Kennady Lake watershed (B2, G2, and H1). To allow estimating base cation concentrations in these lakes, a linear regression was run between specific conductivity and $[BC]^*_0$ using the data for all other lakes. The results of this analysis indicated a strong linear relationship between specific conductivity and $[BC]^*_0$ (r^2 = 0.80) (Figure 8.8-3). The regression equation was then used to estimate base cation concentrations for the three lakes with no base cation data.

Figure 8.8-3 Regression Analysis of Specific Conductivity vs. Base Cation Concentration



µS/cm = microSiemens per centimetre; $[BC]^*_0$ = base cation concentration; keq/ha/y = kiloequivalents per hectare per year.

Table 8.8-8 Summary of Water Chemistry Data for the 19 Local Lakes Included in the Assessment

Lake ID[(a)]	Site Name/ Original Identifier	Specific Conductivity (μS/cm)	TDS (mg/L)	DOC (mg/L)	Colour (TCU)	pH	Sulphate (mg/L)	Nitrate + Nitrite (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Alkalinity (mg/L as $CaCO_3$)	Alkalinity (μeq/L)	Critical Load (keq ha/y)	Acid Sensitivity[(b)]
30	Area 8	18	9	5	10	6.4	1.0	0.014	1.4	0.6	0.9	0.6	7	131	0.221	high
3	A3	18	24	4	8	6.4	1.1	0.002	1.1	0.4	1.2	0.4	15	308	0.206	moderate
5	B1	14	19	7	32	6.1	0.7	0.002	0.8	0.3	1.3	0.3	13	252	0.215	moderate
6	B2	26	-	-	-	6.5	-	-	-	-	-	-	-	-	0.477	-
11	D2	13	38	8	-	6.6	0.5	0.002	1.1	0.5	0.6	0.4	3	68	0.188	high
12	D3	9	20	6	15	6.0	0.4	0.002	0.7	0.3	0.5	0.3	6	128	0.110	high
13	D7	18	23	6	15	6.9	1.2	-	0.8	0.4	2.3	0.4	12	230	0.259	moderate
10	D10	18	20	8	23	6.6	0.7	0.003	1.3	0.5	1.6	0.5	12	237	0.291	moderate
14	E1	17	25	6	40	6.6	1.0	0.002	0.9	0.5	1.8	0.3	9	183	0.269	high
15	E2	40	71	28	150	6.9	2.3	0.003	3.4	1.6	3.4	1.1	10	197	0.952	high
16	E3	21	42	13	58	6.7	0.6	0.022	1.5	0.8	2.3	0.7	9	177	0.386	high
17	F1	13	20	6	-	6.7	0.5	0.002	0.9	0.5	0.5	0.4	4	74	0.185	high
18	G1	21	28	9	40	6.5	1.7	-	1.3	0.6	2.7	0.4	18	360	0.434	moderate
19	G2	14	-	-	-	9.4	-	-	-	-	-	-	-	-	0.216	-
20	H1	16	-	-	-	8.7	-	-	-	-	-	-	-	-	0.267	-
21	I1	17	21	5	18	6.2	1.1	-	0.8	0.4	1.7	0.4	15	291	0.248	moderate
22	I2	17	10	-	-	6.9	1.0	-	2.2	1.1	1.2	0.8	10	200	0.522	moderate
23	J1a	17	5	-	-	8.4	0.5	-	1.6	6.2	0.7	0.6	13	260	0.988	moderate
24	J1b	14	8	-	-	6.6	1.3	-	1.3	0.0	0.0	0.0	8	160	0.073	high

(a) Identifier used on map showing lake location (Figure 8.8-2).

(b) Acid sensitivity using categories as defined by Saffran and Trew (1996).

μS/cm = microSiemens per centimetre; mg/L = milligrams per litre; TCU = true colour unit; TDS = total dissolved solids; DOC = dissolved organic carbon; μeq/L = microequivalents per litre; keq/ha/y = kiloequivalents per hectare per year; “-“= no available data.

Verification of the ANC Threshold

The critical value for ANC (ANC_{lim}) is the value below which biological effects could occur. Based on the value used by Henriksen et al. (1992), an ANC_{lim} value of 20 µeq/L was used in this evaluation. To verify this value, an additional analysis was conducted using data for lakes in the Slave Geological Province, within which Kennady Lake is located.

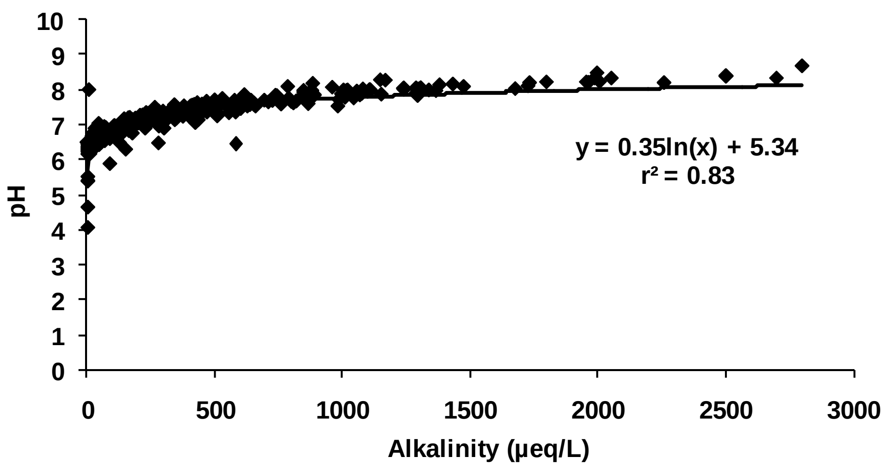
In the Henriksen model, ANC_{lim} was set to protect brown trout, the most common European salmonid, from toxic acidic episodes during the year. The ANC_{lim} was derived from water chemistry, critical load exceedances and fish population status data from 1000 Norwegian lakes (Henriksen et al. 1992; Lien et al. 1992). A value of 20 µeq/L was deemed most appropriate for Norwegian lakes and most Scandinavian countries have adopted this value (Henriksen et al. 1992). However, ANC_{lim} values have been set at 0, 20 and 50 µeq/L in various applications (e.g., Kämäri et al 1992c; Harriman et al. 1995). These values were intended to protect salmonid fisheries (Harriman et al. 1995), or correspond to the ANC where significant changes are expected to occur in a lake's diatom flora (Jenkins et al. 1997).

Brown trout is a European species that was introduced to North America, and as such, may not be an appropriate species for calculating critical loads outside Europe. In North America, there has not been a large-scale investigation of critical loads and ANC_{lim} values comparable to that done in Norway. One approach that has been used in North America involves relating ANC_{lim} to a pH effects threshold (WRS 2002). Numerous studies have shown that a pH of 6 is sufficient to maintain a healthy aquatic ecosystem, and protect fish and other aquatic organisms (based on reviews by RMCC 1990; Environment Canada 1997; Jeffries and Lam 1993; Sullivan 2000). This approach was also adopted in this assessment to verify the appropriateness of the chosen ANC_{lim} value.

To convert the pH threshold of 6 to an estimated ANC for the Kennady Lake watershed, the relationship between pH and ANC was analyzed using the results of a water quality survey (Puznicki 1996) of over 500 lakes in the Slave Geological Province. The Slave Geological Province includes the Kennady Lake watershed, as well as the Lockhart River and Hoarfrost River watersheds. A number of lakes outside these watersheds were also included in the analysis to incorporate a wider range of pH and alkalinity values (Puznicki 1996). Field measured alkalinity was used to estimate ANC. For this analysis, lakes with tea-stained, highly coloured water (>15 true colour units [TCU]) were omitted, as this colouration typically resulted from contact with humic or peaty materials and is generally indicative of elevated DOC concentration (Puznicki 1996).

Regression analysis showed that for lakes in the Slave Geological Province, a pH of 6 corresponds to an ANC value of about 7 µeq/L (Figure 8.8-4). This suggests that the ANC_{lim} value of 20 µeq/L is conservative, and is reasonably close to the level where pH may drop below a level where effects on aquatic biota would be expected to occur. The ANC_{lim} value of 20 µeq/L was also used in an assessment of nearby lakes for the Snap Lake Environmental Assessment Report (De Beers 2002).

Figure 8.8-4 Alkalinity versus pH for Lakes with Colour ≤15 TCU in the Slave Geological Province



Data source: Puznicki (1996).

TCU = true colour unit; µeq/L = microequivalents per litre.

Mean Annual Water Yield

The mean annual water yield (millimetres per year [mm/y]), which is required to calculate mean annual runoff (Q) to a lake, was calculated using baseline hydrologic data available for lakes in the Kennady Lake watershed. Values for lakes within the Kennady Lake watershed were calculated using the water balance model described in the climate section of the Climate and Hydrology Baseline (Annex H).

Acid Input Rates

Background Deposition Rate

A background deposition rate of 0.066 keq/ha/y was derived by combining dry deposition of 0.033 keq/ha/y from the Alberta Environment Regional Lagrangian Acid Deposition (AENV RELAD) model (0.020 keq/ha/y SO_4^{2-} and 0.013 keq/ha/y

NO_3^-) for the extreme northeast portion of Alberta and the wet deposition rate of 0.033 keq/ha/y based on Environment Canada's monitoring data at Snare Rapids, NWT (0.019 keq/ha/y SO_4^{2-} and 0.015 keq/ha/y NO_3^-) (Section 11.4 SON: Air Quality).

Potential Acid Input

The net annual PAI was derived by taking into account changes in the seasonal retention pattern of deposited substances. Since winter (under-ice) conditions effectively prevent direct acid deposition to lakes for about seven months of the year, SO_4^{2-} and NO_3^- deposited during winter accumulates on the snow and ice. During spring freshet, the melting of snow and ice releases the SO_4^{2-} and NO_3^- accumulated over the winter in the watershed into lake water. Plants may not assimilate the NO_3^- during this period because the ground is still frozen and the snowmelt may run overland rather than infiltrating. Thus, it is assumed that the entire NO_3^- deposition accumulated over the winter enters the lake water. Therefore, net annual PAI was calculated using gross PAI for the winter period.

Nitrogen Retention

During open water conditions, when the short growing season occurs, plants completely assimilate NO_3^- deposition up to 5 to15 kg/ha/y (Gordon et al. 2001). Therefore, net NO_3^- deposition above 5 kg/ha/y and all SO_4^{2-} deposition were assumed to enter receiving waterbodies during open water conditions. When the modelled annual deposition of NO_3^- was below the threshold of 5 kg/ha/y, only the SO_4^{2-} deposition was included in the calculation of the net PAI for open water conditions. When NO_3^- deposition was above the threshold, both SO_4^{2-} and the load of NO_3^- over the threshold were included in the calculation of net PAI.

Data Sources

Background water quality data in the Kennady Lake watershed was collected between 1995 and 2005 by various studies during both open water and ice-covered conditions (Table 8.8-9). Additional baseline water quality data were collected in Kennady Lake and several small lakes in the Local Study Area by Golder in 2010 (Annex I, Addendum II, 2010 Additional Water Quality Information) during open water and ice-covered seasons. Data from both seasons were used to evaluate acid sensitivity and calculate critical loads.

Table 8.8-9 Water Quality Studies in the Kennady Lake Watershed (1995 to 2010)

Report Author(s)	Publication Year	Report Title
Jacques Whitford Environment Ltd.	1999	Results of Water Sampling Program For Kennady Lake, July 1999 Survey. Project No. 50091. Submitted to Monopros Ltd., Yellowknife, NWT (Jacques Whitford 1999a)
Jacques Whitford Environment Ltd. and EBA Engineering Consultants Ltd. (EBA)	2001	Gahcho Kué (Kennady Lake) Environmental Baseline Investigations (2000). Project No. 0701-99-13487. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (Jacques Whitford and EBA 2001)
Jacques Whitford Environment Ltd.	2002	Baseline Limnology Program (2001), Gahcho Kué (Kennady Lake). Project No. ABC50254. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (Jacques Whitford 2002a)
Jacques Whitford Environment Ltd.	2002	Data Compilation (1995-2001) and Trends Analysis Gahcho Kué (Kennady Lake). Project No. ABC50310. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (Jacques Whitford 2002b)
Jacques Whitford Environment Ltd.	2003	Gahcho Kué (Kennady Lake) Limnological Survey of Potentially Affected Bodies of Water (2002). Project No. NTY71008. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (Jacques Whitford 2003a)
Jacques Whitford Environment Ltd.	2003	Baseline Limnology Program (2002), Gahcho Kué (Kennady Lake). Project No. NTY71008. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (Jacques Whitford 2003b)
Jacques Whitford Environment Ltd.	2004	Baseline Limnology Program (2003), Gahcho Kué (Kennady Lake). Project No. NTY71037. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (Jacques Whitford 2004)
Golder Associates Ltd.	2010	Annex I, Addendum II, 2010 Water Quality Baseline
AMEC Earth & Environmental	n/a	Unpublished water chemistry data collected in Kennady Lake and surrounding watersheds (AMEC 2004a).
AMEC Earth & Environmental	n/a	Unpublished Aquatic Resources Field Data Collected in Kennady Lake and Surrounding Watersheds (AMEC 2004b).
AMEC Earth & Environmental	n/a	Unpublished water chemistry data collected in Kennady Lake and surrounding watersheds (AMEC. 2005a)
AMEC Earth & Environmental	n/a	Unpublished Aquatic Resources Field Data Collected in Kennady Lake and Surrounding Watersheds (AMEC. 2005b)

n/a = not applicable (not published).

8.8.2 Effects Analysis Methods – Closure

8.8.2.1 Water Quality in Kennady Lake during and after Refilling

8.8.2.1.1 Kennady Lake Closure Water Quality Model

To facilitate mining of the kimberlite pipes, Kennady Lake will be dewatered and divided into separate basins during the construction and operations phases of the Project. The remaining lake will be closed-circuited, and will function as a Water Management Pond (WMP). At closure, the lake will be refilled by importing water from nearby Lake N11. Details regarding water management during all phases of the Project are included in Section 8.4.

The Kennady Lake water quality model was developed to predict concentrations in Kennady Lake during the construction, operations, and closure phases. The model, developed in GoldSim™, is detailed briefly below and described fully in Appendix 8.I.

In general, the water quality model is a flow and mass-balance model that was set up to account for all inputs and processes described in Section 8.4.3. The spatial modelling domain includes the portion of Kennady Lake (i.e., Areas 2 to 7) that is planned to be hydraulically isolated from the surrounding environment during mining operations. Within the closed-circuited areas of Kennady Lake, the lake is planned to be divided by dykes into five basins (i.e., Area 2, Areas 3 and 5, Area 4, Area 6 and Area 7) during the operations phase (Section 8.4.3). Each of these basins was treated as a distinct reservoir within the model.

Within each reservoir, volumes and concentrations were calculated on a monthly time step from Year -2, which corresponds to the start of construction, to Year 121 which is 100 years after the reconnection of the upper areas of Kennady Lake with Area 8 and downstream watershed (i.e., the post-closure period). Inflow volumes and concentrations were included as inputs to each reservoir to account for loadings from natural areas, disturbed areas, mine rock runoff, fine and coarse processed kimberlite runoff and groundwater discharge.

The model assumed complete mixing within each basin at each timestep while the dykes are operational. At closure, when the dykes are planned to be breached, the model reports fully mixed conditions in Areas 3 to 7. No chemical reactions or sinks were assumed to occur in the model, except where volumes of water are sequestered in mine rock pore space.

The water quality model predicted concentrations for a range of water quality parameters at the following key nodes, for specific Project phases:

- Areas 3 and 5 (WMP) during operations, because this water is discharged to Lake N11 (Section 9.8);
- Kennady Lake Areas 3 to 7, at the end of the closure period; and
- Kennady Lake Areas 3 to 7, 100 years into the post-closure period.

Model predictions are made on a monthly basis (e.g., lowest stream flows combined with highest effluent flows during construction) and are restricted to relatively average climate conditions (i.e., 1:2 year wet [median] conditions). Model predictions were based on average climate conditions for three reasons. First, as a lake-dominated system, water quality is less susceptible to inter-annual fluctuations in precipitation and temperature. Second, the majority of changes in water quality parameter concentration due to the Project are large in terms of relative change compared to baseline conditions (see Section 8.8.4.1), so natural variability would be a relatively small contributor to overall change. Finally, using mean conditions allows for a straightforward assessment of incremental changes due to the Project.

Modelled changes in water quality resulting from the Project are the difference between the measured median background concentrations and the modelled water quality at the key nodes. The model uses median background concentrations and conservative estimates of mass loadings from the Project to simulate changes in water quality. The model results are projections that are suitable for the assessment of effects; however, the model does not account for natural variability, and therefore, model results should not be viewed as predictions or forecasts of future conditions.

8.8.2.1.2 Data Sources

Background water quality data in the Kennady Lake watershed was collected between 1995 and 2010. The data were collected by various consultants during open water and under-ice conditions (see Section 8.3). For the purposes of the Kennady Lake water quality assessment, data collected from the sources presented in Table 8.8-10 were used.

Table 8.8-10 Water Quality Studies Used in the Assessment of Kennady Lake, 1995 to 2010

Report Author(s)	Publication Date	Report Title
Jacques Whitford Environment Ltd.	July 1998	Water Quality Assessment of Kennady Lake, 1998 Final Report. Project No. BCV50016. Submitted to Monopros Limited, Yellowknife, NWT (Jacques Whitford 1998)
Jacques Whitford Environment Ltd.	October 14, 1999	Results of Water Sampling Program for Kennady Lake July 1999 Survey. Project 50091. Submitted to Monopros Limited, Yellowknife, NWT (Jacques Whitford 1999a)
Jacques Whitford Environment Ltd.	1999	Trip Report #1 and Data Assessment for Kennady Lake Water Quality - 1999 Survey Program. Submitted to Monopros Limited, Yellowknife, NWT (Jacques Whitford 1999b)
EBA Engineering Consultants Ltd. (EBA) & Jacques Whitford Environment Ltd.	2001	Gahcho Kué (Kennady Lake) Environmental Baseline Investigations (2000) Submitted to De Beers Canada Exploration Ltd., Yellowknife, NWT (EBA and Jacques Whitford Environment Ltd. 2001)
Jacques Whitford Environment Ltd.	March 4, 2002	Baseline Limnology Program (2001) Gahcho Kué (Kennady Lake). Project No. ABC50254. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (Jacques Whitford 2002a)
Jacques Whitford Environment Ltd.	April 29, 2002	Data Compilation (1995-2001) and Trends Analysis Gahcho Kué (Kennady Lake). Project No. ABC50310. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (Jacques Whitford 2002b)
EBA Engineering Consultants Ltd. (EBA)	2002	Gahcho Kué Winter 2001 Water Quality Sampling Program, Gahcho Kué, NWT. Project No. 0701-98-13487.028. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (EBA 2002)
EBA Engineering Consultants Ltd. (EBA)	2003	Kennady Lake Winter 2002 Water Quality Sampling Programme Kennady Lake, NWT. Project # 0701- 98-13487.035. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (EBA 2003)
Jacques Whitford Environment Ltd.	June 4, 2003	Gahcho Kué (Kennady Lake) Limnological Survey of Potentially Affected Bodies of Water (2002). Project No. NTY71008. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (Jacques Whitford 2003a)
Jacques Whitford Environment Ltd.	June 4, 2003	Baseline Limnology Program (2002) Gahcho Kue (Kennady Lake). Project No. NTY71008. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (Jacques Whitford 2003b)
Jacques Whitford Environment Ltd.	January 20, 2004	Baseline Limnology Program (2003) Gahcho Kué (Kennady Lake). Project No. NTY71037. Submitted to De Beers Canada Exploration Inc., Yellowknife, NWT (Jacques Whitford 2004)
EBA Engineering Consultants Ltd. (EBA)	2004	Kennady Lake Winter 2003 Water Quality Sampling Program, Project No. 0701-98-13487.048. Submitted to DeBeers Canada Exploration Inc., Yellowknife, NWT (EBA 2004a)
EBA Engineering Consultants Ltd. (EBA)	2004	Faraday Lake Winter 2003 Water Quality Sampling Program, Project No. 0701-98-13487.048. Submitted to DeBeers Canada Exploration Inc., Yellowknife, NWT (EBA 2004b)
EBA Engineering Consultants Ltd. (EBA)	2004	Kelvin Lake Winter 2003 Water Quality Sampling Program, Project No. 0701-98-13487-048. Submitted to DeBeers Canada Exploration Inc., Yellowknife, NWT (EBA 2004c)

Table 8.8-10 Water Quality Studies Used in the Assessment of Kennady Lake, 1995 to 2010 (continued)

Report Author(s)	Publication Date	Report Title
EBA Engineering Consultants Ltd. (EBA)	2004	Kennady Lake (Winter 2004) Water Quality Sampling Program, Project # 1740071.001. Submitted to DeBeers Canada Exploration Inc., Yellowknife, NWT (EBA 2004d)
AMEC Earth & Environmental	N/A	Unpublished water chemistry data collected in Kennady Lake and surrounding watersheds (2004). Calgary, AB (AMEC 2004a)
AMEC Earth & Environmental	N/A	Unpublished Aquatic Resources Field Data Collected in Kennady Lake and Surrounding Watersheds (2004). Calgary, AB (AMEC 2004b)
AMEC Earth & Environmental	N/A	Unpublished water chemistry data collected in Kennady Lake and surrounding watersheds (2005). Calgary, AB (AMEC 2005a)
Section 8.3	2010	Additional baseline data collected in support of this application

8.8.2.2 Water Quality in Area 8 after Refilling

Although presently part of Kennady Lake, Area 8 is proposed to be hydraulically isolated from the rest of the lake during the construction, operations and closure phases of the Project. During these phases, runoff from natural areas within the Area 8 sub-watershed are expected to be sufficient for maintaining water quality within this basin, as described in Section 8.6. Therefore, water quality was not modelled in Area 8 during these phases of the Project.

In the post-closure period (after 2035), the original flow path of Kennady Lake will be re-established, and Area 8 will receive flows from the refilled portion of Kennady Lake. Therefore, Area 8 was included in the downstream water quality model. This model was developed to predict concentrations in Area 8, the L, M and N watersheds and Lake 410. The model, developed in GoldSim™, is detailed briefly below and fully described in Appendix 8.I.

The hydrology model (Sections 8.7.1 and 8.7.2) formed the basis of the downstream water quality model. Within each watershed, water quality profiles were assigned as baseline chemistry. Throughout the construction, operations, and closure phases of the Project, the downstream watershed was assumed to behave according to baseline conditions, with the following exceptions, which are included in the model:

- water will be discharged from the WMP to Lake N11 during the construction and operations phases;

- water will be drawn from Lake N11 to refill Kennady Lake during the closure phase;
- the flow path from Area 7 to Area 8 will be disconnected during the operations and closure phases; and
- the flow path from Area 7 to Area 8 will be reconnected after Kennady Lake has refilled (i.e., the post-closure period).

The water quality model predicted concentrations for a range of water quality parameters in Area 8 during the post-closure period (in addition to the downstream lake nodes and snapshots described in Section 9.8). The model assumed fully mixed conditions.

8.8.2.3 Stability Analysis of Meromictic Conditions in Tuzo Pit after Closure

The water quality in the Tuzo Pit basin (Tuzo Pit) and in the restored Kennady Lake will be influenced by several input sources. During the initial phase of refilling, water quality will be primarily influenced by groundwater influx and the sources used to fill the pit, namely, water from the WMP and Lake N11 (Section 8.4.3). After Kennady Lake is filled, water quality in Tuzo Pit will be determined by surface runoff to Kennady Lake and surface – groundwater interaction in the Tuzo Pit.

The stability of stratification in Tuzo Pit was analyzed using two methods. These methods, detailed in Appendix 8.I, are as follows:

- hydrodynamic modelling of the first 100 years after refilling, using CE-QUAL-W2; and
- mass balance calculations over 15,000 years using a vertical slice spreadsheet model.

The CE-QUAL-W2 model was used to compute total dissolved solids (TDS), temperature and density at 1 to 3 metre (m) intervals in Tuzo Pit. The model was run iteratively to determine the long-term depth of the pycnocline (the layer of water with the highest density gradient between the two waters of varying density) to delineate the boundary between the low TDS surface water zone and deeper high TDS water zone in the pit. The water below the pycnocline represents the volume of water anticipated to be isolated from surface waters in the refilled Kennady Lake. The volumes of water above and below the pycnocline were then used as inputs to the Kennady Lake Goldsim model.

The vertical slice spreadsheet model was used to calculate long-term TDS concentrations over 15,000 years at 25 m vertical intervals in Tuzo Pit. This model included long-term inflows that were predicted by the hydrogeological model (Section 11.6 SON: Permafrost, Hydrogeology and Groundwater SON).

8.8.3 Effects Analysis Results – Construction and Operation

8.8.3.1 Effects of the Deposition of Dust and Metals from Air Emission to Water Quality and Lake-Bed Sediments in Waterbodies within the Kennady Lake Watershed

8.8.3.1.1 Results

The potential effects of dust and associated metal deposition on water quality were evaluated for 18 lakes within the Kennady Lake watershed.

Effects of Deposition of Dust and Metals and under Baseline Conditions

Under baseline conditions, predicted increases in TSS and metal concentrations relative to background were very small (i.e., <1% for most parameters). These results are consistent with the absence of development in the Project area at the time of start-up.

Effects of Deposition of Dust and Metals from the Project

Predicted maximum concentrations of seven metals during construction and operations are above water quality guidelines in two or more lakes, including aluminum, cadmium, chromium, copper, iron, mercury, and silver (Table 8.8-11). As noted above, predicted concentrations reflect the conservative assumptions used in the air quality modelling and mass balance analysis.

The spatial extent of dust and metal deposition is anticipated to be restricted to localized areas within and close to the Project footprint. Maximum deposition is expected to occur near haul roads along the southern, western and eastern boundary of the development area, and primarily reflect winter fugitive road dust emissions (Section 11.4 SON: Air Quality). In general, elevated deposition of dust and metals is predicted to occur to a distance of approximately 2 km from the development area boundary.

Table 8.8-11 Predicted Concentrations of Metals and TSS in Lakes in the Kennady Lake Watershed under the Application Case

Parameter	Guideline[a]	Background Concentrations (mg/L)			Predicted Maximum Concentrations during Construction and Operations (mg/L)																		
		min	max	average	Area 8[b]	A3[b]	B1[b]	B2	D2[b]	D3[b]	D7[b]	D10	E1[b]	E2	E3	F1	G1[b]	G2[b]	H1[b]	I1[b]	I2	J1a[b]	J1b[b]
Aluminum	0.1	0.006	1.13	0.07	**0.22**	**0.16**	**0.17**	**0.19**	**0.40**	**0.23**	**0.13**	**0.42**	**0.20**	**0.37**	**0.89**	**0.41**	**0.18**	**0.17**	**0.15**	**0.32**	**0.37**	**0.19**	**0.20**
Antimony	-	0.00001	0.0021	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Arsenic	0.005	0.00005	0.0011	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0004	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Barium	-	0.002	0.0224	0.004	0.007	0.006	0.006	0.006	0.010	0.007	0.005	0.011	0.006	0.010	0.020	0.011	0.006	0.006	0.005	0.009	0.010	0.006	0.006
Beryllium	-	0.000005	0.0005	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Boron	1.5	0.001	0.01	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.006	0.005	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006	0.005	0.005
Cadmium	0.000039	0.000001	0.0001	0.00002	**0.0004**	**0.0002**	**0.0002**	**0.0002**	**0.0005**	**0.0003**	**0.0001**	**0.0005**	**0.0002**	**0.0004**	**0.0008**	**0.0006**	**0.0003**	**0.0002**	**0.0002**	**0.0007**	**0.0008**	**0.0003**	**0.0003**
Chromium	0.001	0.00005	0.004	0.0006	**0.002**	**0.001**	**0.001**	**0.002**	**0.003**	**0.002**	**0.001**	**0.004**	**0.002**	**0.003**	**0.008**	**0.004**	**0.002**	**0.001**	**0.001**	**0.003**	**0.003**	**0.002**	**0.002**
Cobalt	-	0.00002	0.002	0.0002	0.0005	0.0004	0.0004	0.0004	0.0007	0.0005	0.0003	0.0008	0.0004	0.0007	0.0015	0.0008	0.0004	0.0004	0.0003	0.0007	0.0008	0.0004	0.0004
Copper	0.002	0.0005	0.012	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**	**0.004**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**
Iron	0.3	0.005	1.28	0.2	**0.4**	**0.3**	**0.3**	**0.4**	**0.8**	**0.5**	0.3	**0.8**	**0.4**	**0.7**	**1.7**	**0.8**	**0.4**	**0.3**	**0.3**	**0.6**	**0.7**	**0.4**	**0.4**
Lead	0.002	0.000011	0.0008	0.0001	0.0003	0.0002	0.0002	0.0002	0.0004	0.0003	0.0002	0.0004	0.0002	0.0004	0.0007	0.0004	0.0002	0.0002	0.0002	0.0004	0.0004	0.0002	0.0002
Manganese	-	0.0011	0.0199	0.005	0.009	0.007	0.007	0.008	0.014	0.009	0.006	0.014	0.008	0.013	0.027	0.014	0.008	0.007	0.007	0.012	0.013	0.008	0.008
Mercury	0.000026	0.0000003	0.00001	0.000006	**0.000034**	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00002	0.00001	0.00002	**0.00006**	**0.00009**	0.00003	0.00002
Molybdenum	0.73	0.000025	0.0025	0.0006	0.0006	0.0006	0.0006	0.0006	0.0007	0.0006	0.0006	0.0007	0.0006	0.0007	0.0008	0.0007	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006
Nickel	0.065	0.0002	0.0132	0.002	0.004	0.003	0.003	0.003	0.006	0.004	0.003	0.006	0.003	0.006	0.012	0.006	0.003	0.003	0.003	0.006	0.0066	0.004	0.004
Selenium	0.001	0.00002	0.0005	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0004	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Silver	0.0001	0.0000003	0.0005	0.00005	**0.0001**	0.0001	0.0001	0.0001	**0.0001**	0.0001	0.0001	**0.0001**	0.0001	**0.0001**	**0.0002**	**0.0001**	0.0001	0.0001	0.0001	**0.0002**	**0.0002**	0.0001	**0.0001**
Strontium	0.049	0.004	0.026	0.008	0.009	0.008	0.008	0.009	0.010	0.009	0.008	0.010	0.009	0.009	0.012	0.010	0.009	0.009	0.008	0.010	0.010	0.009	0.009
Uranium	-	0.000005	0.0003	0.00003	0.00005	0.00004	0.00004	0.00005	0.00007	0.00005	0.00004	0.00007	0.00005	0.00006	0.00011	0.00007	0.00004	0.00004	0.00004	0.00006	0.00006	0.00005	0.00005
Vanadium	-	0.00005	0.0056	0.0007	0.0012	0.001	0.001	0.001	0.002	0.001	0.001	0.002	0.001	0.002	0.003	0.002	0.001	0.001	0.001	0.001	0.002	0.001	0.001
Zinc	0.03	0.0005	0.055	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.010	0.010	0.009	0.009	0.009	0.010	0.01	0.009	0.009
TSS	-	0.5	45	3	36	19	15	18	69	25	10	87	25	81	267	78	21	19	16	64	92	27	30

Note: **Bolding** identifies concentrations above chronic aquatic life guideline.

(a) Water quality guidelines for the protection of aquatic life (CCME 1999).

(b) Fish bearing lake.

TSS = total suspended solids; min = minimum; max = maximum; mg/L = milligrams per litre; "-" = not available or not applicable.

The period of elevated TSS and metal concentrations in affected lakes is expected to be relatively short. During construction and operations, the largest load of suspended sediments to surface waters during the year will occur during spring freshet, when dust deposited to snow during winter and eroded materials enter surface waters. Sediment inputs during other times of the year are anticipated to be sporadic and too small to result in measurable changes in TSS and metal concentrations in lakes, except in localized areas near stream mouths during and immediately after precipitation events.

The length of the freshet period is estimated to range from approximately two days for small lakes to a maximum of one to two weeks based on the length of the freshet for Kennady Lake (Section 8.3.5.2). This would be followed by a period of settling, estimated as less than a month based on observations at Snap Lake (De Beers 2010). Snap Lake is a small lake located adjacent an operating diamond mine in similar terrain as the Project. Post-freshet sampling of Snap Lake typically occurs in early to mid-July (i.e., less than a month after freshet), by which time TSS concentrations in lake water are typically below the analytical detection limit of 3 mg/L.

8.8.3.1.2 Summary

A conservative analysis was conducted to estimate maximum potential changes in TSS and metal concentrations in lakes within the Kennady Lake watershed, to evaluate potential effects of dust and air emissions during construction and operation of the Project. The results of this analysis indicate the concentrations of TSS and certain metals may be elevated during and after freshet, potentially to levels above water quality guidelines. Effects on TSS and metal concentrations are expected to be localized in the immediate vicinity of the Project and temporally restricted to the period during and after freshet.

Predictions of TSS and metal concentrations presented in this section are subject to a high degree of uncertainty, in the direction of predicting higher concentrations than can be realistically expected, based on the degree of conservatism incorporated in the evaluation and experience at operating diamond mines.

8.8.3.2 Effects of Acidifying Emissions to Waterbodies within the Kennady Lake Watershed

8.8.3.2.1 Results

The potential for acidification of lakes was evaluated by comparison of net PAI values to critical loads for baseline conditions, and during construction and operations. Peak emissions during operation were considered in the assessment, which represents a conservative, worst-case scenario as outlined in the Air Quality subject of note (Section 11.4).

Effects of Acidifying Emissions under Baseline Conditions

Predicted net PAI values for baseline conditions are below critical loads for the 19 local lakes included in the assessment (Table 8.8-11). Baseline net PAI values were only marginally above background values and the annual deposition of nitrogen was less than 5 kg/ha/y for all lakes included in the analysis. These results are consistent with the observed lack of acidified lakes in the Kennady lake watershed.

Effects of Acidifying Emissions from the Project

Predicted net PAI values representing peak emissions during construction and operations are below the critical loads for the 19 lakes included in the evaluation of Project-related effects (Table 8.8-12). The annual deposition of nitrogen during construction and operations was less than 5 kg/ha/y for all lakes. Based on these results, Project-related deposition of SO_4^{2-} and NO_3^- in the Kennady Lake watershed is not predicted to result in lake acidification.

Table 8.8-12 Critical Loads and Predicted Acid Input Rates for the 19 Local Lakes Included in the Assessment

Lake ID[a]	Site Name/ Original Identifier	Distance[b] (km)	Direction[b]	Critical Load (keq/ha/y)	Baseline Conditions			Construction and Operations		
					SO_4^{2-} Deposition (keq/ha/y)	NO_3^- Deposition (keq/ha/y)	Net PAI (keq/ha/y)	SO_4^{2-} Deposition (keq/ha/y)	NO_3^- Deposition (keq/ha/y)	Net PAI (keq/ha/y)
30	Area 8	1	ESE	0.221	0.039	0.028	0.055	0.040	0.094	0.095
3	A3	3	N	0.206	0.039	0.028	0.055	0.039	0.065	0.077
5	B1	3	NW	0.215	0.039	0.028	0.055	0.040	0.066	0.078
6	B2	3	WNW	0.477	0.039	0.028	0.055	0.040	0.070	0.081
11	D2	3	W	0.188	0.039	0.028	0.055	0.040	0.093	0.094
12	D3	4	W	0.110	0.039	0.028	0.055	0.040	0.070	0.080
13	D7	6	WNW	0.259	0.039	0.028	0.055	0.039	0.052	0.070
10	D10	4	W	0.291	0.039	0.028	0.055	0.040	0.095	0.096
14	E1	4	W	0.269	0.039	0.028	0.055	0.040	0.073	0.082
15	E2	4	W	0.952	0.039	0.028	0.055	0.040	0.101	0.100
16	E3	3	W	0.386	0.039	0.028	0.055	0.041	0.132	0.118
17	F1	2	NW	0.185	0.039	0.028	0.055	0.041	0.116	0.108
18	G1	2	SE	0.434	0.039	0.028	0.055	0.040	0.079	0.086
19	G2	3	SE	0.216	0.039	0.028	0.055	0.040	0.071	0.081
20	H1	3	ESE	0.267	0.039	0.028	0.055	0.039	0.069	0.080
21	I1	1	E	0.248	0.039	0.028	0.055	0.040	0.159	0.133
22	I2	1	ENE	0.522	0.039	0.028	0.055	0.041	0.204	0.160
23	J1a	2	ENE	0.988	0.039	0.028	0.055	0.040	0.091	0.093
24	J1b	2	ENE	0.200	0.039	0.028	0.055	0.040	0.090	0.092

[a] Identifier used on map showing waterbody locations (Figure 8.8-2).

[b] Distance and direction relative to the Gahcho Kué Project.

km = kilometre; keq/ha/y = kiloequivalents per hectare per year; SO_4^{2-} = sulphate; NO_3^- = nitrate; PAI = Potential Acid input.

8.8.4 Effects Analysis Results – Closure Period

8.8.4.1 Effects of Project Activities to Water Quality in Kennady Lake and Area 8 during and After Refilling

At closure, the lake-bed of Kennady Lake will be modified by the three mine pits and portions of the remaining dykes. The Hearne Pit will be partially backfilled with fine PK, the 5034 Pit will be completely backfilled with mine rock, except for the northern quarter where it borders the Tuzo Pit, and the Tuzo Pit will not be backfilled.

Refilling of Kennady Lake will start by drawing down the water in Areas 3 to 7 and transferring this higher-salinity water to Tuzo Pit. Subsequently, Tuzo Pit and the remaining portions of Kennady Lake will be refilled. The water used to refill Kennady Lake will include natural watershed runoff and supplemental water pumped from the adjacent Lake N11 to expedite lake refilling.

After refilling, Tuzo Pit will represent a new waterbody feature within the restored Kennady Lake. The bottom of the Tuzo Pit will be about 300 metres (m) below the Kennady Lake surface and 285 m below the average bottom of the lake, creating a deep depression within the lake. During and after refilling of the Tuzo Pit, the saline groundwater collected in the bottom of the pit will form a higher density monimolimnion layer, which will be separated from the overlying fresh water by a pycnocline. The development of a pycnocline will create what is referred to as meromictic conditions in the Tuzo Pit, which if stable, will keep the monimolimnion layer isolated from the overlying fresh water indefinitely. A separate analysis of the long-term stability of meromictic conditions in the combined Tuzo Pit is provided in Section 8.8.4.2.

Water quality was modelled throughout the closure phase and the post-closure period in Tuzo Pit and Kennady Lake, which includes all five basins (i.e., Areas 3 and 5, Area 4, Area 6, Area 7 and Area 8). The results of this modelling, which are presented in Section 8.8.4.1, assume that the fresh water in the Tuzo Pit will not interact with the underlying monimolimnion layer. The validity of this assumption is verified as a separate analysis in Section 8.8.4.2.

Because the lake will remain a closed-circuited system until it is refilled and Dyke A is breached, the effects analysis of Kennady Lake does not include the construction, operations or closure phases. Instead, it includes the post-closure period, when Kennady Lake is reconnected to the receiving environment, the natural flow path is restored and fish passage is resumed.

8.8.4.1.1 Effects to Water Quality in Areas 3 to 7 after Refilling Activities

Changes in surface water quality will depend on sources and the water balance within the Kennady Lake watershed throughout the closure phase, including the post-closure period. The following analysis includes the modelling of water quality of the refilled Kennady Lake, including Areas 3 and 5, Area 4, Area 6, and Area 7, and the water in Tuzo Pit above the pycnocline (i.e., the water that will lie above the isolated higher density monimolimnion, which will not interact with surface waters). It was assumed that all waters above the pycnocline would be fully mixed by the time Dyke A is breached. Therefore, results presented and discussed in this section are intended to represent the entire refilled lake, excluding Area 8, which is discussed in Section 8.8.4.2, and the monimolimnion of Tuzo Pit, which is discussed in Section 8.8.4.3.

Concentrations of each of the water quality parameters after the refilling of Kennady Lake and breaching of Dyke A (i.e., during the post-closure period) are presented in Table 8.8-13. Within post-closure, two periods were selected to represent water quality in Kennady Lake:

- immediately after refilling, when Dyke A is breached and the lake is reconnected to the receiving environment; and
- one hundred years after the start of mining operations, to represent long-term, steady-state conditions.

A discussion of the water quality modelling results is provided below, which includes time-series plots for selected water quality parameters. Time series plots for each water quality parameter listed in Table 8.8-13 are provided in Appendix 8.III.

Table 8.8-13 includes a comparison to the Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME 2007) for reference; however, the assessment of effects of changes in water quality to aquatic life is presented in Section 8.9.

The water quality modelling results have been grouped into three categories:

- total dissolved solids (TDS) and major ions;
- nutrients; and
- trace metals.

Table 8.8-13 Predicted Water Quality in Kennady Lake for the Post-closure Period

Regulated Parameter	Units	Water Quality Guidelines [a]	Kennady Lake Baseline WQ	Predicted Concentrations in Kennady Lake	
				Maximum Post-closure Concentration [b]	Expected Long-term Steady State Concentration [b]
Conventional					
pH	pH units	6.5 - 9.0	6.7	6.7 [c]	6.7 [c]
Total Dissolved Solids	mg/L	-	11	162	83
Total Suspended Solids	mg/L	-	1.0	2.0	2.0
Hardness [d]	mg/L as $CaCO_3$	-	6.0	97	47
Major Ions					
Calcium	mg/L	-	1.3	30	13
Chloride	mg/L	-	0.64	69	21
Magnesium	mg/L	-	0.54	5.6	3.4
Potassium	mg/L	-	0.47	5.8	5.7
Sodium	mg/L	-	0.75	17	9.5
Sulphate	mg/L	-	0.89	22	22
Nutrients					
Ammonia	mg/L as N	11 [e]	0.018	3.1	0.021
Nitrate	mg/L as N	2.9	0.035	2.9	0.037
Total Nitrogen	mg/L as N	-	0.33	6.4	0.80
Dissolved Phosphorus	mg/L	-	0.0048	N/A	N/A
Total Phosphorus	mg/L	-	0.0048	N/A	N/A
Dissolved Metals					
Aluminum	mg/L	0.1 [f]	0.0057	0.042	0.042
Antimony	mg/L	-	0.000093	0.0021	0.0019
Arsenic	mg/L	0.005	0.00013	0.0025	0.0024
Barium	mg/L	-	0.0024	0.19	0.19
Beryllium	mg/L	-	0.000048	0.00014	0.00014
Boron	mg/L	1.5	0.002	0.59	0.59
Cadmium	mg/L	0.000003 [g]	0.000014	**0.000032**	**0.000031**
Chromium	mg/L	0.001	0.00012	**0.0045**	0.00078
Cobalt	mg/L	-	0.000083	0.0004	0.00019
Copper	mg/L	0.002 [g]	0.00069	**0.0022**	**0.0021**
Iron	mg/L	0.3	0.018	**0.36**	0.061
Lead	mg/L	0.001 [g]	0.000029	0.00035	0.0002
Manganese	mg/L	-	0.0091	0.055	0.014
Mercury	mg/L	0.000026	0.0000051	0.000015	0.0000092
Molybdenum	mg/L	0.073	0.000059	0.012	0.012
Nickel	mg/L	0.025 [g]	0.00033	0.0017	0.0016
Selenium	mg/L	0.001	0.00003	0.00084	0.00025
Silver	mg/L	0.0001	0.000043	0.000076	0.000059
Strontium	mg/L	-	0.0082	0.19	0.19
Thallium	mg/L	0.0008	0.000017	0.00018	0.000032
Uranium	mg/L	-	0.000024	0.0022	0.00085
Vanadium	mg/L	-	0.000025	0.0027	0.0026
Zinc	mg/L	0.03	0.0028	0.012	0.0045
Total Metals					
Aluminum	mg/L	0.1 [f]	0.0094	0.071	0.07
Antimony	mg/L	-	0.00014	0.0021	0.0019
Arsenic	mg/L	0.005	0.00013	0.0025	0.0024
Barium	mg/L	-	0.0026	0.19	0.19

Table 8.8-13 Predicted Water Quality in Kennady Lake for the Post-closure Period (continued)

Regulated Parameter	Units	Water Quality Guidelines [a]	Kennady Lake Baseline WQ	Predicted Concentrations in Kennady Lake	
				Maximum Post-closure Concentration [b]	Expected Long-term Steady State Concentration [b]
Beryllium	mg/L	-	0.000048	0.00014	0.00014
Boron	mg/L	1.5	0.002	0.59	0.59
Cadmium	mg/L	0.000003 [g]	0.000023	**0.000042**	**0.00004**
Chromium	mg/L	0.001	0.00021	**0.005**	**0.0013**
Cobalt	mg/L	-	0.000085	0.00048	0.00027
Copper	mg/L	0.002 [g]	0.0013	**0.0028**	**0.0027**
Iron	mg/L	0.3	0.042	**0.44**	0.14
Lead	mg/L	0.001 [g]	0.000039	0.00038	0.00022
Manganese	mg/L	-	0.0091	0.056	0.015
Mercury	mg/L	0.000026	0.0000066	0.000017	0.000011
Molybdenum	mg/L	0.073	0.000059	0.012	0.012
Nickel	mg/L	0.025 [g]	0.00048	0.0031	0.0031
Selenium	mg/L	0.001	0.00003	0.00084	0.00025
Silver	mg/L	0.0001	0.000043	0.000076	0.000059
Strontium	mg/L	-	0.0082	0.19	0.19
Thallium	mg/L	0.0008	0.000022	0.00019	0.000038
Uranium	mg/L	-	0.000024	0.0022	0.00085
Vanadium	mg/L	-	0.00021	0.003	0.0029
Zinc	mg/L	0.03	0.0028	0.012	0.0045

a) Chronic Aquatic Health Guidelines from Canadian Environmental Quality Guidelines, Update 7.0 (CCME 2007).

b) Bold font indicates concentration exceeds guideline.

c) Assumed no change in pH based on geochemical characteristics and acidification assessment of local waterbodies.

d) Theoretical hardness calculated based on observed calcium and magnesium concentrations.

e) Dependent on pH and temperature (assumed 15ºC, to give most conservative guideline).

f) Dependent on pH.

g) Dependent on hardness.

N/A - these values are currently being assessed and are not available at this time. They will be provided later in a supplemental filing.

WQ = water quality; mg/L = milligrams per litre; mg/L as $CaCO_3$ = milligrams per litre as calcium carbonate; mg/L as N = milligrams per litre as nitrogen

Total Dissolved Solids and Major Ions

Concentrations of TDS and major ions in Areas 3 to 7 are projected to increase during the operations phase, primarily due to saline groundwater discharged from the mining pits to the WMP. During the closure phase, TDS concentrations are predicted to decrease as higher-TDS water is drained from the lake to Tuzo Pit and fresh water is imported from Lake N11 (Figure 8.8-5).

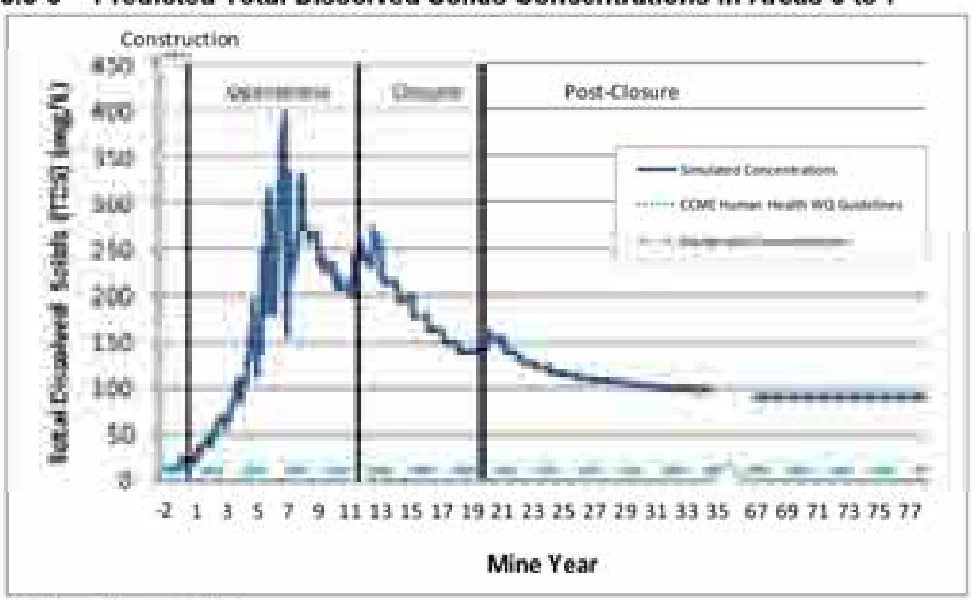
In the post-closure period, concentrations are predicted to continue to decline as Kennady Lake receives fresh water inflows (i.e., natural drainage) from the basin and Dyke A is breached. In one to two decades of post-closure, concentrations are predicted to approach steady state at slightly less than 100 mg/L TDS. Calcium, chloride, magnesium and sodium are predicted to mirror the trends displayed by TDS in Figure 8.8-5. Time series plots for these constituents are provided in Appendix 8.III.

Sulphate (Figure 8.8-6) and potassium are predicted to increase during the operations phase and decline during closure for the reasons described above for TDS. However, these constituents are predicted to increase slightly in the post-closure phase due to continued loading from geochemical sources.

The long-term results presented for the post-closure period reflect a high degree of conservatism. Concentrations of TDS and major ions are predicted to remain elevated above background levels because loading of these constituents from geochemical sources are assumed to continue in perpetuity. Examples of these sources include seepage from the Fine PK Facility, leaching from mine rock and diffusion from PK material in the bottom of Hearne Pit. Processes such as sealing by permafrost, source depletion and burial by sedimentation have not been incorporated into the modelling.

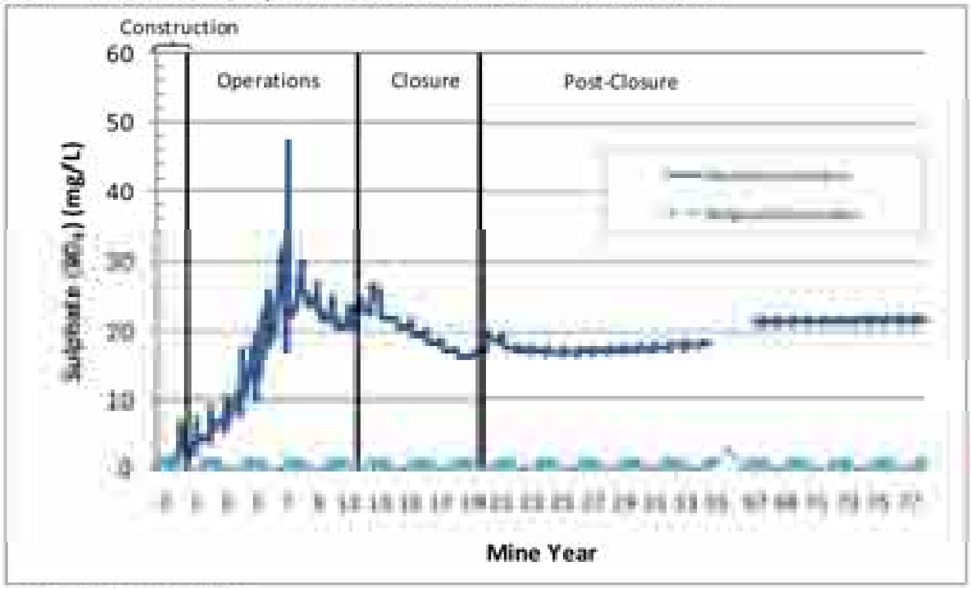
There are no CCME guidelines for TDS or any of the major ions. To put the predicted concentrations into context, TDS and all major ions are predicted to remain above background conditions but below levels that would affect aquatic health (see Section 8.9.3.1.1).

Figure 8.8-5 Predicted Total Dissolved Solids Concentrations in Areas 3 to 7



mg/L = milligrams per litre

Figure 8.8-6 Predicted Sulphate Concentrations in Areas 3 to 7



mg/L = milligrams per litre

Nutrients

Nitrogen

In freshwater systems, nitrogen exists in several forms, including molecular nitrogen, nitrate, nitrite, ammonia and organic nitrogen. The water quality modelling focused on nitrate and ammonia, because these are:

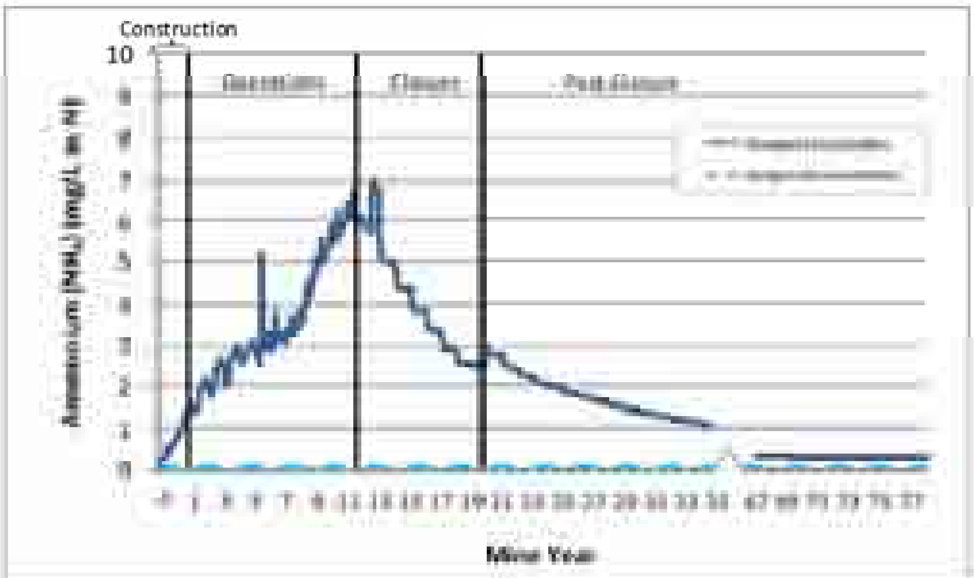
- the most bioavailable forms of nitrogen;
- potential contributors to aquatic toxicity; and
- the predominant forms released in explosives residue.

Total nitrogen was modelled to indicate the total amount of fixed nitrogen in the system. Mining activities are not anticipated to affect concentrations of molecular nitrogen, nitrite or organic nitrogen in Kennady Lake. The modelling considered all forms of nitrogen as conservative masses (i.e., the model did not account for source terms, such as nitrogen fixation, and sink terms, such as volatilization, uptake and nitrification/denitrification).

During the operations period, concentrations of ammonia and nitrate are predicted to increase, primarily due to inputs from blasting residue. These are predicted to decrease during the closure phase as higher concentration water is transferred to Tuzo Pit and fresh water is imported from Lake N11. By the time Dyke A is breached, nitrogen and ammonia are predicted to be at or below water quality guidelines (Table 8.8-13) and decline thereafter to near background levels (Figures 8.8-7 and 8.8-8).

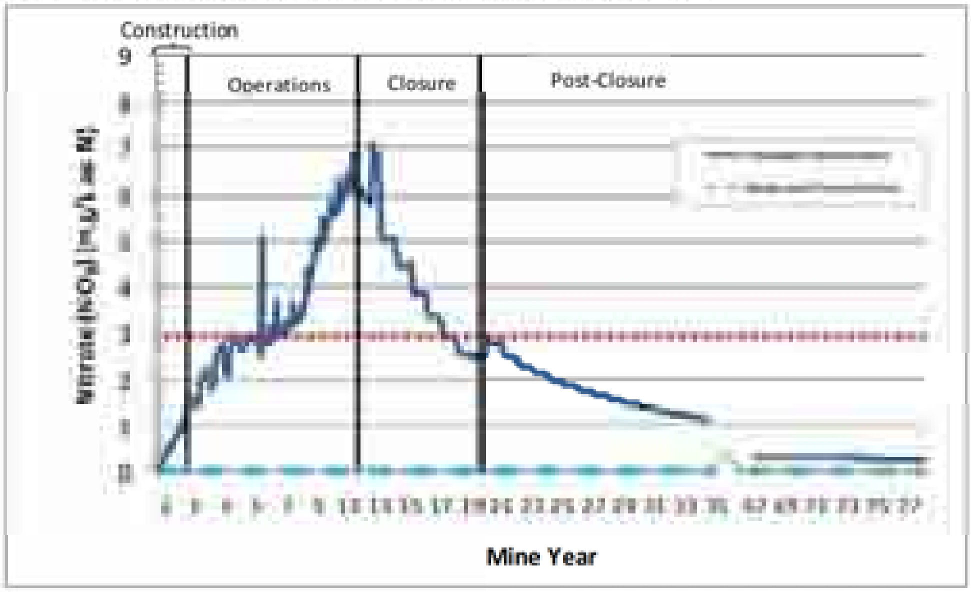
Total nitrogen, for which there is no CCME guideline, is predicted to follow a similar pattern, as it is predominantly comprised of nitrate and ammonia. Based on the total nitrogen concentrations predicted for the post-closure period, nitrogen is not anticipated to be a limiting nutrient.

Figure 8.8-7 Predicted Ammonia Concentrations in Areas 3 to 7



mg/L as N = milligrams per litre as nitrogen

Figure 8.8-8 Predicted Nitrate Concentrations in Areas 3 to 7



mg/L as N = milligrams per litre as nitrogen

Phosphorus

Phosphorus plays an important role in aquatic systems primarily because of its importance in biological metabolism. In contrast to the availability of other nutrients to biota, such as carbon and nitrogen, phosphorus is generally the least abundant. This lack of natural availability commonly leads to phosphorus limitation in lakes, which affects biological productivity. Most natural lakes are considered phosphorus limited or co-limiting with nitrogen.

Model results suggest that there is a potential for phosphorus levels to increase in Kennady Lake as a result of runoff from the reclaimed mine site. The runoff waters mobilize phosphorus from the mine rock, coarse PK and fine PK as they travel through the external structures, with the fine PK being the largest source of phosphorus. However, the modelling analysis was completed assuming free and complete contact between the runoff waters and the materials contained in the mine rock piles, the Coarse PK Pile and the Fine PKC Facility.

De Beers is currently evaluating a variety of environmental design features and mitigation measures to limit contact between site runoff waters and the fine PK located within the Fine PKC Facility and other potential sources. These environmental design features and mitigation measures include, for example:

- Promotion of permafrost development in the Fine PKC Facility

- Use of low permeability cover material to limit infiltration into key areas, such s the Fine PKC Facility.

The effectiveness of these environmental design features and mitigation measures is uncertain and requires further analysis. Accordingly, the amount of phosphorus that may be released into the environment is uncertain at this time. As a result, potential effects related to phosphorus have not been presented and will not be available until such time as additional analysis is completed. This analysis will be provided to the Panel in 2011 following additional work that will be undertaken over the next few months.

Trace Metals

Trace metals can be toxic to aquatic life in high concentrations. The toxicity of some metals (e.g., cadmium, copper, lead, nickel, and zinc) can vary with hardness, with increasing hardness levels resulting in a decrease in the potential toxicity of these metals to aquatic life.

There are several potential loading sources of trace metals to Areas 3 to 7 during the operations phase. Geochemical sources include loadings from mine rock and PK drainage, and pit wall exposure. Groundwater discharge from the active pits will contribute metals during the period when groundwater is discharged to the WMP (see Section 8.4.3.5). Inputs that increase during the operations phase are generally predicted to increase trace metals concentrations during this period, then decline during refilling (i.e., closure), and approach background concentrations as the lake flushes in the post-closure period.

However, some of the geochemical sources are anticipated to continue to contribute loads into the post-closure period, so trace metals that are elevated in these sources are not predicted to approach background conditions. In addition, it was assumed that 1 mg/L of fine sediments will be re-suspended in perpetuity (see Appendix 8.I). These sediments were assumed to have the chemical makeup of solid fine PK.

Surface water from Lake N11 and natural runoff from the upper watershed used to refill Kennady Lake will not be a primary source of metals to the refilled Kennady Lake, as concentrations in these sources are not expected to be higher than background levels.

Predicted trace metal concentrations are discussed in more detail below, and are grouped according to predicted long-term trends.

Trace Metals that are Predicted to Decline in the Post-Closure Period

Of the 23 trace metals that were modelled for this assessment, 11 are predicted to increase in concentration during the operations phase, then steadily decline in concentration as the lake is flushed during the post-closure period. These metals are chromium, cobalt, iron, lead, manganese, mercury, selenium, silver, thallium, uranium and zinc. A timeseries plot of manganese (Figure 8.8-9) illustrates the general trend predicted for these metals.

With the exception of thallium, the primary loading source of these metals to Kennady Lake is groundwater from the active mine pits, hence the decline once pit dewatering is finished. Thallium has two primary loading sources, namely, groundwater and mine rock runoff. Because the concentrations of these metals will be mainly groundwater-driven, the dissolved fraction of these metals is predicted to comprise the majority of the total concentrations. Of these 11 trace metals, chromium and iron are predicted to exceed guidelines in the post-closure phase (Figures 8.8-10 and 8.8-11, respectively).

In the case of chromium, it should be noted that the guideline for chromium (VI) was conservatively applied to total and dissolved chromium predictions, although it is anticipated that most chromium will be present as chromium (III). The basis for this assumption is that the dominant sources of chromium to Kennady Lake are groundwater and seepage from fine PK and waste rock, and these are not highly oxidative systems that would generate chromium (VI). Predicted concentrations of total and dissolved chromium are below the CCME guideline of 0.0089 mg/L for chromium (III).

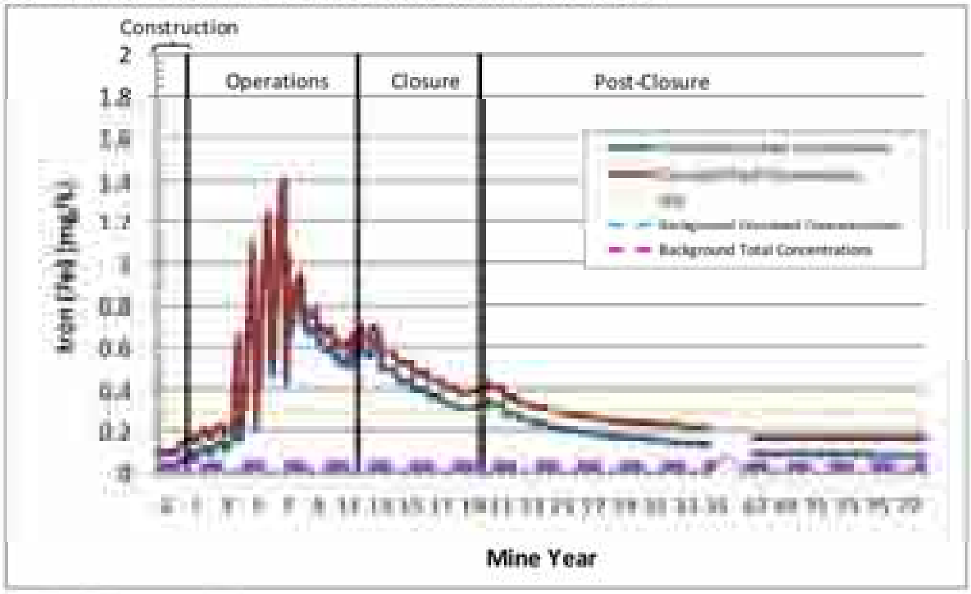
Figure 8.8-9 Predicted Manganese Concentrations in Areas 3 to 7

mg/L = milligrams per litre

Figure 8.8-10 Predicted Chromium Concentrations in Areas 3 to 7

mg/L = milligrams per litre

Figure 8.8-11 Predicted Iron Concentrations in Areas 3 to 7



mg/L = milligrams per litre

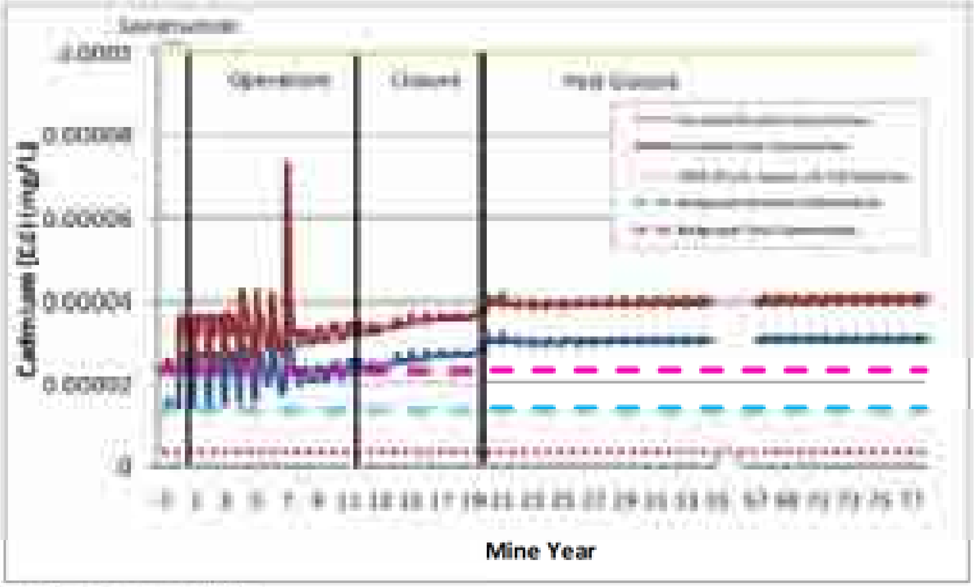
Trace Metals that are Predicted to Remain Constant in the Post-Closure Phase

A second group of metals will be influenced by a combination of sources throughout the operations phase. These metals are predicted to increase mainly due to inputs from groundwater and mine rock runoff, with secondary loading sources from fine PK and process water. They are predicted to increase in concentration relatively steadily throughout the operations phase, rise or fall during the closure period, then remain fairly constant throughout the post-closure period. The lack of decline in post-closure concentrations of these metals is due to the geochemical loading that will occur from the remaining mine rock and fine PK in and near Kennady Lake.

Because the primary loading sources of these metals is groundwater and geochemical reactions, the majority of these metals will be in the dissolved form.

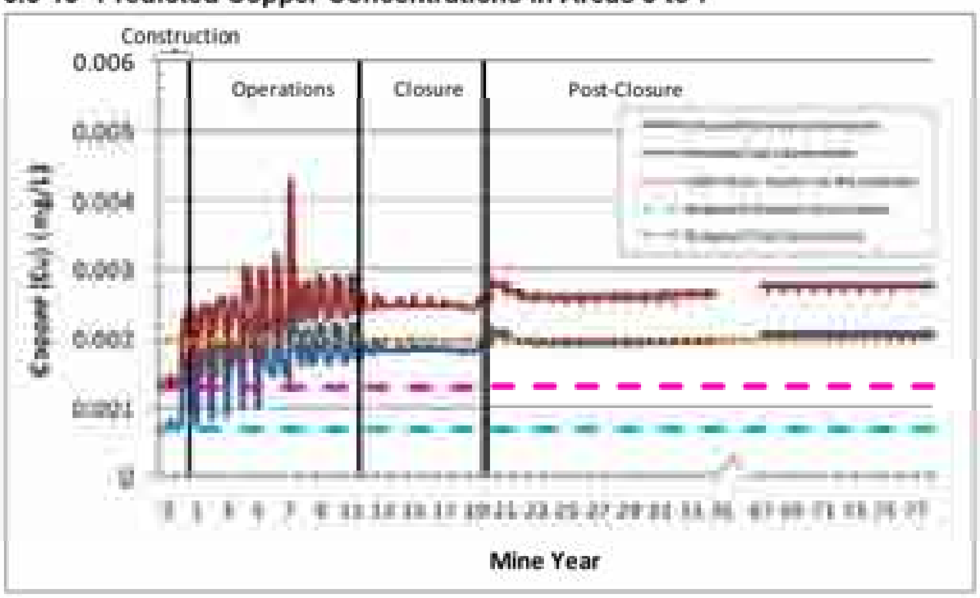
The metals that follow this trend are aluminum, antimony, arsenic, cadmium, copper, nickel and vanadium. Of these seven metals, cadmium and copper are predicted to exceed guidelines in the post-closure period. Representative time series plots are shown for cadmium (Figure 8.8-12), copper (Figure 8.8-13) and vanadium (Figure 8.8-14) to illustrate the general trends of this group of metals.

Figure 8.8-12 Predicted Cadmium Concentrations in Areas 3 to 7



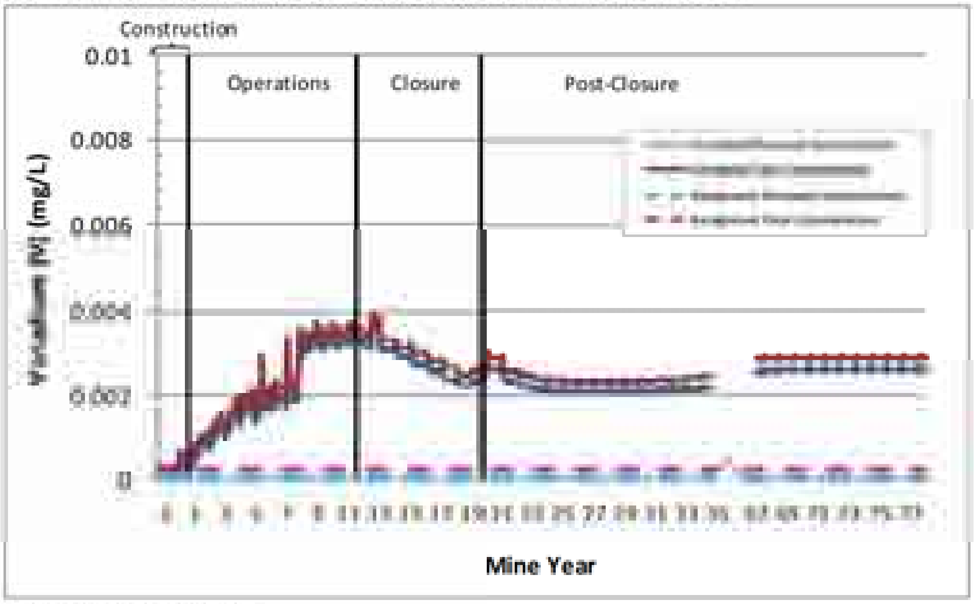
mg/L = milligrams per litre

Figure 8.8-13 Predicted Copper Concentrations in Areas 3 to 7



mg/L = milligrams per litre

Figure 8.8-14 Predicted Vanadium Concentrations in Areas 3 to 7



mg/L = milligrams per litre

Trace Metals that are Predicted to Increase in the Post-Closure Phase

The five remaining trace metals that were modelled are predicted to increase in the post-closure period. Concentrations of these metals, which include barium, beryllium, boron, molybdenum and strontium, will mainly be driven by loadings from geochemical sources. Mine rock, coarse PK and fine PK will contribute loadings of these metals. Because these materials will be present in the post-closure period, concentrations of these metals are predicted to increase after closure, reach steady state conditions in Kennady Lake within about 40 years.

Because geochemical sources are the primary contributors of these metals, the majority of total concentrations will be in the dissolved form. None of these five metals are predicted to exceed water quality guidelines in the post-closure phase. A timeseries plot of strontium concentrations is shown to illustrate the general trends of these five metals (Figure 8.8-15).

Figure 8.8-15 Predicted Strontium Concentrations in Areas 3 to 7

mg/L = milligrams per litre

The potential health effects of all trace metals on aquatic life, including the four metals that are projected to have maximum concentrations above guideline concentrations (i.e., cadmium, chromium, copper and iron), are assessed in Section 8.9. These metals have been measured in Kennady Lake above guideline concentrations under existing environment conditions (Section 8.3.6).

8.8.4.1.2 Effects to Water Quality in Area 8 after Refilling Activities

Water quality in Area 8 during the post-closure phase will be driven by the water flowing from Kennady Lake after Dyke A is breached, with additional dilution from the Area 8 sub-watershed. A general trend for all modelled water quality constituents is described below.

During the operations phase, water quality constituent concentrations are predicted to increase slightly in Area 8 due to evapo-concentration. The construction of Dyke A will result in a reduction in drainage area reporting to Area 8, thereby increasing the residence time and the rate of evaporation relative to recharge. Consequently, all constituents are predicted to increase to slightly above background conditions by the time Dyke A is breached in 2035. Because concentrations were not corrected for the background rate of evapo-concentration, the predicted increases are conservative estimates.

Concentrations of all modelled constituents are predicted to increase when Dyke A is breached. In nearly all cases, concentrations are predicted to peak within five years of Dyke A being breached, as water in Area 8 is replaced with water from the refilled Kennady Lake. Concentrations are generally predicted to decline with time, mirroring those discussed for Kennady Lake in Section 8.8.4.1. In a few cases, discussed in more detail below, concentrations are predicted to increase during the post-closure period and reach a long-term steady state concentration within a few decades.

Regardless of time to reach peak concentrations, both the concentration peaks and steady state concentrations attained in Area 8 are generally predicted to be about 20% lower than peaks in Kennady Lake due to the additional dilution afforded by runoff from the Area 8 catchment. The amount of dilution (on a concentration basis) in Area 8 varies by constituent; those with high concentrations relative to background will receive more than 20% dilution, and those with concentrations closer to background will receive less.

Predicted concentrations in Area 8 during the post-closure phase are listed in Table 8.8-14.

Table 8.8-14 Predicted Water Quality in Area 8 for the Post-Closure Period

Regulated Parameter	Units	Water Quality Guidelines [a]	Kennady Lake Baseline WQ	Predicted Concentrations in Area 8
				Maximum Post-closure Concentration [b]
Conventional				
pH	pH units	6.5 - 9.0	6.7	6.7 [c]
Total Dissolved Solids	mg/L	-	11	94
Total Suspended Solids	mg/L	-	1.0	2.0
Hardness [d]	mg/L as $CaCO_3$	-	6.0	54
Major Ions				
Calcium	mg/L	-	1.3	16
Chloride	mg/L	-	0.64	35
Magnesium	mg/L	-	0.54	3.4
Potassium	mg/L	-	0.47	4.8
Sodium	mg/L	-	0.75	9.7
Sulphate	mg/L	-	0.89	18
Nutrients				
Ammonia	mg/L as N	11 [e]	0.018	1.6
Nitrate	mg/L as N	2.9	0.035	1.5
Total Nitrogen	mg/L as N	-	0.33	3.5
Dissolved Phosphorus	mg/L	-	N/A	N/A
Total Phosphorus	mg/L	-	N/A	N/A

Table 8.8-15 Predicted Water Quality in Area 8 for the Post-Closure Period (continued)

Regulated Parameter	Units	Water Quality Guidelines [a]	Kennady Lake Baseline WQ	Predicted Concentrations in Area 8
				Maximum Post-closure Concentration [b]
Dissolved Metals				
Aluminum	mg/L	0.1 [f]	0.0057	0.035
Antimony	mg/L	-	0.000093	0.0016
Arsenic	mg/L	0.005	0.00013	0.002
Barium	mg/L	-	0.0024	0.15
Beryllium	mg/L	-	0.000048	0.00013
Boron	mg/L	1.5	0.002	0.47
Cadmium	mg/L	0.000003 [g]	0.000014	**0.000029**
Chromium	mg/L	0.001	0.00012	**0.0021**
Cobalt	mg/L	-	0.000083	0.00028
Copper	mg/L	0.002 [g]	0.00069	0.0019
Iron	mg/L	0.3	0.018	0.18
Lead	mg/L	0.001 [g]	0.000029	0.0002
Manganese	mg/L	-	0.0091	0.03
Mercury	mg/L	0.000026	0.0000051	0.000011
Molybdenum	mg/L	0.073	0.000059	0.0098
Nickel	mg/L	0.025 [g]	0.00033	0.0014
Selenium	mg/L	0.001	0.00003	0.00045
Silver	mg/L	0.0001	0.000043	0.000063
Strontium	mg/L	-	0.0082	0.15
Thallium	mg/L	0.0008	0.000017	0.00009
Uranium	mg/L	-	0.000024	0.0011
Vanadium	mg/L	-	0.000025	0.0022
Zinc	mg/L	0.03	0.0028	0.0077
Total Metals				
Aluminum	mg/L	0.1 [f]	0.0094	0.06
Antimony	mg/L	-	0.00014	0.0016
Arsenic	mg/L	0.005	0.00013	0.002
Barium	mg/L	-	0.0026	0.15
Beryllium	mg/L	-	0.000048	0.00013
Boron	mg/L	1.5	0.002	0.47
Cadmium	mg/L	0.000003 [g]	0.000023	**0.000039**
Chromium	mg/L	0.001	0.00021	**0.0025**
Cobalt	mg/L	-	0.000085	0.00034
Copper	mg/L	0.002 [g]	0.0013	**0.0026**
Iron	mg/L	0.3	0.042	0.24
Lead	mg/L	0.001 [g]	0.000039	0.00022
Manganese	mg/L	-	0.0091	0.03
Mercury	mg/L	0.000026	0.0000066	0.000013
Molybdenum	mg/L	0.073	0.000059	0.0098

Table 8.8-15 Predicted Water Quality in Area 8 for the Post-Closure Period (continued)

Regulated Parameter	Units	Water Quality Guidelines [a]	Kennady Lake Baseline WQ	Predicted Concentrations in Area 8
				Maximum Post-closure Concentration [b]
Nickel	mg/L	0.025 [g]	0.00048	0.0026
Selenium	mg/L	0.001	0.00003	0.00045
Silver	mg/L	0.0001	0.000043	0.000063
Strontium	mg/L	-	0.0082	0.15
Thallium	mg/L	0.0008	0.000022	0.000096
Uranium	mg/L	-	0.000024	0.0011
Vanadium	mg/L	-	0.00021	0.0024
Zinc	mg/L	0.03	0.0028	0.0078

a) Chronic Aquatic Health Guidelines from Canadian Environmental Quality Guidelines, Update 7.0 (CCME 2007).

b) Bold font indicates concentration exceeds guideline.

c) Assumed no change in pH based on geochemical characteristics and acidification assessment of local waterbodies.

d) Theoretical hardness calculated based on observed calcium and magnesium concentrations.

e) Dependent on pH and temperature (assumed 15ºC, to give most conservative guideline).

f) Dependent on pH.

g) Dependent on hardness.

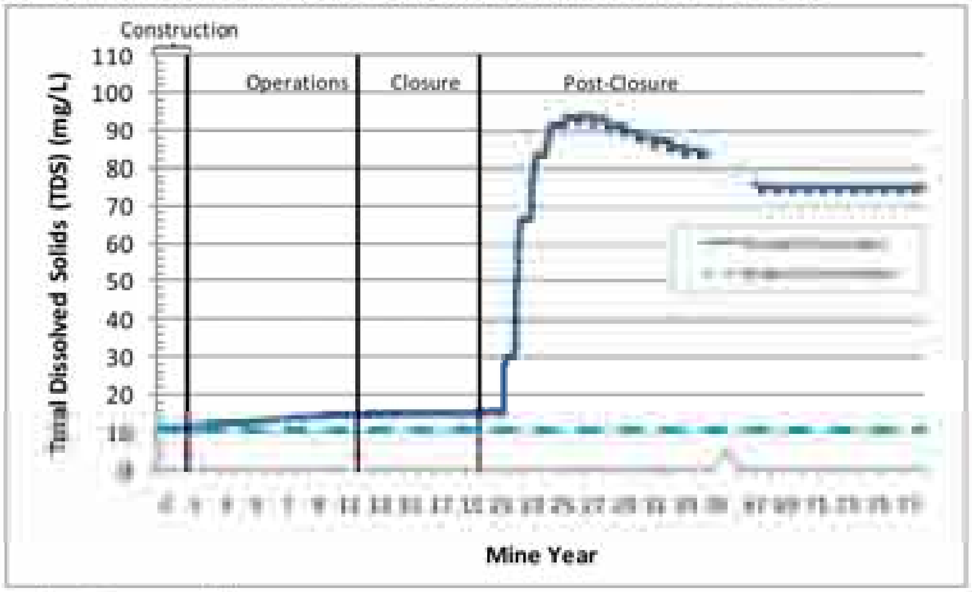
N/A - these values are still currently being assessed and are not available at this time. They will be provided later in a supplemental filing.

WQ = water quality; mg/L = milligrams per litre; mg/L as $CaCO_3$ = milligrams per litre as calcium carbonate; mg/L as N = milligrams per litre as nitrogen.

Total Dissolved Solids and Major Ions

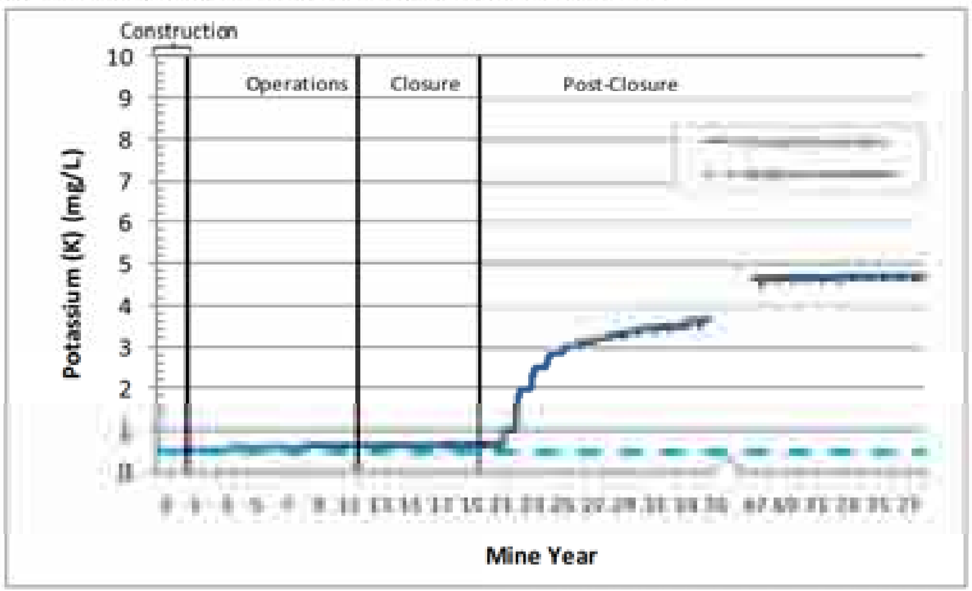
Concentrations of TDS and major ions in Area 8 are predicted to follow the general trends described above. A representative time series plot of TDS concentrations is shown in Figure 8.8-16. All ions follow this trend, except potassium (Figure 8.8-17) and sulphate, which are predicted to increase following closure. The increases in these two ions are consistent with the increases described in Kennady Lake (see Section 8.8.4.1) and due to continued loading from geochemical sources. There are no CCME aquatic life water quality guidelines for TDS and the modelled major ions.

Figure 8.8-16 Predicted Total Dissolved Solids Concentrations in Area 8



mg/L = milligrams per litre

Figure 8.8-17 Predicted Potassium Concentrations in Area 8



mg/L = milligrams per litre

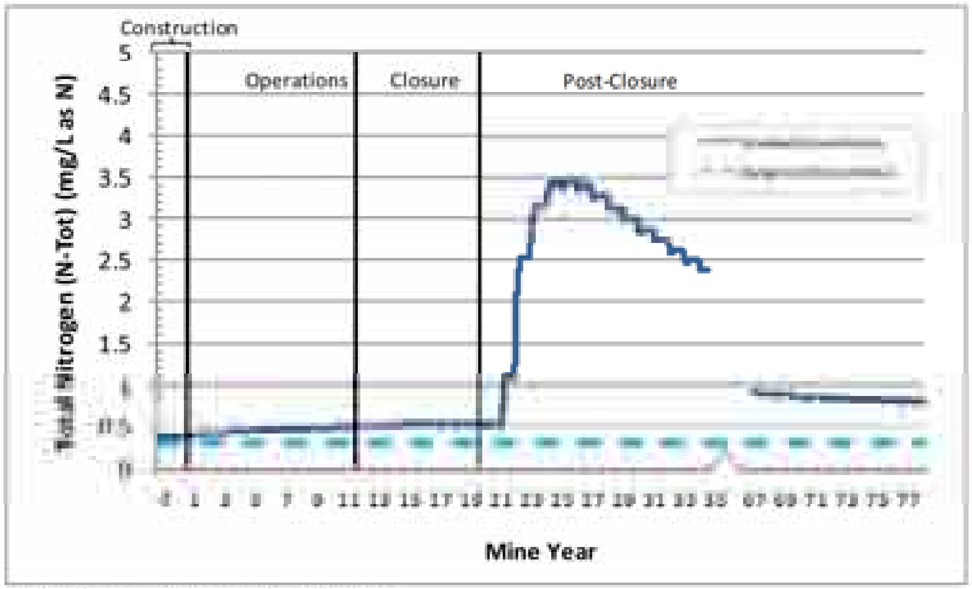
Nutrients

Nitrogen

All forms of nitrogen are predicted to peak in concentration in Area 8 within five years of breaching Dyke A, then return to near-background concentrations, for the reasons described for Kennady Lake in Section 8.8.4.1. A representative time series plot is shown for total nitrogen in Figure 8.8-18. Both nitrate and ammonia concentrations are predicted to remain below CCME guidelines for the protection of aquatic health in Area 8.

Based on the total nitrogen concentrations predicted for the post-closure periods, nitrogen is not anticipated to be a limiting nutrient.

Figure 8.8-18 Predicted Total Nitrogen Concentrations in Area 8



mg/L as N= milligrams per litre as nitrogen

Phosphorus

Model results suggest that there is a potential for phosphorus levels to increase in Area 8 as a result of runoff from the reclaimed mine site. As described in Section 8.8.4.1, the runoff waters mobilize phosphorus from the mine rock, coarse PK and fine PK as they travel through the external structures, with the fine PK being the largest source of phosphorus. However, the modelling analysis was completed assuming free and complete contact between the runoff waters and the materials contained in the mine rock piles, the Coarse PK Pile and the Fine PKC Facility.

De Beers is currently evaluating a variety of environmental design features and mitigation measures to limit contact between site runoff waters and the fine PK located within the Fine PKC Facility and other potential sources. These environmental design features and mitigation measures include, for example:

- Promotion of permafrost development in the Fine PKC Facility

- Use of low permeability cover material to limit infiltration into key areas, such as the Fine PKC Facility.

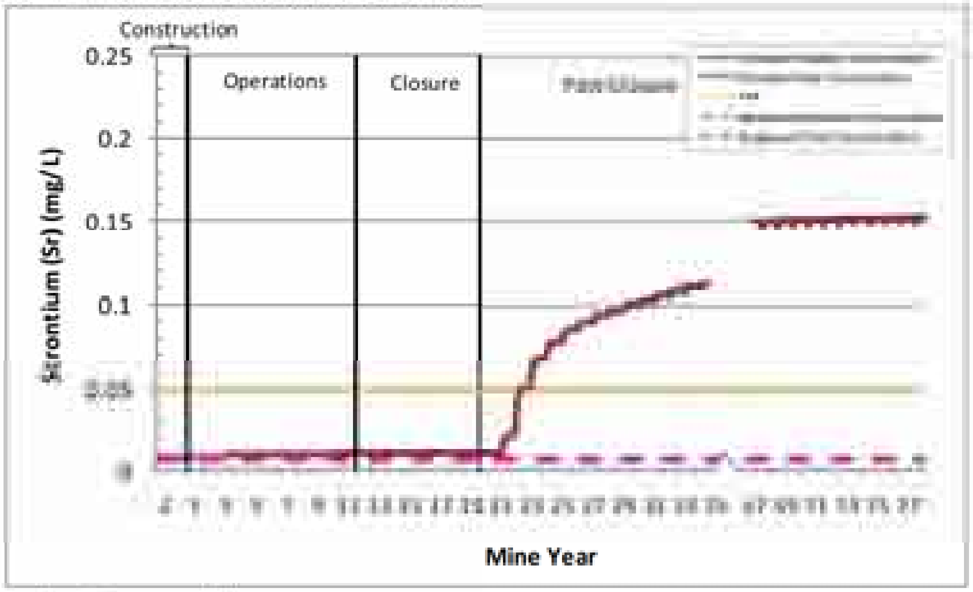
The effectiveness of these environmental design features and mitigation measures is uncertain and requires further analysis. Accordingly, the amount of phosphorus that may be released into the environment is uncertain at this time. As a result, potential effects related to phosphorus have not been presented and will not be available until such time as additional analysis is completed. This analysis will be provided to the Panel in 2011 following additional work that will be undertaken over the next few months.

Trace Metals

Concentrations of trace metals are predicted to follow the general trends described above for Area 8. After the initial period of approximately five years to approach Kennady Lake concentrations, trace metal concentrations are then predicted to decrease, remain relatively constant or decrease, for the reasons described for Kennady Lake in Section 8.8.4.1 for each metal. Representative time series plots are shown for strontium, which is predicted to increase following this five-year period; aluminum, which is predicted to remain relatively constant; and manganese, which is predicted to approach background conditions, in Figures 8.8-19 to 8.8-21, respectively.

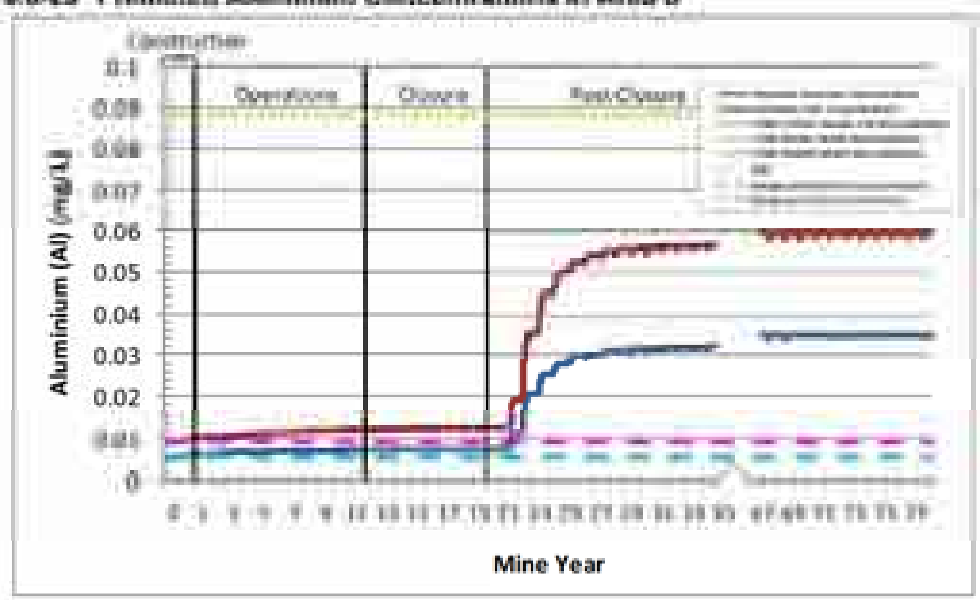
Of the 23 modelled trace metals, cadmium, chromium and copper are predicted to exceed guidelines in the post-closure period. These metals have been measured in Kennady Lake above guideline concentrations under existing environment conditions (Section 8.3.6).

Figure 8.8-19 Predicted Strontium Concentrations in Area 8



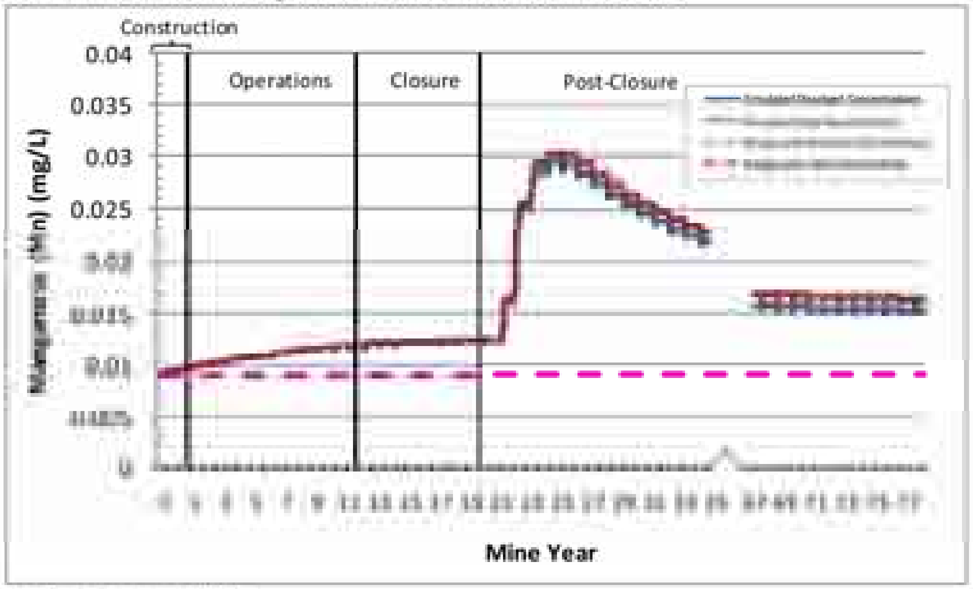
mg/L = milligrams per litre

Figure 8.8-20 Predicted Aluminum Concentrations in Area 8



mg/L = milligrams per litre

Figure 8.8-21 Predicted Manganese Concentrations in Area 8



mg/L = milligrams per litre

The potential health effects of all trace metals on aquatic life, including the three metals that are projected to have maximum concentrations above guideline concentrations (i.e., cadmium, chromium and copper), are assessed in Section 8.9.

8.8.4.2 Long-term Effects of Changes to Pit Water Quality on the Stability of Meromictic Conditions in the Tuzo Pit after Closure

Mining the kimberlite ore will result in three mine pits remaining at the end of operations (see Section 8.4). The first pit to be mined, 5034 pit, will be backfilled with waste rock to the sill between 5034 and Tuzo pit. Above the sill, 5034 will be partially backfilled, and the remaining unfilled portion of the pit will intersect with the portion of Tuzo pit above the sill. Therefore, analysis of Tuzo pit in this section also applies to un-filled portion of 5034 pit.

Hearne pit will be partially backfilled with fine PK and process water, and the final water depth will be approximately 120 m. Because Hearne pit will not be receiving highly saline water, it is assumed that meromixis will not occur in Hearne pit, and that water in the pit will be fully mixed with water in Area 6. This assumption resulted in conservative predictions, because if meromixis does occur in Hearne pit, the Kennady Lake water quality model will predict higher concentrations from the bottom of Hearne pit (via diffusive flux from the fine PK) that can influence long-term water quality in Kennady Lake.

When Tuzo Pit and Kennady Lake are refilled during the closure phase, higher-salinity water from the remaining portions of Kennady Lake will first be transferred to Tuzo Pit. Local runoff and water from Lake N11 will then be used to fill the remaining pit and Kennady Lake, resulting in lower-density water overlying the initially placed water. The presence of a pycnocline (i.e., a density gradient) is expected to result in stratification of water within the pit, which will essentially isolate the underlying water from Kennady Lake.

As described in Section 8.8.2.3, the stability of stratification in Tuzo pit was evaluated using two methods: by hydrodynamic modelling, and by long-term mass balance analysis. The results of these analyses are presented in the following subsections.

8.8.4.2.1 Hydrodynamic Model Predictions

Because it is not known precisely how much mixing will occur in Tuzo pit during the transition from filling with higher- to lower-density water, the model was run iteratively to determine the elevation of a long-term pycnocline. This long-term elevation was determined by initializing the model with two distinct layers, each comprised of either 100% higher-density or lower-density water. The volume of water remaining isolated after being subjected to 100 years of wind-driven mixing was then set as the initial volume in the monimolimnion for the next iteration, as well as the volume that was assumed to be isolated from Kennady Lake in the Kennady Lake model (Section 8.8.4.1).

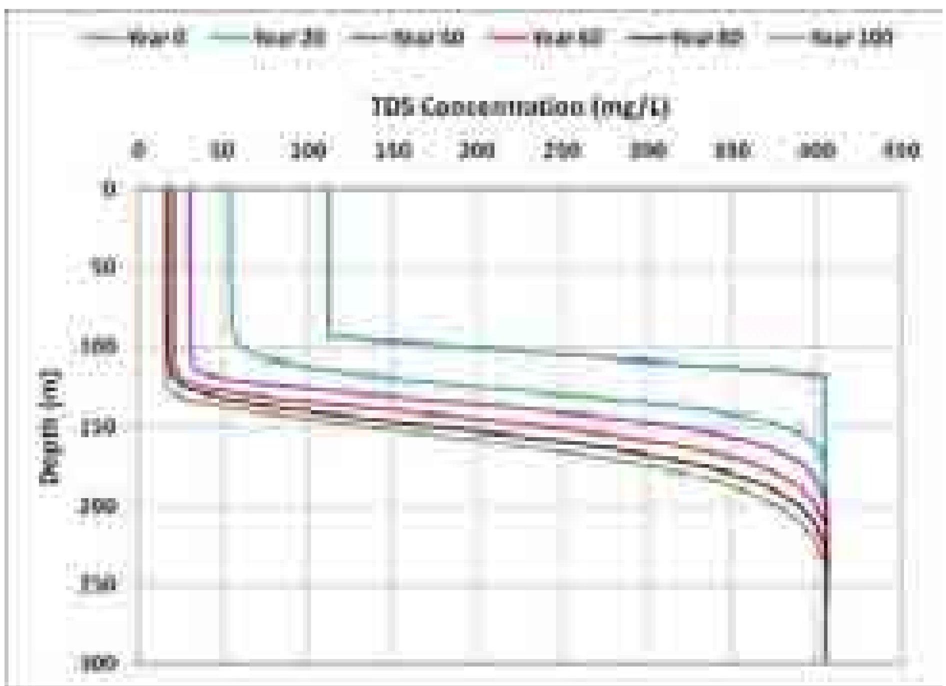
The second iteration was then used to determine the volume of monimolimnion water that might report back to the upper layers due to advection and diffusion. This simulation indicated that the pycnocline would move down slowly over a 100-year period (Figure 8.8-22). These elevations were then converted to volumes based on the storage-elevation curve for Tuzo Pit. A time series of monimolimnion volumes is shown in Figure 8.8-23.

As seen in Figure 8.8-20, the hydrodynamic model predicted a drop in pycnocline elevation of approximately 60 m over the 100-year time frame, which translates to a volume of 7.2 Mm^3 of water reporting to the upper layer of Kennady Lake. This volume of water was added back to the Kennady Lake model (Section 8.8.4.3) to account for the influx of underlying water.

The hydrodynamic results indicate that the rate of drop in pycnocline elevation will decline with time, which has two implications for water quality in Kennady Lake. First, it indicates that influences of Tuzo Pit water on Kennady Lake water quality will diminish with time, because the relative amounts of upward flux water will decrease accordingly. Second, it indicates a strengthening of the stratification as the pycnocline becomes deeper.

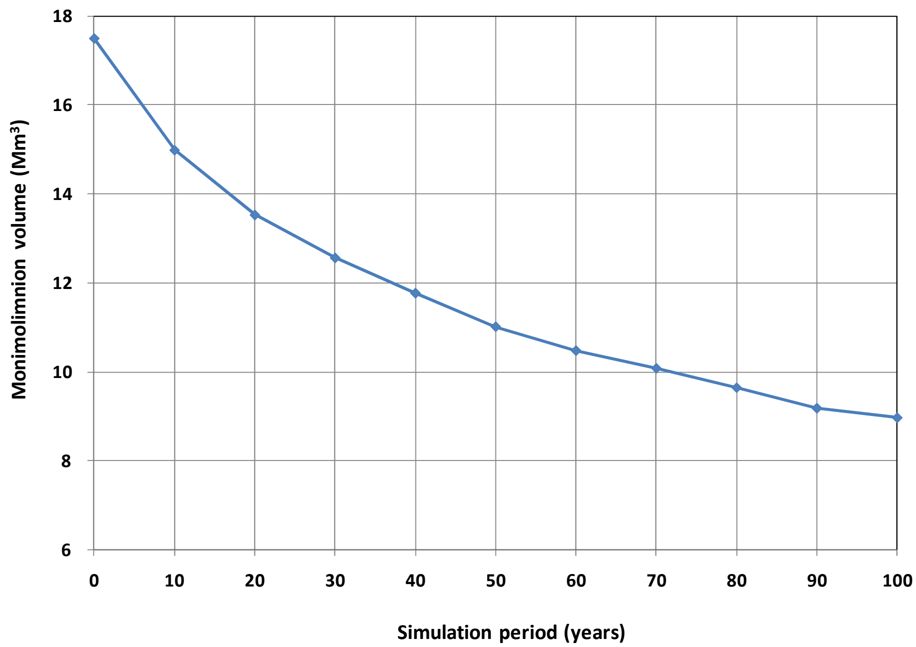
The strengthened stratification is predominantly due to two factors. First, a deeper pycnocline is inherently more stable because wind-driven forces are applied at the lake surface, so the energy required to perturb the system (i.e., the pit lake) increases with depth. Second, the gradual replacement of Kennady Lake waters with natural runoff will reduce the salinity of overlying water, thereby strengthening the pycnocline (i.e., increasing the difference in density between the surface and deep water zones) (Figure 8.8-22). A small influx of groundwater predicted by the groundwater modelling (see Section 11.6) is not predicted to increase salinity at depth over the modelled 100-year time frame.

Figure 8.8-22 Predicted Pycnocline Elevation over 100-year period after Refilling of Tuzo Pit



m = metres; mg/L = milligrams per litre

Figure 8.8-23 Predicted Monimolimnion Volumes over 100-year period after Refilling of Tuzo Pit



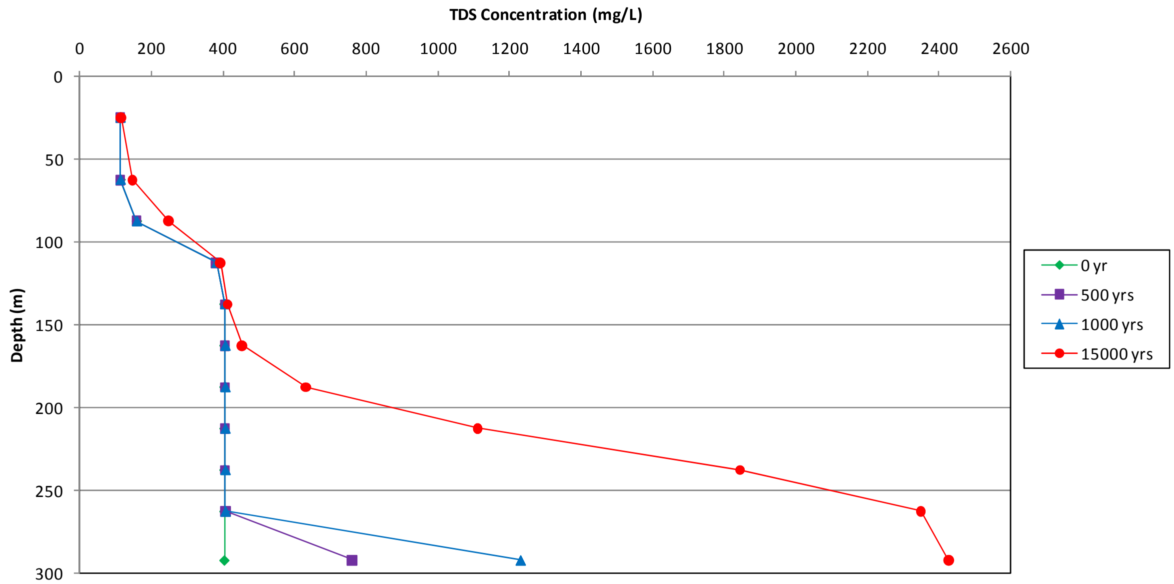
M m^3 = million cubic metres

8.8.4.2.2 Long Term Modelled Total Dissolved Solids Concentrations in the Tuzo Pit

The mass-balance slice model predicted a rising and strengthening stratification in the long term. Although the hydrodynamic simulation indicated very little change in monimolimnion TDS in the first hundred years, the mass-balance slice model indicated that inflows would begin to change TDS at depth in the first thousand years. After 15,000 years, the model indicated that the monimolimnion would increase in TDS and expand upwards due to the slight net inflow (Figure 8.8-24). The deeper pit water will eventually, over the very long term, take on the characteristics of the surrounding deep, high TDS groundwater

While the general trend of increased TDS and upward expansion of the pycnocline is likely reliable, this model may over-predict the extent to which these phenomena may occur. The model did not account for upward diffusion due to a concentration gradient, and it extrapolated groundwater inflows beyond the timeframe modelled by hydrogeological modelling. Nevertheless, it may be concluded with some confidence from this modelling that stratification in Tuzo pit will strengthen with time.

Figure 8.8-24 Modelled Water Column Distribution of Total Dissolved Solids Concentration in the Tuzo Pit Projected Over Time



m = metres; mg/L = milligrams per litre

8.9 EFFECTS TO AQUATIC HEALTH

8.9.1 Introduction

This section assesses the potential for health effects to aquatic life (referred to herein as aquatic health) in the Kennady Lake watershed resulting from the modelled changes in water quality that were presented in Section 8.8.3.1 during construction and operation and in Section 8.8.4.1 during closure. Section 8.8 also evaluated potential changes in water quality resulting from deposition of dust and metals during construction and operation (Section 8.8.3.1). Effects of dust and metals deposition do not apply to closure, because mining activities that generate dust will ceased after operations end and closure and reclamation activities are complete.

Section 8.8 also evaluated potential changes in the water quality of lakes within the Kennady Lake watershed resulting from deposition of acidifying substances, namely sulphate and nitrate. However, water quality modelling results indicate that Project-related deposition of sulphate and nitrate is not predicted to result in acidification in the Kennady Lake watershed.

Summaries of the primary pathways by which changes to aquatic health could occur during construction and operations and during closure are presented in Table 8.9-1 (construction and operations) and Table 8.9-2 (closure).

Table 8.9-1 Valid Pathways and Effects Statements for Effects to Aquatic Health during Construction and Operation

Project Component	Pathway	Effects Statement	Effects Addressed
Construction and Mining Activity	deposition of dust and metals in the Kennady Lake watershed may change aquatic health [a]	effects of air emissions on aquatic health in the Kennady Lake watershed	Section 8.9.3.1

(a) Effects of dust emissions do not apply to closure, because mining activities that generate dust will ceased after operations end.

Table 8.9-2 Valid Pathways and Effects Statements for Effects to Aquatic Health during Closure

Project Component	Pathway	Effects Statement	Effects Addressed
Breaching Dyke A to reconnect Kennady Lake with Area 8	altered water quality in Kennady Lake and Area 8 resulting in changes to aquatic health to waterbodies within the Kennady Lake watershed	effects of water quality changes to aquatic health in waterbodies within the Kennady Lake watershed	Section 8.9.3.2

Based on the primary pathway, three closure scenarios were assessed:

- Initial closure discharge water quality in Kennady Lake. This scenario summarizes the maximum concentrations in Kennady Lake at the end of the closure period, that is, after refilling is complete and just after breaching of Dyke A, which is the dyke between Area 7 and Area 8.
- Long-term water quality in Kennady Lake. This scenario summarizes the maximum concentrations in Kennady Lake 100 years into the post-closure period.
- Post-closure water quality in Area 8. This scenario summarizes the maximum concentrations in Area 8 during the post-closure period, that is, from after refilling of Kennady Lake is complete and full flow is possible between Kennady Lake and Area 8 to 100 years into the post-closure period.

8.9.2 Methods

8.9.2.1 Effects of Air Emissions on Aquatic Health in the Kennady Lake Watershed

Results of the water quality assessment indicate that dust and metals deposition may result in predicted maximum concentrations of suspended solids and some metals exceeding water quality guidelines in two or more lakes (Section 8.8.3.2). These elevated concentrations in surface waters are only expected to occur in short-term pulses during snowmelt and after storm events. The predicted concentrations are based on highly conservative assumptions as used in the air quality modeling and mass balance analysis (Section 8.8.1.1.2). For example, the air quality modeling incorporated conservative assumptions such as not accounting for reductions in dust emissions due to precipitation in summer or snow in winter. The mass balance analysis did not consider total lake volumes as dilution factors in the dust input. Therefore, the predicted concentrations are likely conservative estimates of the maximum potential concentrations. There is no quantitative basis for assessing these predicted concentrations. For example, although elevated suspended solids are expected during freshet, there are no baseline data to indicate what aquatic organisms would be typically exposed to under freshet conditions and therefore, what concentration would be considered “elevated” in relation to baseline. Given the conservative nature of the predicted concentrations, and the limited scientific basis to assess potential effects to short-term changes in this case, the evaluation of potential effects to aquatic health in lakes affected by dust and metals deposition was conducted qualitatively.

8.9.2.2 Effects of Water Quality Changes to Aquatic Health in Waterbodies within the Kennady Lake Watershed

Predicted changes to water quality could affect aquatic health through two exposure pathways:

- direct exposure to substances in the water column; and,
- indirect effects related to possible accumulation of substances within fish tissue via uptake from both water and diet.

Both mechanisms were evaluated as part of the aquatic health assessment. Potential effects related to direct exposure were evaluated based on modelled water quality in Kennady Lake and Area 8 during closure (Section 8.9.2.1.1). Predicted water concentrations were compared with chronic effects benchmarks to evaluate the potential for aquatic health effects due to direct waterborne exposure. The analysis of indirect effects to fish tissue quality was conducted by using measured baseline water quality, modelled water quality, and measured fish tissue concentrations to predict tissue concentrations of chemicals within aquatic organisms (Section 8.9.2.2.2). Predicted tissue concentrations were compared with toxicological benchmarks to evaluate the potential for aquatic health effects related to tissue concentrations. The methods used for both evaluations are outlined in more detail below.

8.9.2.2.1 Direct Waterborne Exposure

Changes to water quality in Kennady Lake and Area 8 after the refilling of Kennady Lake is complete and Dyke A (the dyke between Area 7 and Area 8) is breached were predicted using a dynamic water quality model following the methods described in Section 8.8.2 and Appendix 8.I. The resulting modelled water quality results were passed through a screening procedure to identify substances of potential concern (SOPCs), which are substances for which the modelled concentrations were higher than those observed under baseline conditions and that were also higher than relevant and applicable water quality guidelines for the protection of aquatic life. To assess whether the SOPCs have the potential to affect aquatic health under the evaluated scenarios, modelled concentrations of these substances were compared to chronic effects benchmarks (CEBs), which were derived from a review of available toxicological literature.

The screening procedure used to identify an SOPC was a three-step process. The first step (Step 1) in the process involved assessing which of the modelled parameters had the potential to detrimentally affect aquatic health and which parameters could be excluded from further consideration for one of the following reasons:

- the parameter in question has been shown to have limited potential to affect aquatic health (i.e., innocuous substances);
- potential effects related to the parameter in question are assessed elsewhere in the EIS; and/or
- the parameter in question is a component of another parameter, which is a more suitable focus point for the analysis.

Parameters excluded during the first step of the screening process consisted of:

- sodium, based on work by Mount et al. (1997), which indicates that this substance has low toxicity to aquatic life;
- phosphorus and nitrogen compounds as nutrients, because potential effects related to any potential trophic changes are assessed in

Section 8.10.2.1 (note that nitrate and ammonia were also screened for toxicity effects using water quality guidelines for the protection of aquatic life);

- calcium, chloride, magnesium, sulphate, and potassium, because they are individual ions for which Canadian protection of aquatic life guidelines have not yet been established and they are components of total dissolved solids (TDS), another modelled parameter included in the assessment; and
- the dissolved form of metals, metalloids, and non-metals[4], because they are a component of the corresponding total metal concentrations and total metal measurements are a more conservative basis for assessment than dissolved metals measurements.

The remaining substances, which included total metals, total suspended solids (TSS), and TDS, were subjected to a screening process, which involved comparing predicted maximum concentrations with:

- baseline water quality concentrations (Step 2); and,
- Canadian water quality guidelines for the protection of aquatic life (CCME 1999) (Step 3).

Step 2 recognized that existing concentrations may also exceed water quality guidelines. If the predicted concentration was less than or within 10 percent (%) of the long-term average concentration under baseline conditions, then the parameter was excluded from the assessment, because no incremental impact on aquatic health would be expected. A difference of less than or equal to 10% was not considered to be a change that would represent a potential effect to water quality, because:

- analytical uncertainty can be as high as, or higher than, 10%, depending on the individual parameter in question;
- a difference of less than 10% is unlikely to be statistically significant; for example, with a sample size of less than 200, the 95% confidence interval of the mean of a normally distributed variable with a typical coefficient of variation of 0.6 will be greater than 10%; and,
- effects to aquatic organisms are unlikely to be detectable for a change in a substance concentration of less than 10%.

[4] Henceforth, metals, metalloids (e.g., arsenic), and non-metals (e.g., selenium) will be referred to as metals.

Step 3 involved a comparison to water quality guidelines to determine whether substances with guidelines have the potential to affect aquatic health. For SOPCs with guidelines that were dependent on pH (i.e., aluminum) or hardness (i.e., cadmium, copper, lead, nickel), the predicted pH or hardness associated with those SOPC concentrations were used in the screening. For chromium, which has a guideline that is dependent on speciation, the most conservative guideline was used (i.e., hexavalent chromium) although it is assumed that most of the chromium will be present as trivalent chromium (see Section 8.8.4.1.1).

Water quality guidelines represent levels that, if met in any surface water, will provide a high level of protection to aquatic life. In this assessment, the *Canadian Water Quality Guidelines for the Protection of Aquatic Life* were used; these conservative guidelines are intended to ”protect all forms of aquatic life and all aspects of the aquatic life cycles, including the most sensitive life stage of the most sensitive species over the long term” (CCME 1999). That is, exceedance of a water quality guideline indicates the possibility of adverse effects, but not necessarily a likelihood. At this stage in the screening process, parameters without guidelines were identified as SOPCs, with the exception of those specifically excluded above.

For each SOPC, predicted concentrations were compared to chronic effects benchmarks (CEBs). The CEBs were developed using species sensitivity distributions (SSDs) whenever sufficient toxicity data were available. In the absence of sufficient data, CEBs were defined using the lowest chronic toxicity test value available for species relevant to the Gahcho Kué Project (Project) area. The toxicity database excluded non-resident species, which improved the relevance of the CEBs to the receiving environment of Kennady Lake and the downstream lakes.

The CEBs represent substance concentrations above which changes to aquatic health could occur on the scale of individual organisms. The benchmarks are less conservative (i.e., more realistic) than water quality guidelines, but retain a level of conservatism for the evaluation of population-level effects, which would require concentrations to be higher than the CEBs described herein. Consequently, the CEBs are considered to be conservative thresholds by which potential effects to aquatic health can be assessed. Further detail as to the methods used to derive the CEBs is provided in Appendix 8.IV.

8.9.2.2.2 Indirect Exposure - Changes to Fish Tissue Quality

In addition to assessing potential effects to aquatic health due to direct waterborne exposure, potential effects due to changes in fish tissue quality were assessed. Potential changes to fish tissue concentrations in Kennady Lake and

Area 8 at closure were estimated by multiplying predicted maximum concentrations in water by parameter-specific bioaccumulation factors (BAFs). Only those parameters for which toxicological benchmarks could be defined were considered. These parameters, hereafter called substances of interest (SOI), were:

- aluminum
- antimony
- arsenic
- cadmium
- chromium
- copper
- lead
- mercury
- nickel
- selenium
- silver
- vanadium
- zinc

Site-specific BAFs for each SOI were derived for each lake and fish species using water quality concentrations and fish tissue concentrations measured during the baseline sampling programs. The lake- and species-specific BAFs were calculated using the following formula:

$$BAF_{(lake,\ species)} = C_{Fish} \div C_{Water}$$

where:

$BAF_{(lake,\ species)}$ = bioaccumulation factor for a specific lake and fish species

C_{Fish} = concentration of substance “x” in fish (milligrams per kilogram wet weight [mg/kg wet wt])

C_{Water} = concentration of substance “x” in water (mg/L).

The term C_{Water} was set to the median concentration observed in the water quality samples collected from the lake being considered. Given that water quality in the study lakes was similar among years, all available baseline water quality data were pooled and overall median water concentrations were calculated. The term C_{Fish} was similarly set to the median concentration observed in fish muscle tissue samples collected from either Kennady Lake, Lake N16, Kirk Lake, or Lake 410. All non-detectable tissue concentration results were set to the corresponding detection limit, which resulted in conservative multiplication factors.

Bioaccumulation factors were derived based on concentrations of substances measured in muscle tissue of lake trout and round whitefish. Only whole-body concentration data were available for slimy sculpin, and these were not included in BAF derivation based on the following rationale:

- The primary concern in terms of potential effects on fish health is large-bodied fish such as lake trout and round whitefish. These species are abundant in Kennady Lake, form a key component of the lake ecosystem, and are fished for consumption. Slimy sculpin are small-bodied, benthic feeding fish that are not abundant in the study lakes and are not fished. During the baseline sampling program in 2007, sculpin had to be collected from the outlet creeks of the lakes to obtain sufficient sample for tissue analysis.
- Analysis of whole body samples of sculpin unavoidably leads to the inclusion of gut contents in the analysis, and this can give unreliable measurements of the actual concentrations of substances in the tissues of the sculpin. Sculpin are benthic feeding fish that have a relatively high potential to ingest sediment with their prey. Thus, by including gut contents, whole body measurements can result in artificially inflated measurements of metals that are abundant in mineral sediments (e.g., aluminum), due to the inclusion of prey and incidentally-ingested sediment in the gut in the analysis.

The whole-body sculpin tissue concentrations of several metals, including aluminum and several other substances abundant in mineral sediments, were substantially higher than concentrations measured in lake trout and round whitefish (Annex J). The concentrations measured in sculpin whole body analyses are therefore considered most likely to be artefactual (i.e., reflecting the inclusion of sediment and prey in the gut), and not an accurate representation of the accumulation of these substances in fish tissue. Inclusion of the sculpin whole body concentration data in the BAF analysis would result in unrealistic estimates of tissue concentrations in fish. Therefore, the sculpin data were excluded and the BAF analysis was based on lake trout and round whitefish. The lake- and species-specific BAFs were categorized by level of reliability based on the frequency of detections in the water and tissue data. The BAFs calculated from water and tissue concentrations with high detection frequencies were considered the most reliable BAFs, and therefore were selected preferentially over less reliable BAFs. The reliability criteria were:

- If both water and tissue concentrations were frequently detected, then the resulting BAF was considered to be the most reliable;
- If water was detected frequently, but tissue was not, then the resulting BAF was considered to be less reliable, but still an acceptable upper-bound estimate (i.e., likely a conservative over-estimate) for the purposes of this assessment;
- If water was infrequently detected, and tissue was frequently detected, then the resulting BAF was considered less reliable and a potentially lower-bound estimate for the purposes of this assessment; and

- If both water and tissue were infrequently detected, then the resulting BAF was considered to be unreliable and was not used in this assessment.

The BAFs for each SOI used in the indirect exposure assessment are summarized in Table 8.9-3.

Table 8.9-3 Selected Bioaccumulation Factors for the Indirect Exposure Assessment

Substance of Interest	Selected Bioaccumulation Factor	Reliability Category
Aluminum	278	less reliable; upper-bound estimate
Antimony	2729	less reliable; upper-bound estimate
Arsenic	417	less reliable; upper-bound estimate
Cadmium	237	less reliable; lower-bound estimate
Chromium	78	most reliable
Copper	839	most reliable
Lead	80	less reliable; upper-bound estimate
Mercury	9450	less reliable; lower-bound estimate
Nickel	232	most reliable
Selenium	3000	less reliable; lower-bound estimate
Silver	2000	less reliable; upper-bound estimate
Vanadium	95	most reliable
Zinc	379	most reliable

Predicted fish tissue metal concentrations were compared to toxicological benchmarks that have been shown in laboratory studies to be associated with sublethal effects in fish. Jarvinen and Ankley (1999) provide a database linking effects on aquatic organisms and concentrations of inorganic and organic chemicals in various fish tissues. Both acute and chronic effect-endpoints for a range of species and trophic levels are provided in the database. Occasionally, only lethal endpoints were available. A summary of the Jarvinen and Ankley (1999) endpoints that were relevant to the current assessment is provided in Table 8.9-4

Table 8.9-4 Fish Tissue Effects Concentrations

Substance of Interest	Effects Concentration (mg/kg wet weight)	Endpoint	Tissue	Fish, Age/Size
Aluminum	20	survival – reduced	whole body	Atlantic salmon, alevin
	<8	growth – no effect		
	1.15	survival – no effect	muscle	rainbow trout, 171 g
Antimony	9.0	survival – reduced 50%	whole body	rainbow trout, fingerling
	5.0	survival – no effect		

Table 8.9-4 Fish Tissue Effects Concentrations (continued)

Substance of Interest	Effects Concentration (mg/kg wet weight)	Endpoint	Tissue	Fish, Age/Size
Arsenic	11.2	survival – reduced	carcass	rainbow trout, juvenile
	6.1	survival, growth – no effect		
	3.1	growth – reduced		
Cadmium	2.8	survival, growth – no effect	muscle	rainbow trout, adult
	0.6	reproduction – reduced	muscle	
	0.4	reproduction – no effect	muscle	
Chromium	0.58	survival – no effect	muscle	rainbow trout, 150 to 200 g
Copper	3.4	survival, growth, reproduction – no effect	muscle	brook trout, embryo, adult, juvenile
	0.5	survival – no effect	muscle	rainbow trout, 138 g
Lead	4.0	survival – no effect	carcass	rainbow trout, under-yearlings
	2.5 to 5.1	growth – no effect	whole body	brook trout, embryo – juvenile
Mercury	5.8	survival – no effect growth – reduced	muscle	chum salmon, fry, juvenile
	5.0	growth, survival – no effect	whole body	rainbow trout, juvenile
	0.8	growth – no effect	whole body	fathead minnow, adult
Nickel	118.1	survival – reduced 50%	white muscle	carp, 15 g
	58.0	survival – no effect	white muscle	freshwater carp, 15 g
	0.82	survival – no effect	muscle	rainbow trout, 150 to 200 g
Silver	0.06	survival, growth – no effect	whole body	bluegill, young-of-the-year
	0.003	survival, growth – no effect	carcass	largemouth bass, young-of-the-year
Vanadium	5.33	survival – no effect	carcass	rainbow trout, juvenile
	0.41	growth – reduced		
	0.02	growth – no effect		
Zinc	60	survival, growth – no effect	whole body	Atlantic salmon, juvenile
	4.5	survival, growth – no effect	whole body	brook trout, embryo-larvae

Source: Jarvinen and Ankley (1999).

mg/kg = milligrams per kilogram; < = less than; g = gram; % = percent.

Benchmarks were selected from the Jarvinen and Ankley (1999) database to represent levels beyond which detrimental effects (e.g., reduced growth or reproductive success) may occur. However, for some SOIs, available information was limited to no observed effect concentrations (NOECs). The parameters for which only NOECs were available were arsenic, chromium, copper, lead, mercury, nickel, silver, and zinc. The tissue-based NOECs are similar to most water-based no-effect thresholds in that concentrations less than a NOEC are not considered likely to lead to detrimental effects, whereas the opposite is not necessarily true (i.e., concentrations in excess of NOECs will not necessarily result in detrimental effects). This resulted in benchmarks that were overly conservative estimates of effects thresholds, and predicted fish tissue concentrations were interpreted with this limitation in mind.

Although the Jarvinen and Ankley (1999) database includes information for selenium, the selenium threshold used herein originates from the United States Environmental Protection Agency (US EPA 2004), which represents a more up-to-date assessment of potential effects of selenium on fish health. The threshold derived from the US EPA (2004) data was evaluated by a review of more recent selenium toxicity studies with coldwater fish (Holm et al. 2005, Muscatello et al. 2006, Rudolph et al. 2008, McDonald et al. 2010) and was determined to be an appropriately protective benchmark for fish species that occur in the study area.

8.9.3 Results

8.9.3.1 Effects of Air Emissions to Aquatic Health in the Kennady Lake Watershed

Results of the water quality assessment indicate that dust and metals deposition may result in predicted maximum concentrations of suspended solids and some metals (aluminum, cadmium, chromium, copper, iron, mercury, and silver) that exceed water quality guidelines in some lakes, including both fish-bearing and non-fishing bearing lakes (Section 8.8.3.2). However, the predicted concentrations are likely conservative estimates of the maximum potential concentrations as they reflect the conservative assumptions used in the air quality modeling and mass balance analysis (Section 8.8.1.1.2).

The spatial extent of the dust and metals deposition is expected to be restricted to localized areas within the Project footprint. Most of the deposition will impact the affected lakes during the short period of freshet, when dust deposited to snow enters surface waters. The length of the freshet period is estimated to range from a few days in small lakes to 1 to 2 weeks in Kennady Lake. Therefore, the period of elevated suspended solids and metals in affected lakes is expected to be relatively short. Given the conservatism in the predicted concentrations, and the relatively short duration of the exposure to elevated concentrations, the potential for adverse effects from dust and metals deposition is considered to be low. Follow-up monitoring will be undertaken to confirm this evaluation.

8.9.3.2 Effects of Changes to Water Quality on Aquatic Health in Waterbodies within the Kennady Lake Watershed during Closure

8.9.3.2.1 Direct Waterborne Exposure

Based on the three-step screening process described in Section 8.9.2.2.1, 13 SOPCs were identified in Kennady Lake under the initial closure discharge water quality scenario (Table 8.9-5):

- TDS
- antimony
- barium
- beryllium
- cadmium
- chromium
- cobalt
- copper
- iron
- manganese
- strontium
- uranium
- vanadium

Based on the three-step screening process described in Section 8.9.2.2.1, 12 SOPCs were identified in Kennady Lake under the long-term water quality scenario (Table 8.9-6):

- TDS
- antimony
- barium
- beryllium
- cadmium
- chromium
- cobalt
- copper
- manganese
- strontium
- uranium
- vanadium

Based on the three-step screening process described in Section 8.9.2.2.1, 12 SOPCs were identified in Area 8 under the post-closure scenario (Table 8.9-7):

- TDS
- antimony
- barium
- beryllium
- cadmium
- chromium
- cobalt
- copper
- manganese
- strontium
- uranium
- vanadium

A summary of the SOPCs identified at each assessment point is presented in Table 8.9-8.

Table 8.9-5 Initial Screening Results for Kennady Lake under Initial Closure Discharge Water Quality Scenario

Parameter	Kennady Lake Background Concentrations (Long-term Average) (mg/L)	CCME Freshwater Aquatic Life Guideline (mg/L)[(a)]	Predicted Maximum Concentration (mg/L)	Screening		Retained as Substance of Potential Concern?
				Higher than Predicted Background + 10%?	Higher than CCME Guideline?	
Conventional Parameters						
Total Dissolved Solids	11	-	162	yes	-	**yes**
Total Suspended Solids	<2[(b)]	5[(c)]	1.0	no	no	no
Nutrients						
Ammonia as Nitrogen	0.018	4.5[(d)]	3.1	yes	no	no
Nitrate as Nitrogen	<0.007[(b)]	2.9	2.9	yes	no	no
Total Metals						
Aluminum	0.0094	0.1[(e)]	0.071	yes	no	no
Antimony	0.00014	-	0.0021	yes	-	**yes**
Arsenic	0.00013	0.005	0.0025	yes	no	no
Barium	0.0026	-	0.19	yes	-	**yes**
Beryllium	0.000048	-	0.00014	yes	-	**yes**
Boron	0.002	1.5	0.59	yes	no	no
Cadmium	0.00002	0.000032[(f)]	0.000042	yes	yes	**yes**
Chromium	0.00021	0.001[(g)]	0.0050	yes	yes	**yes**
Cobalt	0.000085	-	0.00048	yes	-	**yes**
Copper	0.0013	0.002[(f)]	0.0028	yes	yes	**yes**
Iron	0.042	0.3	0.44	yes	yes	**yes**
Lead	0.000039	0.002[(f)]	0.00038	yes	no	no
Manganese	0.0091	-	0.056	yes	-	**yes**
Mercury	0.0000066	0.000026	0.000017	yes	no	no
Molybdenum	0.000059	0.073	0.012	yes	no	no
Nickel	0.00048	0.065[(f)]	0.0031	yes	no	no
Selenium	0.000025	0.001	0.00084	yes	no	no
Silver	0.000043	0.0001	0.000076	yes	no	no
Strontium	0.0082	-	0.19	yes	-	**yes**
Thallium	0.000022	0.0008	0.00019	yes	no	no
Uranium	0.000024	-	0.0022	yes	-	**yes**
Vanadium	0.00021	-	0.0030	yes	-	**yes**
Zinc	0.0028	0.03	0.012	yes	no	no

(a) From CCME (1999).

(b) Median detection limit.

(c) Guideline is dependent on background concentration: predicted concentration must not be more than 5 mg/L higher than the background concentration.

(d) Guideline is dependent on temperature and pH. The value is based on pH = 7.0, temperature = 18°C.

(e) Aluminum guideline is dependent on pH; guideline shown is for pH ≥6.5, which corresponds to expected conditions in Kennady Lake.

(f) Guideline is hardness dependant; value shown based on a maximum predicted hardness of 97 mg/L as calcium carbonate ($CaCO_3$).

(g) Guideline is for chromium (VI), because it is more conservative than the chromium (III) guideline of 0.0089 mg/L.

mg/L = milligrams per litre; % = percent; < = less than; - = no guideline available or predicted concentration was less than the observed maximum background.

Table 8.9-6 Initial Screening Results for Kennady Lake under the Long-term Water Quality Scenario

Parameter	Kennady Lake Background Concentrations (Long-term Average) (mg/L)	CCME Freshwater Aquatic Life Guideline (mg/L)[a]	Predicted Maximum Concentration (mg/L)	Screening		Retained as Substance of Potential Concern?
				Higher than Predicted Background + 10%?	Higher than CCME Guideline?	
Conventional Parameters						
Total Dissolved Solids	11	-	83	yes	-	**yes**
Total Suspended Solids	<2[b]	5[c]	1.0	no	no	no
Nutrients						
Ammonia as Nitrogen	0.018	4.5[d]	0.021	yes	no	no
Nitrate as Nitrogen	<0.007[b]	2.9	0.037	yes	no	no
Total Metals						
Aluminum	0.0094	0.1[e]	0.070	yes	no	no
Antimony	0.00014	-	0.0019	yes	-	**yes**
Arsenic	0.00013	0.005	0.0024	yes	no	no
Barium	0.0026	-	0.19	yes	-	**yes**
Beryllium	0.000048	-	0.00014	yes	-	**yes**
Boron	0.002	1.5	0.59	yes	no	no
Cadmium	0.00002	0.000017[f]	0.000040	yes	yes	**yes**
Chromium	0.00021	0.001[g]	0.0013	yes	yes	**yes**
Cobalt	0.000085	-	0.00027	yes	-	**yes**
Copper	0.0013	0.002[f]	0.0027	yes	yes	**yes**
Iron	0.042	0.3	0.14	yes	no	no
Lead	0.000039	0.001[f]	0.00022	yes	no	no
Manganese	0.0091	-	0.015	yes	-	**yes**
Mercury	0.0000066	0.000026	0.000011	yes	no	no
Molybdenum	0.000059	0.073	0.012	yes	no	no
Nickel	0.00048	0.025[f]	0.0031	yes	no	no
Selenium	0.000025	0.001	0.00025	yes	no	no
Silver	0.000043	0.0001	0.000059	yes	no	no
Strontium	0.0082	-	0.19	yes	-	**yes**
Thallium	0.000022	0.0008	0.000038	yes	no	no
Uranium	0.000024	-	0.00085	yes	-	**yes**
Vanadium	0.00021	-	0.0029	yes	-	**yes**
Zinc	0.0028	0.03	0.0045	yes	no	no

(a) From CCME (1999).

(b) Median detection limit.

(c) Guideline is dependent on background concentration: predicted concentration must not be more than 5 mg/L higher than the background concentration.

(d) Guideline is dependent on temperature and pH. The value is based on pH = 7.0, temperature = 18°C.

(e) Aluminum guideline is dependent on pH; guideline shown is for pH ≥6.5, which corresponds to expected conditions in Kennady Lake.

(f) Guideline is hardness dependant; value shown based on a maximum predicted hardness of 47 mg/L as calcium carbonate ($CaCO_3$).

(g) Guideline is for chromium (VI), because it is more conservative than the chromium (III) guideline of 0.0089 mg/L.

mg/L = milligrams per litre; % = percent; < = less than; - = no guideline available or predicted concentration was less than the observed maximum background.

Table 8.9-7 Initial Screening Results for Area 8 Under Post-closure Scenario

Parameter	Kennady Lake Background Concentrations (Long-term Average) (mg/L)	CCME Freshwater Aquatic Life Guideline (mg/L)[a]	Predicted Maximum Concentration (mg/L)	Screening		Retained as Substance of Potential Concern?
				Higher than Predicted Background + 10%?	Higher than CCME Guideline?	
Conventional Parameters						
Total Dissolved Solids	11	-	94	yes	-	yes
Total Suspended Solids	<2[b]	5[c]	1.0	no	no	no
Nutrients						
Ammonia as Nitrogen	0.018	4.5[d]	1.6	yes	no	no
Nitrate as Nitrogen	<0.007[b]	2.9	1.5	yes	no	no
Total Metals						
Aluminum	0.0094	0.1[e]	0.060	yes	no	no
Antimony	0.00014	-	0.0016	yes	-	yes
Arsenic	0.00013	0.005	0.0020	yes	no	no
Barium	0.0026	-	0.15	yes	-	yes
Beryllium	0.000048	-	0.00013	yes	-	yes
Boron	0.0025	1.5	0.47	yes	no	no
Cadmium	0.00002	0.000019[f]	0.000039	yes	yes	**yes**
Chromium	0.00021	0.001[g]	0.0025	yes	yes	**yes**
Cobalt	0.000085	-	0.00034	yes	-	yes
Copper	0.0013	0.002[f]	0.0026	yes	yes	yes
Iron	0.042	0.3	0.24	yes	no	no
Lead	0.000039	0.001[f]	0.00022	yes	no	no
Manganese	0.0091	-	0.030	yes	-	yes
Mercury	0.0000066	0.000026	0.000013	yes	no	no
Molybdenum	0.000059	0.073	0.0098	yes	no	no
Nickel	0.00048	0.025[f]	0.0026	yes	no	no
Selenium	0.000025	0.001	0.00045	yes	no	no
Silver	0.000043	0.0001	0.000063	yes	no	no
Strontium	0.0082	-	0.15	yes	-	yes
Thallium	0.000022	0.0008	0.000096	yes	no	no
Uranium	0.000024	-	0.0011	yes	-	yes
Vanadium	0.00021	-	0.0024	yes	-	yes
Zinc	0.0028	0.03	0.0078	yes	no	no

(a) From CCME (1999).

(b) Median detection limit.

(c) Guideline is dependent on background concentration: predicted concentration must not be more than 5 mg/L higher than the background concentration.

(d) Guideline is dependent on temperature and pH. The value is based on pH = 7.0, temperature = 18°C.

(e) Aluminum guideline is dependent on pH; guideline shown is for pH ≥6.5, which corresponds to expected conditions in Kennady Lake.

(f) Guideline is hardness dependant; value shown based on a maximum predicted hardness of 54 mg/L as calcium carbonate ($CaCO_3$).

(g) Guideline is for chromium (VI), because it is more conservative than the chromium (III) guideline of 0.0089 mg/L.

mg/L = milligrams per litre; % = percent; < = less than; - = no guideline available or predicted concentration was less than the observed maximum background.

Table 8.9-8 Summary of Substances of Potential Concern Identified in Kennady Lake and Area 8 during Modelled Closure Scenarios

Parameter[a]	Kennady Lake		Area 8
	Initial Closure Discharge Water Quality	Long-term Water Quality	Post-closure Water Quality
Conventional Parameters			
Total Dissolved Solids	√	√	√
Total Suspended Solids			
Nutrients			
Ammonia			
Nitrate			
Total Metals			
Aluminum			
Antimony	√	√	√
Arsenic			
Barium	√	√	√
Beryllium	√	√	√
Boron			
Cadmium	√	√	√
Chromium	√	√	√
Cobalt	√	√	√
Copper	√	√	√
Iron	√		
Lead			
Manganese	√	√	√
Mercury			
Molybdenum			
Nickel			
Selenium			
Silver			
Strontium	√	√	√
Thallium			
Uranium	√	√	√
Vanadium	√	√	√
Zinc			

[a] Checkmark (√) indicates that the substance in question was identified as a substance of potential concern (SOPC).

For the direct waterborne exposure assessment, CEBs were derived for the SOPCs. For TDS, the CEB took the form of a range of concentrations, which were derived based on a review of the applicable literature. For the remaining SOPCs, single point benchmarks were identified, following the approach outlined in Appendix 8.IV. The predicted water concentrations summarized in Tables 8.9-5 through 8.9-7 were compared to the CEBs to conservatively evaluate the potential for adverse effects to aquatic health. The results of these comparisons are discussed below, beginning with TDS.

Total Dissolved Solids

Total dissolved solids was identified as an SOPC in Kennady Lake and Area 8, because of a projected increase in TDS concentrations over those that currently occur. The largest predicted increase occurs in Kennady Lake during the initial closure discharge phase of the Project, when TDS levels are predicted to increase from an existing maximum concentration of about 11 mg/L to a peak of 162 mg/L (Table 8.9-4). Long-term water quality in Kennady Lake and maximum post-closure TDS concentrations in Area 8 will be similar at maximum concentrations of 83 and 94 mg/L, respectively.

Total dissolved solids concentration (TDS) is a measurement of inorganic salts (e.g., sodium, potassium, calcium, magnesium, chloride, sulphate, and bicarbonate), organic matter, and other dissolved materials in water (Weber-Scannell and Duffy 2007). Toxicity can be caused by an increase in salinity, changes in ionic composition of the waters, or through toxicity of individual ions (Weber-Scannell and Duffy 2007). Sensitivity to TDS varies by species and is dependent on both the absolute concentration of all of the major ions contained in solution (effectively the absolute TDS concentration) as well as their relative abundance. In general, Mount et al. (1997) found that relative ion toxicity to freshwater species was potassium > bicarbonate = magnesium > chloride > sulphate, whereas calcium and sodium did not cause significant toxicity. However, ratios of particular TDS constituents, such as the ratio of calcium to sodium, may affect toxicity (Goodfellow et al. 2000). Species sensitivity may also vary with life stage; for example, fish embryos appear to be more sensitive if exposed before fertilization as opposed to after fertilization (Weber-Scannell and Duffy 2007). There is a very wide range of TDS and major ion concentrations in natural waterbodies. As a result of the significant variations in sensitivity of aquatic organisms and large range of concentrations in natural waterbodies, water quality guidelines have not been established in Canada for TDS or most major ions.

Background TDS in Kennady Lake is a mixture of calcium, chloride, magnesium, potassium, sodium, and sulphate, with calcium being slightly more abundant than the other ions. At the start of the post-closure phase, the ionic composition of the waters in Kennady Lake will be dominated by chloride, followed by calcium. During the post-closure phase, the three main constituents contributing to TDS in Kennady Lake and Area 8 will be chloride, sulphate, and calcium.

Toxicity data on the effects of TDS on freshwater species indicate that aquatic life in Kennady Lake or Area 8 will be largely unaffected by the projected increase in salinity. Beadle (1969), as cited in Bierhuizen and Prepas (1985), noted that freshwater species tend to be routinely found in waters with TDS levels of less than 1,000 mg/L, whereas they start to disappear when TDS levels exceed 3,000 mg/L (Hammer et al. 1975).

Adverse effects to fish are not expected at the predicted TDS concentrations in Kennady Lake and Area 8. Optimal habitat for northern pike (*Esox lucius*), one of the fish species present in Kennady Lake, includes TDS concentrations in the range of 80 to 800 mg/L (US Fish and Wildlife Service 1982). Northern pike and other freshwater fish species can be found in environments with higher TDS concentrations. For example, Buffalo Lake, which is located near Stettler, Alberta, has a moderate salinity (i.e., TDS concentrations around 1,500 mg/L) and contains northern pike, along with white suckers (*Catostomus commersonii*) and burbot (*Lota lota*) (University of Alberta 2008).

Most of the laboratory studies with fish embryos and swim-up fry have been conducted with TDS mixtures dominated by calcium and sulphate (e.g., Chapman et al. 2000, Stekoll et al. 2003, Brix et al. 2010). There were no adverse effects on early life stages of rainbow trout (*Oncorhynchus mykiss*) after seven days exposure to 2,000 mg/L TDS (Chapman et al. 2000). Brix et al. (2010) found no significant effects of elevated TDS on fertilization success and reported a 72-h EC20 of >2,782 mg/L for Arctic grayling (*Thymallus arcticus*) and a 24-h EC20 of >1,817 mg/L for Dolly Varden (*Salvelinus malma*). However, embryo water absorption was affected in 14-h exposures, with LOECs of 1,402 mg/L for Arctic grayling and 964 mg/L for Dolly Varden. Stekoll et al. (2003) found that salmonid embryos were most sensitive to TDS when exposed during fertilization: the 24-h LOECs ranged from 250 to 1,875 mg/L. Brannock et al. (2002) found that calcium chloride and sodium sulphate had the most detrimental effect on fertilization rates in king salmon (*Oncorhynchus tshawytscha*) and pink salmon (*Oncorhynchus gorbuscha*). As predicted closure concentrations in Kennady Lake and Area 8 are below these levels, negligible effects to fish health are expected.

Potential effects to pelagic invertebrates also are not expected to occur. Most of the TDS toxicity data are from studies with cladocerans, such as *Ceriodaphnia dubia*, and *Daphnia magna*, because these species are common laboratory test organisms. Predicted ion concentrations and TDS levels are lower than toxic thresholds identified by Cowgill and Milazzo (1990) for these species (i.e., 1,200 mg/L sodium chloride [NaCl]). Predicted concentrations are also lower than the 48-h LC50s reported by Mount et al. (1997) for *Ceriodaphnia dubia* for solutions containing a mixture of ions, including sodium, sulphate, bicarbonate, calcium, chloride and magnesium (i.e., 1,510 to greater than 5,700 mg/L). Although neither of these cladocerans may be present in Kennady Lake, they are recognized as being among the most sensitive invertebrates for a wide range of substances. For example, *Daphnia magna* and *Ceriodaphnia dubia* are more sensitive to calcium chloride than copepods (Baudouin and

Scoppa 1972). As the predicted TDS and major ion concentrations in Kennady Lake and Area 8 are expected to be below the levels associated with effects in the literature, negligible effects to pelagic invertebrates are expected.

Toxicity data specific to benthic invertebrates indicate that benthic invertebrate populations in Kennady Lake or Area 8 will be largely unaffected by the projected increase in salinity. Chapman et al. (2000) reported a 10-d LOEC of 1,750 mg/L for survival of *Chironomus tentans* exposed to synthetic TDS mixtures (TDS consisted mainly of calcium sulphate). Hynes (1990) described no effects on the benthic invertebrate community of a lake in northern Saskatchewan receiving treated uranium mill effluent where TDS levels increased from 76 to 2,700 mg/L. The major ions primarily responsible for this increase were calcium, sodium, chloride, and sulphate. No statistically significant decreases in abundance or species diversity were observed in the affected lake relative to reference conditions.

Based on the above, predicted changes to major ion levels and TDS concentrations in Kennady Lake and Area 8 are expected to have a negligible effect on aquatic health.

Remaining Parameters

In addition to TDS, 12 other SOPCs were identified in one or more of the assessment scenarios for direct waterborne exposure:

- antimony
- barium
- beryllium
- cadmium
- chromium
- cobalt
- copper
- iron
- manganese
- strontium
- uranium
- vanadium

During closure, maximum concentrations of total antimony, barium, beryllium, cadmium, chromium, cobalt, manganese, uranium, and vanadium are predicted to remain below the CEB identified for each substance, as shown in Table 8.9-9. As a result, the predicted increases in the concentrations of these nine substances are expected to have a negligible effect on aquatic health in Kennady Lake and Area 8 under closure conditions.

Maximum concentrations of the remaining three SOPCs, which include total copper, iron, and strontium are projected to be above their respective benchmarks at one or more points during closure (Table 8.9-9). The environmental relevance of these predictions is discussed below.

Table 8.9-9 Comparison of Maximum Concentrations to Chronic Effects Benchmarks for Selected Substances of Potential Concern

Substance of Potential Concern	Chronic Effect Benchmark (mg/L) [(a)]	Kennady Lake		Area 8
		Maximum Concentration in Initial Closure Discharge Water Quality (mg/L)	Maximum Concentration in Long-Term Water Quality (mg/L)	Maximum Concentration in Post-closure Water Quality (mg/L)
Antimony	0.157	0.0021	0.0019	0.0016
Barium	5.8	0.19	0.19	0.15
Beryllium	0.0053	0.00014	0.00014	0.00013
Cadmium	0.00026 [(b)]	0.000042	0.000040	0.000039
Chromium	0.0083 [(c)]	0.0050	0.0013	0.0025
Cobalt	0.0093	0.00048	0.00027	0.00034
Copper	0.002	**0.0028 (0.0022)** [(d)]	**0.0027 (0.0021)**	**0.0026** (0.0019)
Iron	0.3	**0.44** (0.36)	**-** [(e)]	**-**
Manganese	1.455	0.056	0.015	0.031
Strontium	0.049 [(f)]	**0.19 (0.19)**	**0.19 (0.19)**	**0.15 (0.15)**
Uranium	0.015	0.0022	0.00085	0.0011
Vanadium	0.0338	0.0030	0.0029	0.0024

Bolded concentrations are greater than corresponding chronic effects benchmark.

(a) Developed as outlined in Appendix 8.IV.

(b) The CEB for cadmium varies with hardness; the reported value is based on a hardness of 47 mg/L, which is the lowest predicted hardness of the three scenarios presented in this table.

(c) The CEB for chromium varies with speciation; the CEB for chromium (VI) is 0.0083 mg/L whereas the CEB for chromium (III) is 0.089 mg/L. Although it is anticipated that most chromium will be present as chromium (III) (Section 8.8.4.1.1), the more conservative CEB was used in the current assessment.

(d) Dissolved concentrations are shown in parentheses.

(e) - = parameter was not identified as a substance of potential concern (SOPC) at the scenario indicated.

(f) The available data did not support derivation of a CEB from a species sensitivity distribution. The adopted value of 0.049 mg/L is the lowest reported effects concentration, which is several orders of magnitude lower than the next-lowest value and therefore likely to be highly conservative.

mg/L = milligrams per litre.

Copper is a component of Kennady Lake bed sediment. Another source of copper to Kennady Lake as a result of the Project is from the PK, which will either be deposited in the Fine PKC Facility, or placed in the mined-out Hearne open pit. Predicted copper concentrations in Kennady Lake and Area 8 marginally exceed the CEB (Table 8.9-9).

Despite the predicted exceedances of the CEB, the potential for copper to cause adverse effects to aquatic life in Kennady Lake and Area 8 is considered to be low. The CEB for copper is based on the CCME guideline, which is intended to be conservative and protective of the most sensitive species. The predicted concentrations summarized in Table 8.9-9 are only slightly greater than the CEB, indicating the possibility (but not necessarily the likelihood) of effects to the most sensitive species. However, the CCME guideline does not consider the potential for other water quality characteristics (e.g., dissolved organic carbon) to reduce bioavailability and ameliorate copper toxicity. Furthermore, the CCME guideline is based on toxicity tests with naive organisms, whereas organisms inhabiting Kennady Lake potentially have some degree of acclimation or adaptation to copper, given that baseline sediment copper concentrations exceed the CCME interim sediment quality guideline (Section 8.3.6.2.1). Given the small magnitude by which predicted maximum concentrations exceed the CEB, and given the potential for ameliorating factors discussed above, the potential for adverse effects from copper is considered to be low. Follow-up monitoring will be undertaken to confirm this evaluation.

Iron is a common constituent of bed sediment in Kennady Lake, as outlined in Section 8.3.6.2.1 (Table 8.3-22). Bed sediment, entrained in site runoff and carried into the water management pond, is likely a source of iron in the Kennady Lake initial closure discharge scenario. Another source of iron in the predicted water quality is from groundwater. Most of the iron is predicted to exist in dissolved form (Table 8.9-9), and the dissolved concentrations of iron are predicted to be slightly above the corresponding CEB (Table 8.9-9).

The potential for iron to cause adverse effects to aquatic life in Kennady Lake is considered to be low. The CEB for iron is based on the CCME guideline, which is intended to be conservative and protective of the most sensitive species. The predicted concentrations summarized in Table 8.9-8 are only slightly greater than the CEB, indicating the possibility (but not necessarily the likelihood) of effects to the most sensitive species. As summarized in Section 8.IV.2.7, iron concentrations similar to the CEB have been reported by some authors to elicit sublethal effects on cladocerans (Dave 1984). However, other authors have reported effects thresholds for the same species more than an order of magnitude higher than the CEB (Biesinger and Christensen 1972). Lethal effects on cladocerans and effects on fish and other taxa have only been reported at much higher iron concentrations, greater than the CEB and greater than all predicted iron concentrations in Kennady Lake. Thus, the predicted iron concentrations summarized in Table 8.9-9 are not expected to result in adverse effects to aquatic life.

The source of strontium in Kennady Lake is likely from the PK and process water. Strontium is projected to be higher than the CEB in both of the Kennady Lake closure scenarios and in the Area 8 closure scenario (Table 8.9-9). However, the CEB is very low and likely highly conservative, and the actual likelihood of adverse effects to aquatic life is therefore highly uncertain. The CEB was based on a 28-d LC10 with rainbow trout embryos (Appendix 8.IV, Table IV-8) reported by Birge et al. (1979). This value was several orders of magnitude lower than any other reported toxicity datum, including studies with rainbow trout fry and other fish species. Given the high level of uncertainty in the toxicity data reported by Birge et al. (1979), and given that the maximum predicted strontium concentrations in Kennady Lake are orders of magnitude lower than all other effects concentrations in the toxicity dataset, the potential for adverse effects from strontium is considered likely to be low.

8.9.3.2.2 Indirect Exposure - Changes to Fish Tissue Quality

Predicted fish tissue concentrations in Kennady Lake and Area 8 are above toxicological benchmarks for only one SOI: silver (Tables 8.9-10 to 8.9.12). All predicted concentrations for other SOIs were below their respective tissue benchmarks.

The predicted silver concentrations in fish from all three scenarios ranged from 0.12 to 0.15 milligrams per kilogram wet weight (mg/kg ww) (Tables 8.9-10 to 8.9-12), which are higher than the toxicological benchmark of 0.06 mg/kg ww. The benchmark was based on a 180-d NOEC for survival and growth of bluegill (*Lepomis macrochirus*). A low-effect tissue threshold could not be found for silver, either in Jarvinen and Ankley (1999) or during a literature search for concentrations of silver in muscle or whole body. Therefore, the selected tissue benchmark, which is based on a no-effect threshold, is likely a highly conservative basis for assessing the potential for predicted silver concentrations to cause effects to fish.

The predicted silver concentrations are similar to the maximum baseline tissue concentration in the dataset used to derive the silver BAF. The maximum baseline tissue concentration was 0.09 mg/kg ww. Therefore, fish tissue silver concentrations are predicted to increase only marginally above baseline conditions as a result of the Project. Given the modest predicted increase, and given that both baseline and predicted tissue concentrations only marginally exceed the available no-effects benchmark, the potential for the predicted silver concentration to cause effects to fish is concluded to be low.

Based on the above results, changes to concentrations of all substances considered in this assessment are predicted to result in negligible effects to aquatic health in Kennady Lake.

Table 8.9-10 Predicted Metal Concentrations in Fish Tissues in Kennady Lake under Initial Closure Discharge Water Quality Scenario

Metal	Predicted Maximum Concentration (mg/L)	Bioaccumulation Factor	Estimated Fish Tissue Concentrations (mg/kg ww) [(a)]	Toxicological Benchmark (mg/kg ww)[(b)]
Aluminum	0.071	278	19.7	20
Antimony	0.0021	2729	5.8	9
Arsenic	0.0025	417	1.0	3.1
Cadmium	0.000042	237	0.0098	0.6
Chromium	0.0050	78	0.39	0.58
Copper	0.0028	839	2.4	3.4
Lead	0.00038	80	0.030	4.0
Mercury	0.000017	9450	0.16	0.8
Nickel	0.0031	232	0.72	0.82
Selenium	0.00084	3000	2.5	2.58
Silver	0.000076	2000	**0.15**	0.06
Vanadium	0.0030	95	0.28	0.41
Zinc	0.012	379	4.6	60

(a) **Bolded** estimated fish tissue concentrations are greater than corresponding toxicological benchmark.

(b) Benchmarks originate from Jarvinen and Ankley (1999), with the exception of selenium; the selenium benchmark is based on data contained in US EPA (2004) expressed as wet weight assuming a moisture content of 76%.

mg/L = milligrams per litre; mg/kg ww = milligrams per kilogram wet weight.

Table 8.9-11 Predicted Metal Concentrations in Fish Tissues in Kennady Lake under Long-term Water Quality Scenario

Metal	Predicted Maximum Concentration (mg/L)	Bioaccumulation Factor	Estimated Fish Tissue Concentrations (mg/kg ww) [(a)]	Toxicological Benchmark (mg/kg ww) [(b)]
Aluminum	0.070	278	19.6	20
Antimony	0.0019	2729	5.2	9
Arsenic	0.0024	417	1.0	3.1
Cadmium	0.000040	237	0.0096	0.6
Chromium	0.0013	78	0.10	0.58
Copper	0.0027	839	2.3	3.4
Lead	0.00022	80	0.018	4.0
Mercury	0.000011	9450	0.10	0.8
Nickel	0.0031	232	0.71	0.82
Selenium	0.00025	3000	0.75	2.58
Silver	0.000059	2000	**0.12**	0.06
Vanadium	0.0029	95	0.27	0.41
Zinc	0.0045	379	1.7	60

(a) **Bolded** estimated fish tissue concentrations are greater than corresponding toxicological benchmark.

(b) Benchmarks originate from Jarvinen and Ankley (1999), with the exception of selenium; the selenium benchmark is based on data contained in US EPA (2004) expressed as wet weight assuming a moisture content of 76%.

mg/L = milligrams per litre; mg/kg ww = milligrams per kilogram wet weight.

Table 8.9-12 Predicted Metal Concentrations in Fish Tissues in Area 8 under Post-closure Water Quality Scenario

Metal	Predicted Concentration (mg/L)	Bioaccumulation Factor	Estimated Fish Tissue Concentrations (mg/kg ww) [(a)]	Toxicological Benchmark (mg/kg ww) [(b)]
Aluminum	0.060	278	17	20
Antimony	0.0016	2729	4.4	9
Arsenic	0.0020	417	0.83	3.1
Cadmium	0.000039	237	0.0093	0.6
Chromium	0.0025	78	0.19	0.58
Copper	0.0026	839	2.2	3.4
Lead	0.00022	80	0.018	4.0
Mercury	0.000013	9450	0.12	0.8
Nickel	0.0026	232	0.61	0.82
Selenium	0.00045	3000	1.4	2.58
Silver	0.000063	2000	**0.13**	0.06
Vanadium	0.0024	95	0.23	0.41
Zinc	0.0078	379	2.9	60

(a) **Bolded** estimated fish tissue concentrations are greater than corresponding toxicological benchmark.

(b) Benchmarks originate from Jarvinen and Ankley (1999), with the exception of selenium; the selenium benchmark is based on data contained in US EPA (2004) expressed as wet weight assuming a moisture content of 76%.

mg/L = milligrams per litre; mg/kg ww = milligrams per kilogram wet weight; < = less than.

8.9.4 Sources of Uncertainty

Key sources of uncertainty in this aquatic health assessment were the data used to estimate exposure and effects.

The predicted water concentrations are a source of uncertainty in this aquatic health assessment and Section 8.8 outlines the assumptions used in the water quality modelling. To address this uncertainty, maximum predicted water concentrations were used as conservative estimates of the exposure concentrations for aquatic life in the Kennady Lake watershed during the post-closure period.

The predicted tissue concentrations are a source of uncertainty in this aquatic health assessment. The predicted tissue concentrations were derived from predicted water concentrations and BAFs derived using baseline conditions. To address this uncertainty, maximum predicted water concentrations and the highest BAF for each SOI was used to calculate tissue concentrations, which provided a conservative estimate of predicted tissue concentrations.

A source of uncertainty in the effects assessment was that the potential for the predicted water concentrations to cause adverse effects on aquatic life in Kennady Lake could not be assessed with site-specific toxicity data. There are no toxicity data for populations of aquatic life in the Kennady Lake watershed and toxicity data from the scientific literature were used as surrogates. In general, these toxicity data were based on studies with naïve laboratory organisms tested under optimal culture conditions. Therefore, the use of literature-based data is a conservative approach to address this source of uncertainty. In the direct waterborne assessment, either the estimated hazard concentration above which 5% of the species would be affected or the lowest chronic toxicity value was used as the CEB. In the fish tissue quality assessment, the lowest tissue concentration related to an effect from waterborne exposure was used to assess effects. Finally, individual-level effects were used to judge the potential of effects on populations. These approaches provided conservatism to the effects assessment.

8.10 EFFECTS TO FISH AND FISH HABITAT

This section assesses the potential for effects to fish and fish habitat in Kennady Lake and in small lakes and streams in the Kennady Lake watershed resulting from physical changes, and changes to water quantity and quality. Summaries of the valid pathways for effects to fish and fish habitat are presented in Table 8.10-1 for construction and operations, and in Table 8.10-2 for closure.

The assessment of effects to water quality were assessed in Section 8.8 and resulting effects to fish health were assessed in Section 8.9; therefore, only conclusions of the aquatic health assessment are presented herein under Section 8.10.4.3.3. The recovery of the aquatic ecosystem in Kennady Lake for fish and lower trophic levels (i.e., phytoplankton and zooplankton) is addressed in Section 8.11.

Sections 8.10.1 and 8.10.2 provide an overview of the methodology used to analyze the effects to fish and fish habitat in the Kennady Lake and its watershed during construction and operations, and closure, respectively. The discussion of analysis results for construction and operations is provided in Section 8.10.3 and for closure and post-closure in Section 8.10.4.

For the purposes of the assessment, fish habitat is defined as the area required by fish for spawning, nursery, rearing, food supply (e.g., benthic invertebrates), overwintering, and migration.

Table 8.10-1 Valid Pathways for Effects to Fish and Fish Habitat in Kennady Lake and the Kennady Lake Watershed – Constructions and Operation

Project Activity	Pathway	Effects Statement
Project footprint (e.g., dykes, mine pits, Coarse PK Pile and Fine PKC Facility, mine rock piles, access roads, mine plant, airstrip)	project development in the Kennady Lake watershed will result in the loss of fish habitat	Effects of Project construction and operations activities to fish and fish habitat in Kennady Lake, and streams and lakes within the Kennady Lake watershed
Dewatering of Kennady Lake	dewatering of much of Kennady Lake and other small lakes may cause mortality and spoiling of fish, temporary loss in productive capacity, and the alteration of flows, water levels, and channel/bank stability in Area 8	
Isolation and diversion of upper Kennady Lake watersheds	change of flow paths and construction of retention and diversion dykes in the A, B, D and E watersheds may result in loss of stream habitat, alteration of water levels and lake areas, shoreline erosion, re-suspension of sediments and sedimentation, and changes to lower trophic levels, fish communities, and migration	
Construction and mining activity (air emissions)	deposition of dust and particulate matter may cause increases in suspended sediment, and changes to aquatic health	

Table 8.10-2 Valid Pathways for Effects to Fish and Fish Habitat in Kennady Lake and the Kennady Lake Watershed – Closure and Post-Closure

Project Activity	Pathway	Effects Statement
Removal and reclamation of Project infrastructure in Kennady Lake basin	development of fish habitat compensation works	Effects of Project closure and post-closure activities to fish and fish habitat in Kennady Lake, and streams and lakes within the Kennady Lake watershed
Removal of the temporary diversion dykes in the B, D and E watersheds	change of flow paths in the B, D, and E watersheds may result in alteration of water levels and lake areas, changes to lower trophic levels, fish communities and migration	
Refilling of Kennady Lake	continued isolation of Area 8 during refilling	
Post-Closure Activities	changes to nutrient levels may result in changes to lower trophic communities, dissolved oxygen levels, fish habitat, and fish communities	
	changes to aquatic health may affect fish populations and abundance	

8.10.1 Effects Analysis Methods – Construction and Operation

8.10.1.1 Effects of Project Footprint on Fish Habitat

Changes to fish habitat will occur in Kennady Lake and the Kennady Lake watershed due to the development of the Project, e.g., excavation of the mine pits, placement of mine rock, placement of PK, dykes, and other construction activities. The affected habitat areas include portions of Kennady Lake and adjacent lakes within the Kennady Lake watershed that will be permanently lost, portions that will be physically altered after dewatering and later submerged in the refilled Kennady Lake, and portions that will be dewatered (or partially dewatered) but not otherwise physically altered before being submerged in the refilled Kennady Lake. The methods for quantification included the following steps:

- Habitat area determination;
- Habitat suitability determination; and
- Calculation of Habitat Units.

A brief summary is provided below; more details can be found in the Conceptual Compensation Plan (CCP) (Section 3, Appendix 3.II).

The areal quantity of fish habitat permanently lost, physically altered, or dewatered as a result of the Project was determined using a Geographic Information System (GIS) to overlay the Project footprint over habitat classification maps of the affected waterbodies. Habitat was classified into categories of substrate type, gradient and depth. The area of each habitat category within the Project footprint was digitized using GIS for each waterbody and quantified in hectares. The area of the watercourse affected was determined by multiplying the length of each watercourse segment by an assumed width for permanently affected watercourses (3 m). Kennady Lake tributary streams are generally small and less than 3 m wide (Annex J).

The suitability of fish habitat permanently lost, physically altered or dewatered by the Project was quantified using a modified Habitat Evaluation Procedure (HEP). With a HEP approach, habitat suitability is assigned to discrete habitat types using Habitat Suitability Index (HSI) models developed for fish species known or assumed to be present in affected areas. The HSI models were used to quantify the suitability of habitat categories for various life-history stages, and for each fish species present on a scale of 0 (unsuitable) to 1 (optimal). Habitat suitabilities were determined for all permanently lost or affected waterbodies and for the eight fish species known to occur in Project area (lake trout, round whitefish, Arctic grayling, northern pike, burbot, lake chub, slimy sculpin, and ninespine stickleback).

The area and suitability of fish habitat permanently lost, physically altered, or dewatered by the Project were integrated into a single, dimensionless unit called a Habitat Unit (HU). For each species, HUs permanently lost or altered were calculated as the product of the area lost for each habitat category and the suitability of that habitat category for each life-history stage. For each permanently lost or altered waterbody, the HUs are then summed across all habitat categories and species life-history stages to calculate the total HUs lost for a species in a given waterbody.

8.10.1.2 Effects of Kennady Lake Dewatering

Effects of dewatering the main basins of Kennady Lake during mine operations included the direct effects of dewatering activities on the fish population of Kennady Lake, the temporary loss of fish habitat while Kennady Lake is dewatered, and the effects of the dewatering discharge on flows, water levels, and channel/bank stability in Area 8. The effects of the dewatering discharge on fish and fish habitat downstream of Area 8 are discussed in Section 9.10 (Key Line of Inquiry: Downstream Water Effects). The effects of isolation of Area 8 are discussed in a separate section (Section 8.10.1.4).

The quantification of changes to water levels in Area 8 resulting from the diversions is based on the data and results presented in the Effects to Water Quantity section (Section 8.7). The effects on fish and fish habitat were assessed qualitatively, taking into account the fish species present, their habitat use, and life history requirements.

8.10.1.3 Effects of Diversions

The quantification of changes to streamflows and water levels resulting from the diversions is based on the data and results presented in the Effects to Water Quantity section (Section 8.7). Effects to fish and fish habitat in lakes from these changes were assessed by considering the amount and type of habitat in the nearshore areas that will be flooded and the effects to fish based on the use of these habitat types by different life stages of fish present. Habitat use was based on results of baseline investigations and from the published literature. Effects in streams were assessed by calculating the amount of habitat that will be temporarily or permanently lost downstream of dykes and the known use of these streams by different fish species for spawning and rearing or as migration routes.

The effects of shoreline erosion and sedimentation on fish and fish habitat in the diversion lakes were assessed qualitatively following a review of the Effects to Water Quantity section (Section 8.7). Effects on lower trophic levels were assessed qualitatively, taking into account the above information.

Effects on fish migrations and communities in the diverted watersheds were assessed qualitatively, through consideration of the fish species present in each watershed and their habitat use, as well as their life history requirements.

8.10.1.4 Effects of Isolation on Fish and Fish Habitat in Area 8

The effects of isolation of Area 8 on fish migrations and communities in Area 8 were assessed qualitatively, taking into account the fish species present in Area 8 and their habitat use and life history requirements. The changes to flows downstream of Area 8 were quantified in the Effects to Water Quantity section for downstream effects (Section 9.7) and discussed in more detail in Section 9.10.

8.10.1.5 Effects of Dust Deposition on Fish and Fish Habitat

Windborne dust from Project facilities and exposed lake bed sediments, and air emissions from Project facilities, may result in increased deposition of dust in the surrounding area. Changes in total suspended solids (TSS) in lake water from deposition on the lake surface and within the watershed, for selected lakes in the Kennady Lake watershed, were quantified in the Effects to Water Quality section (Section 8.8.1.1). Predicted changes in TSS in local lakes are considered to be conservative (high) estimates of the maximum potential changes that could occur during construction and operations.

To provide an indication of the potential effects of increased TSS on fish in these waterbodies, the Newcombe and Jensen (1996) dose-response relationship was applied. This relationship estimates the magnitude of adverse effect expected when fish are exposed to a given concentration of sediment over a given period. Their dose-response relationship generated a severity of effect (SEV) value ranging from 0 to 14. An SEV value of zero implied no effect. SEV values of one to three indicated behavioural changes are expected, four to eight indicated sublethal effects ranging from increased respiration and coughing rates to major physiological stress. Lethal and paralethal effects are expected with SEV values of 9 to 14.

Potential effects to aquatic health from dust and metals deposition were evaluated in the Effects to Aquatic Health section (Section 8.9). The results of the Aquatic Health assessment were then used to describe and assess changes that relate to fish and fish habitat (i.e., fish populations and communities). A discussion of the methods, models, and assumptions used in the Water Quality and Aquatic Health assessments can be found in Sections 8.8 and 8.9.

8.10.2 Effects Analysis Methods – Closure and Post-closure

Areas 3 to 7 of Kennady Lake will remain a closed-circuited system until completion of refilling and breaching of Dyke A at the end of the closure period; during closure, the effects analysis for fish and fish habitat only includes Area 8 of Kennady Lake, as well as other lakes and streams in the Kennady Lake watershed. The post-closure period includes the period when water quality is restored, the refilled Areas 3 to 7 are reconnected to Area 8, the natural flow path is re-established, and fish passage is resumed.

8.10.2.1 Effects of Habitat Enhancement to Fish and Fish Habitat

Compensation options have been developed and evaluated for the Project (see CCP, Section 3, Appendix 3.II). The methods for quantification of the habitat gains include the following steps:

- Preliminary Habitat Quantification;
- Planned Detailed Habitat Quantification;
- Habitat Area Determination;
- Habitat Suitability Determination; and
- Calculation of Habitat Units.

A brief summary is provided below; more details can be found in the CCP (Section 3, Appendix 3.II). Preliminary estimates of habitat gains potentially achieved from the compensation options under consideration were quantified using GIS. The footprint of each compensation option was overlaid on maps of the project area that included bathymetry of lakes in the Project area.

Detailed quantification of habitat gains potentially achieved by the selected compensation options will be included in the detailed compensation plan that is to be completed in 2011. The general strategy for quantification is equivalent to the approach taken for quantifying permanently lost, physically altered, or dewatered habitats (Section 8.10.1.1).

8.10.2.2 Effects of Rediverting B, D, E Watersheds to Kennady Lake

The quantification of changes to streamflows and water levels at closure is based on the data and results presented in the Effects to Water Quantity section (Section 8.7). Effects to fish and fish habitat in lakes from these changes were assessed qualitatively through understanding the amount and type of habitat in the nearshore areas that will have lowered water levels and estimating the effects to fish based on the use of these habitat types by different life stages of fish present. Habitat use was based on results of baseline investigations and from the published literature. Effects in streams were assessed by evaluating the potential use of these streams by different fish species for spawning and rearing or as migration routes. The effects of shoreline erosion and sedimentation on fish and fish habitat in the diversion lakes were assessed qualitatively following a review of the Effects to Water Quantity section (Section 8.7). Effects on lower trophic levels were assessed qualitatively, taking into account the above information.

Effects on fish migrations and communities in the diverted watersheds were assessed qualitatively, through consideration of the fish species present in each watershed and their habitat use, as well as their life history requirements.

8.10.2.3 Effects of Continued Isolation of Area 8 during Refilling of Kennady Lake

The effects on fish and fish habitat of the continued isolation of Area 8 were evaluated as described for operations in Section 8.10.1.4 above.

8.10.2.4 Effects of Changes in Nutrient Levels in the Refilled Kennady Lake

As discussed in the water quality assessment (Section 8.8.4.1), model results suggest that phosphorus concentrations in Kennady Lake may increase in the post-closure period. The predicted increases result from runoff waters coming into contact with the mine rock piles, Coarse PK Pile and the Fine PKC Facility. More specifically, if there are no environmental design features or mitigation measures in place, the runoff waters mobilize phosphorus from the mine rock, coarse PK and fine PK as they travel through the external structures, with the fine PK being the largest source of phosphorus.

De Beers is currently evaluating a variety of environmental design features and mitigation measures to limit contact between site runoff waters and the fine PK located within the Fine PKC Facility and other potential sources. These environmental design features and mitigation measures include, for example:

- Promotion of permafrost development in the Fine PKC Facility.
- Use of low permeability cover material to limit infiltration into key areas, such s the Fine PKC Facility.

The effectiveness of these environmental design features and mitigation measures is uncertain and requires further analysis. Accordingly, the amount of phosphorus that may be released into the environment is uncertain at this time. As a result, potential effects related to phosphorus have not been presented and will not be available until such time as additional analysis is completed. This analysis will be provided to the Panel in 2011.

When available, the analysis of potential effects related to predicted changes in nutrient levels will consider the following components of fish and fish habitat:

- lower trophic communities, including phytoplankton, zooplankton benthic invertebrates;
- fish production rates;
- changes to physical habitat, including the availability of spawning habitat and dissolved oxygen levels; and
- fish community structure.

8.10.2.5 Effects of Changes to Aquatic Health

Fish populations and abundance can be affected by changes in water quality if they result in changes in aquatic health (i.e., fish and invertebrate health). Potential effects to aquatic health were evaluated in the Effects to Aquatic Health section (Section 8.9) through direct exposure to substances in the water column and indirect effects related to possible accumulation of substances within fish tissue via uptake from both water and diet. The assessment was based on modelled water quality in the main basins of Kennady Lake and Area 8 during closure and post-closure.

The results of the Aquatic Health assessment were then used to describe and assess changes that relate to fish and fish habitat (i.e., fish populations and communities). A discussion of the methods, models, and assumptions used in the Water Quality and Aquatic Health assessments can be found in Sections 8.8 and 8.9.

8.10.2.6 Long-Term Effects

Recovery of Fish Community

The recovery of the fish community in Kennady Lake in post-closure is described in Section 8.11. The recovery was qualitatively assessed using relevant information from a literature review, expected physical conditions and modelled water quality after the lake has been refilled and stabilized, and the ecological concepts of colonization, natural succession, and trophic interactions between plankton, benthic invertebrate, and fish communities. The duration of the predicted recovery was based on the expected timing of recovery of plankton and benthic invertebrate communities, the changes to the lake from the Project, and the life history attributes of the species expected to establish self-sustaining populations in the refilled Kennady Lake.

8.10.3 Effects Analysis Results – Construction and Operation

8.10.3.1 Effects of Changes to Fish Habitat from Project Footprint

Changes to fish habitat will occur due to the development of the Project, e.g., excavation of the mine pits, placement of mine rock piles, the Water Management Pond (WMP), Coarse PK Pile and Fine PKC Facility, dykes, and other construction activities. The affected habitat areas include the following:

- portions of Kennady Lake and adjacent lakes within the Kennady Lake watershed that will be permanently lost;
- portions of Kennady Lake that will be physically altered after dewatering and later submerged in the refilled Kennady Lake; and
- portions of Kennady Lake that will be dewatered (or partially dewatered) but not otherwise physically altered before being submerged in the refilled Kennady Lake.

These affected habitat areas are described below; more details are provided in the CCP (Section 3, Appendix 3.II).

Permanently Lost Areas

The permanently lost areas are those affected by the following:

- The Fine PKC Facility (Areas 1 and 2, Lake A1, Lake A2, Lake A5, Lake A6, Lake A7);
- The Coarse PK Pile (Area 4 and Lake Kb4);
- West Mine Rock Pile (Area 5 and Lake Ka1);

- South Mine Rock Pile (Area 6); and
- Dykes C, D, H, I and L.

The Project will result in the permanent loss of 194.56 ha of lake area (Table 8.10-3). The majority of the losses will occur in Kennady Lake (154.61 ha), representing about 19% of the total pre-development Kennady Lake area of 813.57 ha. The remainder of the permanently lost areas includes the complete loss of Lakes A1, A2, A5, A7, Ka1 and Kb4, and partial losses of small portions of Lakes A3, A6, and N7. The largest category of habitat that will be permanently lost is deep lake bed covered by fine substrate, with additional habitat loss occurring in other areas dominated by fine substrates (which is typically of relatively low habitat quality). A considerable proportion of the remaining permanent losses will occur in areas dominated by boulder, which is typically of relatively high habitat quality. The Project will also result in the permanent loss of 0.51 ha of watercourse area in tributaries to Kennady Lake (Table 8.10-4).

Table 8.10-3 Lake Areas Permanently Lost as a Result of the Project

Mine Infrastructure	Area Permanently Lost (ha)										
	Kennady Lake	A1	A2	A3	A5	A6	A7	Ka1	Kb4	N7	Total[(a)]
Fine Processed Kimberlite Containment Facility	59.24	34.45	3.07	-	0.14	0.07	0.12	-	-	-	97.09
Coarse Processed Kimberlite Pile	1.05	-	-	-	-	-	-	-	1.03	-	2.08
West Mine Rock Pile	34.08	-	-	-	-	-	-	0.94	-	-	35.03
South Mine Rock Pile	52.71	-	-	-	-	-	-	-	-	-	52.71
Dyke C	-	-	-	0.09	-	-	-	-	-	-	0.09
Dyke D	-	-	-	-	-	-	-	-	-	0.04	0.04
Dyke H	0.62	-	-	-	-	-	-	-	-	-	0.62
Dyke I	2.25	-	-	-	-	-	-	-	-	-	2.25
Dyke L	4.67	-	-	-	-	-	-	-	-	-	4.67
Total	**154.61**	**34.45**	**3.07**	**0.09**	**0.14**	**0.07**	**0.12**	**0.94**	**1.03**	**0.04**	**194.56**

(a) Totals may not be exact due to rounding errors.

Table 8.10-4 Watercourse Areas Permanently Lost as a Result of the Project

Stream	Length (m)	Assumed Width (m)	Area (m^2)
A1	100	3	300
A2	20	3	60
A3	294	3	882
A5	115	3	345
A6	371	3	1,113
A7	31	3	213
B1	94	3	282
F1	168	3	504
Ka1	170	3	510
Kb4	309	3	927
Total Area (m^2)			**5,136**
Total Area (ha)			**0.51**

m = metre; m^2 = square metre; ha = hectare.

In the calculation of Habitat Units (HUs), fish-bearing lakes that are expected to be affected include the following:

- Lake A1 has a total of 110.34 HUs, all of which will be permanently lost due to the Project; most of the HUs are for lake trout (22.36 HUs), Arctic grayling (21.15 HUs), and burbot (20.34 HUs);
- Lake A2 has a total of 15.74 HUs, all of which will be permanently lost due to the Project; the largest amounts of HUs are for slimy sculpin (3.09 HUs), lake trout (2.84 HUs), and Arctic grayling (2.59 HUs);
- a total of 0.90 HUs will be permanently lost in Lake A3 due to the Project; the largest amounts of HUs are for slimy sculpin (0.28 HUs);
- a total of 0.08 HUs will be permanently lost in Lake N7 due to the Project; the largest amounts of HUs are for lake trout (0.02 HUs), Arctic grayling (0.02 HUs), and burbot (0.02 HUs);
- permanent habitat losses in Kennady Lake will total 1,157 HUs, which represents about 20% of the HUs currently in Kennady Lake (i.e., total of 5,826 HUs); the species most affected by the lost habitat include lake chub (206 HUs), lake trout (185 HUs), slimy sculpin (171 HUs), and burbot (170 HUs).

Lakes A5, A6, A7, Ka1, and Kb4 were assessed as being non-fish bearing in the baseline assessment (Section 8.3, Annex J, Addendum JJ), and, therefore, not considered further in the calculation of HUs permanently lost.

Physically Altered and Re-submerged Areas

Fish habitats that will be physically altered during operations and then submerged in the refilled Kennady Lake include the following:

- Part of Kennady Lake Area 3 (affected by Dyke B);
- Part of Kennady Lake Area 4 (affected by Tuzo Pit, Dyke B, Dyke J, and CP6 Berm);
- Part of Kennady Lake Area 6 (affected by Hearne Pit, 5034 Pit, Dyke K, Dyke N, Road between Hearne Pit and Dyke K, CP3 Berm, CP4 Berm, and CP5 Berm); and
- Part of Kennady Lake Area 7 (affected by Dyke A and Dyke K).

The Project will result in 83.32 ha of lake area being physically altered and re-submerged at closure. All of this area will be located in Kennady Lake (Table 8.10-5), representing about 10% of the total pre-mine Kennady Lake area of 813.57 ha. The largest category of habitat that will be physically altered and re-submerged is deep lake bed covered by fine substrate. Almost 70% of the habitats to be physically altered and re-submerged will occur in areas dominated by fine substrates, which is typically of relatively low quality. A considerable proportion of the remaining affected area will occur in areas dominated by boulder, which is typically of relatively high quality.

Table 8.10-5 Areas in Kennady Lake that are Physically Altered and then Re-Submerged at Closure

Mine Infrastructure	Area Physically Altered and Re-Submerged (ha)
Hearne Pit	13.87
Tuzo Pit	20.81
5034 Pit	19.8
Dyke A	0.35
Dyke B	16.13
Dyke J	0.41
Dyke K	2.89
Dyke N	3.99
Roads	3.96
Water Collection Pond Berms	1.12
Total[a]	**83.32**

[a] Total may not be exact due to rounding errors.

ha = hectares.

In terms of HUs, habitat losses in Kennady Lake from areas that will be physically altered and re-submerged at closure will total 610 HUs), which represents about 11% of the HUs currently in Kennady Lake. The amounts of habitat units lost will be highest for lake trout (104 HUs) and lake chub (97 HUs).

Dewatered and Re-submerged Areas

The areas that will be dewatered (or partially dewatered) but not otherwise altered before being re-submerged include the following:

- Portions of Kennady Lake Areas 3 through 7 (those parts that are not either permanently lost or physically altered);
- Lake D1; and
- Streams D1, D2, and E1.

The Project will result in approximately 435.90 ha of lake area being dewatered and re-submerged at closure but that will remain otherwise unaltered. This area includes 434.06 ha in Kennady Lake, which represents about 53% of the total pre-mine Kennady Lake area, and 1.87 ha in Lake D1. The largest category of habitat that will be physically altered and re-submerged is deep lake bed covered by fine substrate (46.96 ha). Almost 60% of the habitats that will be dewatered and re-submerged, but otherwise unaltered is deep lake bed covered by fine substrate (262.66 ha). The Project will also result in 0.23 ha watercourse area in tributaries to Kennady Lake (Streams D1, D2, and E1) being dewatered and re-submerged at closure, but that will remain otherwise unaltered.

The number of habitat units in Kennady Lake from areas that will be dewatered and then re-submerged at closure, but will remain otherwise unaltered, will total about 3,011 HUs, which represents about 52% of the HUs currently in Kennady Lake. The amount of habitat units lost will be highest for lake chub (502 HUs) and lake trout (495 HUs). Lake D1 has a total of 4.61 HUs, all of which will be unaltered but dewatered and then re-submerged at closure. The largest amounts of habitat units in Lake D1 are for burbot (1.65 HUs).

Compensation Plan

Where prevention of harmful habitat alteration or loss is not feasible, fish habitat of equivalent or higher productive capacity will be developed. The CCP (Section 3, Appendix 3.II) describes the various options considered for providing compensation, and presents a proposed fish habitat conceptual compensation plan to achieve no net loss of fish habitat according to DFO’s Fish Habitat Management Policy (DFO 1986, 1998, 2006). The options include: construction of impounding dykes to raise lake levels; construction of finger reefs in Kennady

Lake; construction of habitat structures on the decommissioned mine pits/dykes; and widening the top bench of pits to create shelf areas where they extend onto land. More information on compensation works is included in Section 8.10.4.1.

8.10.3.2 Effects of Dewatering on Fish and Fish Habitat

Dewatering Areas 2 to 7 of Kennady Lake is required to allow mining of the three diamond-bearing kimberlite pipes located under the lake-bed. Dyke A will be constructed at the narrows separating Areas 7 and 8 during the construction phase. Dyke A will allow the dewatering of Areas 2 through 7 while maintaining similar lake levels in Area 8. A portion of Area 1 (Lakes A1 and A2) will also be dewatered into Lake A3 after Dyke C is constructed.

Dewatering will result in the temporary loss of fish populations and lower trophic communities from the main basins of Kennady Lake. During operations, Areas 6 and 7 will be completely dewatered and Areas 2 through 5 will be partially dewatered. Kennady Lake is known to support eight species of fish, including, in order of abundance, round whitefish, lake trout, lake chub, Arctic grayling, northern pike, burbot, slimy sculpin, and ninespine stickleback. Lakes in the A watershed are known to support Arctic grayling, burbot, round whitefish, lake trout, and northern pike.

Removal of Fish

Fish salvage will be conducted to remove fish from Areas 2 to 7 before and during dewatering. The fish salvage is intended to minimize the waste of fish caused by the dewatering of Kennady Lake. The salvage would occur prior to and during dewatering of the lake and would also include removal of fish from Lakes A1 and A2 prior to partial dewatering and fine PK storage. Because Kennady Lake contains large-bodied and small-bodied fish species with a variety of habitat preferences, a combination of gear types would be used to maximize capture efficiency. These gear types could include gill nets, trap-nets, minnow traps, boat and backpack electrofishing, and angling. The fish salvage will be designed and implemented in consultation with Fisheries and Oceans Canada (DFO) and local Aboriginal communities, and may follow the draft General Fish-out Protocol for Lakes and Impoundments in the Northwest Territories and Nunavut (Tyson et al no date), as appropriate. Project-specific protocols for fish salvage will be developed prior to initiating the salvage.

The fish salvage at the Diavik Diamond Mine (McEachern et al. 2003) showed a survival rate of approximately 50% for fish captured during the salvage. Therefore, the possibility exists that fish could be moved to other lakes near Kennady Lake. This option would depend on the availability of barren lakes (i.e., those containing no large fish species) in the Project area and the approval of DFO and input from local Aboriginal communities. Release of captured fish to other fish-bearing lakes is not recommended because of the possibility of negative effects to the lake receiving the fish. These negative effects could include disease, parasites, genetic implications, and inter-species and intra-species density-dependent interactions (i.e., predation and competition). Based on the project-specific protocols developed, salvaged fish may be provided to Aboriginal communities to avoid wasting of fish. Capture techniques and salvage protocols for Lake A1 and Lake A2 will be similar to those for Kennady Lake.

Temporary Habitat Loss

Dewatering will result in the temporary loss of productive capacity of fish habitat within Areas 2 to 7 of Kennady Lake. Although Areas 2 to 5 will only be partially dewatered and will serve as the WMP for the Project, the depth, habitat, suspended sediment and water quality conditions in these areas will not be suitable to support a fish community. As described in Section 8.10.3.1 and the CCP (Section 3, Appendix 3.II), 434.06 ha of Kennady Lake will be dewatered and re-submerged at closure but will remain otherwise unaltered, representing about 53% of the total pre-mine Kennady Lake area. Similarly, 1.87 ha in Lake D1 will be dewatered and then re-submerged at closure. The majority of the habitats that will be unaltered but dewatered and re-submerged will occur in areas dominated by fine substrates, which is typically of low quality. However, since they are not being altered, habitat losses incurred during dewatering will be offset by equivalent habitat gains during refilling.

The loss of the fish community and the productive capacity of the fish habitat will last for the 13 years of construction and operations, the estimated 8 year refill period, and an additional period until the lower trophic communities and fish populations have re-established after closure. However, it is expected that a self-sustaining fish community will be present in Kennady Lake post-closure. The recovery of fish and lower trophic communities, and the productive use of fish habitat, are described in Section 8.11.

Changes to Lake Levels and Lake Areas

As described in the Effects to Water Quantity section (Section 8.7), estimated water levels in Area 8 will be slightly augmented relative to baseline conditions during Kennady Lake dewatering. However, discharges into Area 8 will be limited to ensure that 2-year flood conditions are not exceeded in Area 8 or its outlet channel (Stream K5); no effects to shoreline stability would be expected (Section 8.7.3.2). The estimated increase in the maximum depth of 0.03 m and surface area of less than 1% would not have any effect on fish habitat, as it would be well within the natural variability of the basin. Effects to fish and fish habitat from alteration of flows in the Area 8 outlet channel (Stream K5) are addressed in Section 9.10.

8.10.3.3 Effects of Watershed Diversions on Fish and Fish Habitat

To reduce the volume of runoff entering the controlled areas of Kennady Lake, the A, B, D and E watersheds will be diverted to the adjacent N watershed (see Figure 8.4-3). The watersheds will be diverted by constructing earth-fill dykes in their respective outlet channels to increase lake elevation and by constructing diversion channels to carry backed-up water away from Kennady Lake.

In the A watershed, a permanent dyke C will be constructed at the south end of Lake A3 to increase the water level in Lake A3 and divert its flow north to Lake N9 through a constructed channel.

In the B watershed, dyke E will be constructed between Lake B1 and the north end of Kennady Lake to prevent inflow to Kennady Lake and to divert all watershed B flow north to Lake N8 thorough a constructed channel. Near the end of operations, dyke E will not be removed, but will be partially breached to allow the flow from Lake B1 and upstream lakes to return to Kennady Lake.

In the D watershed, a temporary dyke F will be constructed between lakes D1 and D2 to increase water levels in lakes D2 and D3, resulting in one raised lake, D2-D3. The waters from the raised lake, together with flow from upstream lakes D4 and D7, will be diverted to the northwest shore of Lake N14 thorough a constructed channel. Lake D1, the lowermost lake in the D watershed, will continue discharging to Kennady Lake; however, its recharge area will be greatly reduced by dyke F. Near the end of operations, dyke F will be removed and the flow paths will be returned to pre-Project conditions (i.e., through Lake D1 to Kennady Lake).

In the E watershed, a temporary dyke G will be constructed to increase the water level in Lake E1 and divert the flow to the south shore of Lake N14 thorough a short constructed channel. Near the end of operations, dyke G will be removed and the flow paths will be returned to pre-Project conditions (i.e., through Stream E1 to Kennady Lake).

The diversions in the A and B watersheds will connect to lakes and streams in the east part of the N watershed (lakes N6 to N2), which drain into Lake N1. The diversions in the D and E watersheds will connect to lakes and streams in the west part of the N watershed, which also drains into Lake N1, but through lakes

N14, N17, N16, and N11 (in that order). The two diversion pathways converge in Lake N1, which in turn drains into Lake 410.

Watershed diversions will result in raised water levels in lakes A3, D2, D3, and E1 during operations. Pre-diversion (baseline) and post-diversion (operations) lake areas, maximum depths and known fish species in these lakes are shown in Table 8.10-6. The fish species recorded in N watershed lakes downstream of the diversions are shown in Table 8.10-7.

Table 8.10-6 Pre-Diversion (Baseline) and Post-diversion (Operations) Lake Areas and Depths in Diverted Lakes of the A, B, D and E Watersheds and Fish Species Known to Inhabit the Lakes

Lake	Lake Area (ha)		Maximum Depth (m)		Fish Species Recorded
	Baseline	Operations	Baseline	Operations	
A3	23.8	46.6	12.4	15.9	ARGR, BURB, LKTR, NRPK
B1	8.2	8.2	4.1	4.1	ARGR, LKTR, NNST, SLSC
B2	6.6	6.6	1.1	1.1	none
B3	1.5	1.5	-	-	not sampled
D1	1.9	1.9	3.8	3.8	BURB, NRPK
D2	12.5	104 [a]	1.0	4.6 [a]	NRPK
D3	38.4		3.0		BURB, LKTR, NRPK
D7	40.2	40.2	4.5	4.5	ARGR, BURB, NRPK
E1	20.2	27.0	3.9	4.7	NRPK, SLSC
E2	3.0	3.0	0.4	0.4	none
E3	1.1	1.1	0.7	0.7	none

[a] Raised water levels will result in one lake D2-D3.

ha = hectare; m = metre: ARGR = Arctic grayling; BURB = burbot; LKTR = lake trout; NRPK = northern pike; LKCH = lake chub; NNST = ninespine stickleback; SLSC = slimy sculpin; - = not sampled for depth.

Table 8.10-7 Fish Species Recorded in the N Watershed Lakes Downstream of the Diversions

Diversion	Lake	Fish Species Recorded
Downstream lakes along the A and B watersheds diversion	N2	ARGR, LKCH, LKTR, NNST, RNWH, SLSC
	N3	ARGR, BURB, LKCH, RNWH
	N4	ARGR, LKCH
	N5	ARGR, LKCH, LKTR, NNST, RNWH, SLSC
	N6	ARGR, BURB, LKTR, NNST, RNWH
Downstream lakes along the D and E watersheds diversion	N11	not sampled
	N14	ARGR, LKCH, LKTR, LNSC, NNST, SLSC
	N16	BURB, CISC, LKCH, LKTR, LNSC, NNST, RNWH, SLSC, WHSC[a]
	N17	BURB, LKCH, LKTR, SLSC
410	410	BURB, CISC, LKCH, LKTR, NRPK, RNWH, SLSC

[a] The reported presence of white sucker in Lake N16 may potentially be a misidentification.

ARGR = Arctic grayling; BURB = burbot; LKTR = lake trout; NRPK = northern pike; CISC = cisco; RNWH = round whitefish; LNSC = longnose sucker; WHSC = white sucker; LKCH = lake chub; NNST = ninespine stickleback; SLSC = slimy sculpin.

The streams connecting the diverted lakes are generally short in length (between 63 and 538 m). Most feature fish passage potential during the entire open water period; however, even some of the larger streams (e.g., N2 between lakes N2 and N1) can present barriers to fish movement during low flow periods in the fall. Fish species recorded in streams between the diverted lakes, as well as in streams downstream of the diverted watersheds are shown in Table 8.10-8.

Table 8.10-8 Channel Length, Fish Passage Potential and Fish Species Known to Inhabit the Streams between Diverted Lakes of the B, D, E and N Watersheds

Stream	Channel Length (m)	Fish Passage Potential[a]	Fish Species Recorded
B1	94	spring to fall	ARGR
B2	169	spring only	not sampled
B3	332	spring only	not sampled
D1	118	spring to fall	ARGR, BURB, NNST
D2	228	spring to fall	ARGR, BURB, NRPK, SLSC
D3	97	spring to fall	not sampled
D4	428	spring to fall	SLSC
D7	206	spring to fall	SLSC
E1	426	spring to fall	ARGR, BURB, NNST, NRPK
E2	290	spring only	not sampled
N1[b]	70	spring to fall	BURB, LKCH, SLSC
N2[b]	228	spring/summer	ARGR, BURB, LKCH, LNSC, NNST, SLSC
N3[b]	65	spring to fall	ARGR, BURB, LKCH, LKTR, LNSC, SLSC
N4[b]	63	spring/summer	ARGR, BURB, LKCH, NNST, SLSC
N5[b]	73	spring/summer	ARGR, BURB, LKCH, NNST, SLSC
N6[b]	155	spring/summer	ARGR, BURB, LKCH, NNST, SLSC
N11[c]	174	spring to fall	BURB, LKCH, SLSC
N14[c]	500	spring/summer	ARGR
N16[c]	538	spring to fall	ARGR, BURB, LKCH, LKTR, LNSC, SLSC
N17[c]	348	spring to fall	ARGR, BURB, LKCH, LKTR, LNSC, NNST, SLSC

(a) Seasons of potential fish passage estimated during habitat assessments.
(b) Streams downstream of the A and B watersheds diversion.
(c) Streams downstream of the D and E watersheds diversion.
m = metre: ARGR = Arctic grayling; BURB = burbot: LKTR = lake trout; NRPK = northern pike; LNSC = longnose sucker; LKCH = lake chub; NNST = ninespine stickleback; SLSC = slimy sculpin.

Eleven fish species in total have been recorded in the lakes and streams potentially affected by the diversions (Tables 8.10-6 to 8.10-8). Some species, such as Arctic grayling, lake trout, burbot, ninespine stickleback, and slimy sculpin, have been recorded in most of the affected watersheds. Other species, such as longnose sucker, white sucker, cisco and lake chub, have been recorded only in the N watershed and not in the A, B, D and E watersheds. Conversely, northern pike have not been recorded in the N watershed, although they are common in the A, D, and E watersheds.

Potential effects to fish and fish habitat in the diverted watersheds include the following:

- loss of stream and lake habitat downstream of dykes;
- increased lake levels and lake areas upstream of dykes;

- changes to erosion, resuspension of sediments, and sedimentation;
- changes to fish migrations; and
- changes to fish communities.

These effects are discussed separately in the following subsections.

Loss of Stream Habitat Downstream of Dykes

Habitat downstream of the dykes will be dewatered and lost to fish residing in upstream lakes, which will include Stream A3 in the A watershed, Stream B1 in the B watershed, Streams D1 and D2 in the D watershed, and Stream E1 in the E watershed. The loss of fish habitat resulting from the placement of the dykes and the dewatering of downstream stream segments, and Lake D1, is described in Section 8.10.3.1 and included in the CCP (Section 3, Appendix 3.II) to ensure that no net loss in fish habitat is achieved for the Project. Fish species and habitat use in each of the diversion watersheds is summarized below.

A Watershed

Arctic grayling and northern pike use Stream A3 as a movement corridor and for juvenile rearing; however, the spawning habitat quality for these species has been assessed as low. Ninespine stickleback had also been confirmed to use Stream A3 and, based on captures in the neighboring waterbodies, burbot and slimy sculpin may also be present.

B Watershed

Loss of Stream B1 downstream of dyke E is likely to affect Arctic grayling as it will eliminate natural spawning habitat for this species in the B watershed. The persistence of Arctic grayling in the B watershed will depend on Arctic grayling using habitat constructed in the diversion channel and immigration of Arctic grayling from the N watershed. Lake trout, slimy sculpin, and ninespine stickleback, the only other fish species besides Arctic grayling captured in the B watershed, spawn and rear in lakes and will not be affected by the loss of Stream B1. Small numbers of round whitefish and burbot may also be intermittently present in Lake B1 but do not require access to Stream B1 for spawning, rearing, or foraging.

D Watershed

Northern pike, burbot, Arctic grayling, lake trout, and slimy sculpin are known to use lakes and streams in the D watershed upstream of the proposed dyke F. Although not documented by fish captures, these waterbodies are also likely to contain ninespine stickleback. Arctic grayling in Kennady Lake use streams within the D watershed for spawning, but the numbers of fish using these streams is small in comparison to the numbers of Arctic grayling using streams downstream of Kennady Lake. Lakes in the D watershed appear to be one of the primary northern pike spawning locations as large numbers of adult northern pike have been captured moving upstream into Lake D2 in spring. Use of lakes in the D watershed by lake trout is minimal and likely limited to seasonal foraging.

Loss of Lake D1 (through the reduction of recharge area) is expected to have a small effect on fish populations in the D watershed. Lake D1 is a small (1.9 ha) lake with a maximum depth of 3.8 m, which is relatively deep in comparison to most lakes of this size in the Kennady Lake watershed. The nearshore habitat is comprised mostly of boulder/cobble substrates covered with fine sediments. This type of habitat is generally of low value to most fish species. However, areas of higher-quality clean boulder/cobble substrates and areas of submerged and emergent vegetation exist in this lake. Loss of vegetation is expected to have a small effect on northern pike and ninespine stickleback populations because much larger areas of aquatic vegetation exist in lakes upstream of the dyke, specifically in lakes D2, D3, and D7. Similarly, areas of clean boulder/cobble substrates used by lake trout, burbot and slimy sculpin exist in the other larger, upstream lakes. The amount of overwintering habitat lost in Lake D1 is small in comparison to the amount that will continue to be available, principally in Lake D7 (lake area of 40 ha and maximum depth of 4.5 m) and in the raised Lake D2-D3 (lake area of 104 ha and maximum depth of 4.6 m).

Loss of streams D1 and D2 will result in the loss of two of the three streams in the D watershed with habitat suitable for Arctic grayling spawning. These losses, combined with the loss of suitable spawning habitat in Stream D3 when the water level in Lake D2 is raised, will eliminate all natural spawning habitat for Arctic grayling in the D watershed.

Persistence of Arctic grayling in the D watershed during operations will depend on the spawning use of habitat in the diversion channel constructed between Lake D3 and Lake N14 and immigration of Arctic grayling from Lake N14 and waterbodies farther downstream. An artificial stream constructed at the Ekati Diamond Mine was found to allow fish migration and provide spawning and nursery habitat for Arctic grayling, albeit with 63% lower standing stock than natural streams (Jones et al. 2003). The diversion channel between Lake D3 and Lake N14 will be designed and constructed to allow fish passage while also incorporating lessons learned from the Ekati Diamond Mine experience to increase Arctic grayling production.

E Watershed

Loss of Stream E1 downstream of dyke G is likely to affect Arctic grayling as it will eliminate natural spawning habitat for this species in the E watershed. The persistence of Arctic grayling in the E watershed will depend on Arctic grayling using habitat constructed in the diversion channel between lakes E1 and N14 and immigration of Arctic grayling from the N watershed.

Northern pike, burbot, slimy sculpin and ninespine stickleback, the only other fish species besides Arctic grayling captured in the E watershed, spawn and rear primarily in lakes and will not be substantially affected by the loss of Stream E1.

Changes to Lake Levels and Lake Areas Upstream of Dykes

Raising water levels in Lakes A3, D2, D3, and E1 will result in increased lake habitat area. This increase will be permanent in Lake A3, but water levels in the remaining lakes will be lowered to pre-Project (i.e., baseline) conditions after dykes F and G are removed at the end of operations. Water level in Lake A3 will be raised by about 3.5 m, resulting in a 95% increase in the surface area of the lake. In lakes D2 and D3, the water level will be raised by 2.8 m and 1.6 m, respectively, creating one lake with a surface area approximately twice as large as the combined pre-Project area of the two lakes. Water level in Lake E1 will be raised by about 0.8 m, resulting in a 34% increase in the surface area of the lake.

Raised water levels may create a benefit to fish residing in these lakes during mine construction and operations. These benefits will be manifested largely from the additional space and increased amount of overwintering habitat for all resident species. Populations of northern pike and ninespine stickleback may also benefit from the increased spawning and rearing habitat in areas with flooded vegetation.

Shoreline Erosion, Resuspension of Sediments and Sedimentation

Raising lake levels in Lakes A3, D2, D3, and E1 will create new shorelines at higher elevations than the existing shorelines, which will expose new soils, often on steeper slopes than the existing shorelines, to wave erosion and potential instability due to permafrost disturbance. This can result in shoreline erosion and an increased sediment load into the lakes. Total suspended sediment (i.e., TSS) can affect fish directly and settling of the sediment (i.e., sedimentation) can affect nearby habitats.

The nature and extent of adverse effects of increased TSS is influenced by both the TSS concentration and the duration of exposure. Fish can tolerate low TSS concentrations for long periods and high concentrations for short periods without suffering adverse effects. The effects of sediment deposition can include infilling of interstitial spaces between substrate particles that provide habitat for rearing of fry or incubation of eggs, covering aquatic plants, which can provide habitat for juvenile rearing or incubation of eggs, and potential shifts to benthic communities. The severity of the effect depends on the type of habitat and its use by fish.

The shorelines in the diversion lakes are currently dominated by boulders and large cobble substrates. Nearshore habitats in Lakes A3, B1, D2, and D3 are dominated by boulder substrates, with some areas of cobble or bedrock. The presence of these large substrates will promote long-term stability of the shorelines. Rates of shoreline erosion are related to composition of bank material (Newbury and McCullough 1984), and boulder shorelines reduce erosional forces, compared to fine sediment (Fitzpatrick 1995). As described in the Effects to Water Quantity section (Section 8.7.3.3), increases in TSS concentrations in the raised lakes are expected to be low due to the armouring action of morainal materials and the rapid settling of its coarse fractions from the water column, along with the location of organic soils in low-gradient locations. A baseline monitoring program will be established and mitigation measures will be applied if areas of substantial erosion are identified during construction and operations. It is also expected that any increases in TSS concentrations due to shoreline erosion would occur during spring freshet or storm events. Fish are routinely exposed to higher TSS levels during these periods and would tolerate the levels in the short-term. Fish would also show a behavioural response, moving away from any shoreline areas with a high sediment load. As a result, negligible effects on fish and fish habitat are expected from shoreline erosion, resuspension of sediments, and sedimentation.

Changes to Lower Trophic Levels

Changes in water levels and lake areas in Lakes A3, D2-D3, and E1 are expected to increase habitat area available for plankton and benthic invertebrates, once new lake areas are fully colonized. This will result in overall increased total biomass of plankton and benthic invertebrates in these lakes, after a period of adjustment to the new water levels. Based the topography of land around Lakes D2-D3 and E1, the enlarged lakes will have relatively large shallow areas suitable for development of benthic algae, which will in turn provide food for benthic invertebrates. The increased lake levels are also expected to result in reduced benthic invertebrate biomass in deeper areas of these lakes, as their benthic fauna becomes more typical of deep-water areas, which are usually characterized by lower invertebrate density and richness.

Production of plankton and benthic invertebrate communities in the A, B, D and E watersheds is not expected to be negatively affected with the raising of the lake levels and their diversion to the N watershed, but will require a period of adjustment to the new water level. As explained above, diversions are not expected to substantially increase TSS concentrations in the water column or appreciably alter other water quality parameters upon which invertebrate production is dependent (i.e., phosphorus, nitrogen, carbon). However, some initial changes in water quality are expected after flooding of the new areas, as fine sediments are redistributed and any residual organic material is used by bacteria. These changes are anticipated to be small after the first year of elevated lake levels; the baseline monitoring program will also identify areas where mitigation would be required to minimize sources of suspended sediments.

Development of aquatic vegetation will likely be limited by the type of substrates that will be flooded (i.e., mostly coarse materials) and low nutrient concentrations. Over time (i.e., anticipated as less than five years), existing lower trophic communities will colonize new habitat created by raising water level. The initial colonizers in newly-flooded areas will likely be midges, followed by non-insect groups, such as fingernail clams and mollusks. Once established, the benthic community of newly-flooded areas is predicted to be one of low density and diversity, which is typical of lakes in the region.

Changes to Fish Migrations

Dykes in streams A3, B1, D2 and E1 will interrupt the movements of fish between Kennady Lake and waterbodies upstream of the dykes. This effect will be permanent for the A watershed, but will be limited to the period of mine operations for the B, D and E watersheds. The effect of the dykes on fish migrations is mainly limited to the potential interruption of obligatory migrations that a particular fish species would need to make to and from Kennady Lake to fulfill its life history requirements. This situation would occur only if there was some unique habitat available in Kennady Lake or in the streams downstream of the dykes that were unavailable in watersheds A, B, D or E.

Loss of access to the lowermost streams in the A, B, D and E watersheds is likely to affect Arctic grayling, which currently use these stream habitats for spawning and rearing. As natural spawning habitats for Arctic grayling do not currently exist in these watersheds upstream of the dykes, persistence of this species will depend on whether Arctic grayling use habitat constructed in the diversion channels and any immigration of Arctic grayling from the N watershed. Arctic grayling are common in the N watershed and it is likely that they will move into the upstream watersheds (A, B, D and E) after they are connected through the newly constructed diversion channels.

The diversion channels connecting B1, D2-D3, and E1 to the N watershed and Lake A3 to the L watershed will be designed to provide spring spawning and rearing habitat for Arctic grayling and allow the seasonal passage of fish between lakes that approximates natural conditions. Physical features of these channels will include the following:

- bank and bottom substrates will consist predominantly of cobble, boulder and gravel to allow Arctic grayling spawning and to limit erosion;
- riffle and pool sequencing will be included; and
- slopes, channel depths, and widths will be sufficient to allow fish passage throughout the open-water season; designs will ensure that water velocities in spring will be low enough to avoid creating barriers and that sufficient flow is present in late summer/fall to allow fish to move to overwintering habitat downstream, if necessary.

Northern pike have been documented to use lake and stream habitat in the A, D, and E watersheds and suitable spawning, rearing, and overwintering habitats exist in these watersheds upstream of the dykes. The dykes will preclude the annual spring spawning migrations of adults from Kennady Lake and prevent potential recruitment from this system. Although the dykes will in effect isolate the northern pike populations within their respective watersheds for the duration of mine operations (and permanently in Lake A3), it is likely that the isolated populations will be self-sustaining. Unlike Arctic grayling populations that can be augmented in these watersheds through potential immigration from the N watershed, the presumed absence of northern pike in the N watershed would preclude similar recruitment. During baseline sampling, northern pike have not been captured in lakes and streams in the N watershed, although they are present in Kennady Lake and downstream to Lake 410; therefore, it appears that northern pike are absent from the N watershed, or are present at extremely low numbers. As a result of the diversions, it will be possible for northern pike from Kennady Lake to move into the upper part of the N watershed, where suitable spawning and rearing habitat exists in shallow bays of downstream lakes. It should be noted, however, that the lower part of the N watershed is already well connected to Lake 410 (i.e., Lake N16 is about 15 km upstream from Lake 410) and northern pike have not taken advantage of this connection to disperse into the N watershed. Although habitat conditions in the Kennady and N watersheds are generally similar, differences in the abundance and distribution of aquatic vegetation may have contributed to the apparent difference in northern pike use of the two watersheds. As such, the probability of northern pike dispersing into the N watershed via the proposed diversion channel in the upper part of the N watershed (i.e., from D and E watersheds to Lake N14) is expected to be low, and no substantial changes to the resident fish communities in the N watershed are anticipated.

Small populations of burbot, slimy sculpin, and ninespine stickleback will likely continue to spawn in the diverted watersheds. These species are not known to undergo extensive migrations between waterbodies and the loss of connectivity to Kennady Lake is not likely to affect their abundance. The lakes upstream of the dykes are deep enough (exceed 3.4 m and will be even deeper after the water levels are raised) to provide suitable overwintering habitat. Nearshore habitats in lakes A3, B1, D2, D3, D7 and E1 (all upstream of the dykes) include clean boulder/cobble substrates used by slimy sculpin and burbot for spawning and rearing, and submerged and emergent aquatic vegetation used by northern pike and ninespine stickleback for spawning, rearing, and foraging. As such, all life history requirements for these species can be fulfilled in the diverted watersheds, without the need to access Kennady Lake.

A second effect of the dykes on fish migrations is the prevention of out-migrations of juvenile and young-of-the-year fish to Kennady Lake. Although not specifically documented, it is expected that some proportion of each year class migrate out of lakes in the A, B, D and E watersheds down to Kennady Lake each year. These emigrations are most likely in response to density-dependent competition for food and space but may also be in response to increased predation in the smaller lakes.

Prevention of downstream emigration to Kennady Lake is expected to have a minor effect on fish populations in lakes upstream of the dykes. These lakes have a carrying capacity which, like all lakes in the Kennady Lake area, is limited by low nutrient availability. The lakes can be assumed to be at their natural carrying capacity and will remain at or near this carrying capacity during mine operations, regardless of whether fish can emigrate to Kennady Lake. If the carrying capacity is exceeded, the fish will be able to disperse to lakes in the N watershed through the constructed diversion channels.

Changes to Fish Communities in the A, B, D and E Watersheds

Persistence of fish populations in the diverted A, B, D and E watersheds will be dependent on the following:

- suitable water quality;
- the continued production of plankton and benthic invertebrate communities; and
- the continued availability of and access to habitat necessary to complete their life histories.

As noted above, water quality is expected to remain suitable for aquatic life in the A, B, D and E watersheds during diversions, and plankton and benthic invertebrate communities are expected to remain viable in the lakes that are predicted to increase in size.

Populations of small-bodied fish, such as ninespine stickleback and slimy sculpin, are likely to persist in diverted watersheds during mine operations because suitable spawning, rearing, and foraging habitat for each species will be available and there is no critical habitat in Kennady Lake that any of these species require to complete their life histories.

Northern pike, like ninespine stickleback, require aquatic vegetation for spawning and rearing (Scott and Crossman 1973; Casselman and Lewis 1996; Richardson et al. 2001). This type of habitat does not exist in the B watershed and if any northern pike are present in Lake B1 (none have been reported to date), they would be unlikely to reproduce successfully. Aquatic vegetation exists in lakes A3, D2, D3, D7, and E1, and these lakes will continue to provide suitable habitat for northern pike and ninespine stickleback throughout mine operations. Increasing the depth and area of lakes D2, D3 and E1 may actually create a benefit to northern pike and ninespine stickleback residing in these lakes during mine construction and operations because of the increased amount of riparian vegetation flooded when raising these lakes.

Few lake trout have been captured in the A, B, and D watersheds and none have been reported in the E watershed. This is most likely because the smaller size and shallower depths of these lakes are generally unsuitable for lake trout, which prefer lakes with deeper water that have low water temperatures in summer and high levels of dissolved oxygen year round. Lake trout that have been captured in lakes in the B and D watersheds are likely using the lakes seasonally for rearing and feeding, e.g., juvenile lake trout that move out of Kennady Lake in the summer to feed and escape predation from adults. Lake trout are fall spawners that use boulder/cobble substrates at depths exceeding 2 m along the shorelines of lakes for spawning. These lakes will likely continue to provide the same amount of habitat for lake trout that currently exists. However, as it is unlikely that these lakes currently support self-sustaining lake trout populations, it is not expected that this species will persist in these lakes during operations.

Small numbers of burbot have been captured in lakes A3, D3 and D7. Burbot have not been reported in the B watershed. Although they were captured in Stream E1 near the Kennady Lake confluence, it is not known if they are present in Lake E1. Burbot spawn in similar habitat as lake trout; however, they do so in late winter under the ice (Richardson et al. 2001). Lakes A3, D3 and D7 will likely continue to provide the same amount of habitat for burbot that currently exists.

All available spawning and rearing areas used by Arctic grayling in the A, B, D and E watersheds are located under the footprint or downstream of the proposed dykes. As such, the construction of the dykes will negatively affect Arctic grayling reproduction. The persistence of Arctic grayling in the diverted watersheds, therefore, will be dependent on the suitability of spawning and rearing habitat constructed in the diversion channels and the use of this new habitat by Arctic grayling. The diversion channels between lakes A3 and N9, lakes B1 and N8, lakes D1 and N14, lakes D2-D3 and N14, and lakes E1 and N14 will be designed and constructed to allow fish passage and to provide suitable substrate and habitat conditions to allow Arctic grayling spawning and rearing. Lessons learned at the Ekati Diamond Mine and other places where artificial channels were constructed will be used to maximize the potential for Arctic grayling production.

In addition to creating appropriate spawning and rearing habitats in the constructed diversion channels, the persistence of Arctic grayling in the diverted watersheds will likely be influenced by potential immigration of Arctic grayling from the neighboring lakes in the N watershed. These lakes and interconnecting streams are known to support a large number of Arctic grayling, some of which may migrate to the diverted watersheds if the newly constructed channels provide adequate fish passage conditions.

8.10.3.4 Effects of Isolation of Area 8 on Fish and Fish Habitat

This section assesses the ability of Area 8 to support a fish population and effects to fish migration in and out of Kennady Lake while isolated.

Changes to Lower Trophic Communities

Isolation of Area 8 during operations and closure from the remainder of Kennady Lake was predicted to result in a slight increase in nutrient concentrations due to evaporative concentration of solutes in lake water (Section 8.8.4.1.2). Between construction and the end of operations, total phosphorus was predicted to gradually increase from a mean background concentration of 0.005 mg/L to less than 0.007 mg/L, along with a proportional increase in concentrations of nitrogen compounds. This change is not expected to alter the trophic status of Area 8 from oligotrophic (i.e., TP range of 0.004 to 0.010 mg/L) (CCME 1999). However, this increase in nutrient concentrations is expected to result in a slight increase in productivity of plankton and benthic invertebrate communities, without notable changes in community composition or dissolved oxygen concentration.

Changes to Fish Community

Area 8 is unique in comparison to the other basins of Kennady Lake because it is long (about 4 km), narrow (typically less than 500 m wide), and shallow (generally less than 4 m deep). Two deep areas (greater than 8 m deep) exist in Area 8; however, habitat greater than 4 m deep represents less than 8% of the total surface area of Area 8. Results of the radio-telemetry program showed that lake trout and Arctic grayling migrating from the Kennady Lake outlet (Stream K5) to Areas 2 to 7, moved quickly through Area 8 presumably because habitat conditions were more suitable in Areas 2 to 7. Similar data are unavailable for round whitefish; however, similar avoidance of Area 8 is expected. However, habitat in Area 8 is relatively diverse in comparison to habitat in the other basins of Kennady Lake, and nearshore habitat includes clean boulder/cobble substrates, as well as bedrock slopes, and shallow, silt-covered embayments with aquatic vegetation.

Arctic grayling are the only fish species in Kennady Lake known to make extensive migrations between the main basins of Kennady Lake and the Kennady Lake outlet (Stream K5). These fish migrate downstream in spring to spawn in the streams immediately downstream of the Kennady Lake outlet (Stream K5). Most of these fish then return to Kennady Lake soon after spawning. Lake trout and northern pike are also known to migrate out of Kennady Lake in spring but in small numbers; lake trout presumably migrate to feed on congregations of spawning Arctic grayling, and northern pike migrate to spawn in weedy bays and flooded riparian tundra in downstream lakes.

Fish are known to use sub-optimal habitat (Birtwell and Korstrom 2002; Birtwell et al. 1999; Jones and Tonn 2004) and, therefore, individuals of each species may persist, but it is uncertain whether residual populations of round whitefish and lake trout will persist in Area 8 during mine operations. The main habitat factors that make the persistence of residual populations of these fish species in Area 8 uncertain include the following:

- Area 8 is shallow and does not provide the same cover or refuge from higher summer water temperatures that is available in other, deeper basins of Kennady Lake; and
- the shallower depth and lower dissolved oxygen levels suggests that the volume of overwintering habitat in Area 8 is smaller than in the other basins of Kennady Lake.

Under baseline conditions, winter dissolved oxygen concentrations were lower in Area 8 compared to Areas 3, 5, and 6. Lake trout and round whitefish are salmonids that generally require higher dissolved oxygen concentrations than non-salmonid species. For example, optimal dissolved oxygen habitat for lake trout is greater than 6 mg/L (MacLean et al. 1990; Clark et al. 2004; Ryan and Marshall 1994; Marshall 1996; Evans 2005).

In Areas 3, 5, and 6, minimum winter dissolved oxygen concentrations were generally higher than 6 mg/L at depths down to 8 to 9 m. In comparison, in Area 8, minimum winter dissolved oxygen concentrations were generally higher than 6 mg/L at depths down to 6 m, resulting in more limited overwintering habitat at shallower depths. Although water with dissolved oxygen concentrations exceeding 6 mg/L does exist at depths less than 4 m, ice thickness is typically 2 m in winter and the volume of suitably oxygenated water for salmonids in Area 8 is less than other basins in Kennady Lake. The change in lake levels in Area 8 during operations is small (i.e., less than 0.1 m) and no change in trophic status is predicted based on increased nutrient concentrations; as a result, overwintering habitat conditions are not expected to be affected. However, as a result of the existing overwintering limitations in Area 8 and the elimination of alternative overwintering refugia in Areas 2 through 7, lake trout and round whitefish may not continue to persist in Area 8 throughout the operational period.

Northern pike are more likely to persist in Area 8 than round whitefish or lake trout because they can tolerate lower dissolved oxygen concentrations and because aquatic vegetation is relatively common in Area 8 compared to other basins of Kennady Lake. Northern pike are tolerant of low dissolved oxygen concentrations (less than 3 mg/L) (Ford et al. 1995; Casselman and Lewis 1996) and will be able to overwinter successfully in Area 8. Vegetation for northern pike spawning and rearing is typically found in shallow embayments along the southern shoreline and near the Kennady Lake outlet (Stream K5). Weedy areas of lakes downstream of Kennady Lake may also provide spawning and feeding habitat for Kennady Lake northern pike. Northern pike residing in Kennady Lake currently use aquatic vegetation in lakes of the D watershed for spawning and rearing; this habitat will be unavailable to northern pike in Area 8 during operations. Although northern pike residing in Area 8 during operations will be able to use aquatic vegetation in Area 8 and in lakes and streams downstream for spawning and rearing, it is likely that the isolation of Area 8 from the D watershed will affect northern pike. There may also be a reduction in potential prey availability in Area 8 compared to that of the entire Kennady Lake (including round whitefish and juvenile lake trout). Therefore, there may a reduction in the growth and overall production of the northern pike population in Area 8.

Arctic grayling show considerable low oxygen tolerance for salmonids (Eriksen 1975 as cited in Hubert et al. 1985); although the overwintering habitat in Area 8 will be more limited than currently exists in Kennady Lake, it is expected that Arctic grayling will be to persist in Area 8 during isolation. Although some of Kennady Lake Arctic grayling spawning and rearing occurs in the tributaries upstream of Kennady Lake, most takes place in streams downstream of Area 8. Burbot are also expected to persist in Area 8 because they can forage successfully on the bottom or among boulders along the shoreline and can use limited overwintering habitat more effectively than the salmonids.

Populations of small-bodied fish species such as lake chub, ninespine stickleback, and slimy sculpin are more likely to persist in Area 8 than the larger-bodied fish species. This is due to their ability to find suitable cover in the boulder substrates present along the shoreline and their greater tolerance for lower dissolved oxygen concentrations than salmonids. The diversity of habitat in Area 8 is expected to provide the entire habitat necessary for all of the smaller-bodied fish species; as a result, the lack of access to small lakes within the Kennady Lake watershed is not expected to affect the small-bodied fish populations in Area 8.

Changes to Fish Migrations from Downstream Fish Communities

There will be flow changes in the Area 8 outlet channel (Stream K5) which will affect fish migration into and out of Area 8 during the operations period. Effects to fish and fish habitat from alteration of flows in Stream K5 are assessed in Section 9.10.

8.10.3.5 Effects of Dust Deposition on Fish and Fish Habitat

Total Suspended Particulate Deposition

The increased deposition of dust may enter surface waters, particularly during spring freshet, and could result in increased concentrations of suspended sediments in lake water. The spatial extent of dust and metal deposition is anticipated to be restricted to localized areas within and close to the Project footprint, with maximum deposition expected to occur near haul roads along the southern, western, and eastern boundary of the development area, and primarily reflect winter fugitive road dust emissions (Section 11.4 Subject of Note: Air Quality). The concentrations of TSS in nearby lakes may be elevated during and after freshet (Section 8.8.3.1, Table 8.8-11). The predicted maximum TSS concentrations for fish-bearing lakes range from 10 to 69 mg/L. The largest predicted maximum TSS concentrations are for lakes D2 (69 mg/L) and I1 (64 mg/L), with all of the other lakes being less than 30 mg/L.

The nature and extent of adverse effects of increased TSS on fish is influenced by both the TSS concentration and the duration of exposure. Fish can tolerate low TSS concentrations for long periods and high concentrations for short periods without suffering adverse effects.

The period of elevated TSS in affected lakes is expected to be short, where the largest load of suspended sediments to surface waters during the year will occur during spring freshet, when dust deposited to snow during winter and eroded materials enter surface waters. Sediment inputs during other times of the year are anticipated to be sporadic and too small to result in measurable changes in TSS concentrations in lakes. The length of the freshet period is estimated to range from approximately a few days to a few weeks, depending on lake size. The particles would be expected to settle fairly quickly, within less than a month.

Based on the Newcombe and Jensen (1996) dose-response relationship, the Severity of Effect (SEV) values suggest that exposure to peak TSS concentrations such as those estimated to occur could cause responses ranging from moderate to major physiological stress (i.e., reduction in feeding rate and feeding success). No lethal and paralethal effects would be anticipated. This is likely an overestimation for the following reasons:

- Predicted changes in TSS are considered to be conservative (high) estimates of the maximum potential changes that could occur during construction and operations (See Section 8.8.1.3).
- The period of exposure in the dose-response relationship is to peak concentrations; however, the peak levels are transitory, with the particles settling fairly quickly after snowmelt. As a result, the model likely overestimates the true duration period.

Nevertheless, the overestimation was used as a worse-case scenario for the dose-response relationship; the actual response is expected to be less. Furthermore, fish are routinely exposed to higher TSS levels during spring freshet periods and would tolerate the levels in the short-term.

The increases in sediment would be too small to produce measurable effects on fish habitat. Most of the increased suspended sediment will occur during spring freshet. Although it will settle out of the water column fairly quickly, the high water levels, wave action, and currents will move the sediment off any sensitive habitat areas in the nearshore areas of lakes (e.g., spawning shoals or vegetation) into the deeper main basin of the lake.

In summary, effects of TSS from dust and particulate deposition are expected to be localized in the immediate vicinity of the Project and temporally restricted to the period during and after freshet.

Aquatic Health

Potential effects to aquatic health from dust and metals deposition were evaluated in the aquatic health assessment (Section 8.9.3.1). The maximum concentrations of some metals (aluminum, cadmium, chromium, copper, iron, mercury, and silver) were predicted to exceed water quality guidelines in some lakes. However, similar to TSS, the predicted maximum metal concentrations are likely conservative estimates (Section 8.8.1.1.2); the spatial extent of the dust and metals deposition is also expected to be restricted to localized areas and occur primarily for a short period during spring freshet. Given the conservatism in the predicted concentrations, and the length of the exposure to elevated concentrations, the potential for adverse effects to aquatic health from dust and metals deposition was considered in the aquatic health assessment to be low (Section 8.9.3.1), with follow-up monitoring being undertaken to confirm. As a result, no effects to fish populations or communities would be expected to occur from changes in aquatic health.

8.10.4 Effects Analysis Results – Closure and Post-closure

8.10.4.1 Effects of Development of Fish Habitat Compensation Works on Fish and Fish Habitat

To compensate for habitat permanently lost or altered due to proposed mine development (as described in Section 8.10.3.1), and eliminate potential adverse effects due to changes in habitat area, the Project includes a habitat compensation plan designed to create new fish habitat (see CCP, Section 3, Appendix 3.II). The objective of the plan is to provide compensation habitats to offset predicted habitat losses so that there is no net loss of fish habitat according to DFO's Fish Habitat Management Policy (DFO 1986, 1998, 2006).

Several of the identified compensation options focus on the construction of habitat structures within specific areas of Kennady Lake. Others focus on opportunities for habitat compensation in adjacent areas. Although some of the habitat compensation works may potentially be developed during the operations phase of the Project, most of the compensation habitat will be developed at closure. Compensation features will be permanent structures designed to provide habitat for the fish community that will be re-established in the Kennady Lake watershed after closure. The following options have been identified:

- Option 1a: raising the water level of some lakes to the west of Kennady Lake (in the D watershed) to a level greater than what would be required only for development of the Project through construction of impounding dykes.
- Option 1b: raising the water level of some lakes to the west of Kennady Lake (in the D, E, and N watersheds) to the same level as in Option 1a, but creating more habitat than Option 1a by involving more lakes and land area.

- Option 1c: additional raising, after mine closure, the water level in the flooded area created by Option 1b.
- Option 2: raising Lake A3 to a greater elevation than would be only for development of the Project.
- Option 3: constructing finger reefs in Areas 6 and 7.
- Option 4: developing habitat enhancement structures in Area 8.
- Option 5: constructing shallow littoral and reef habitat structures on the shallow portions of the backfilled Hearne Pit within Kennady Lake.
- Option 6: constructing shallow littoral and reef habitat structures on the shallow portions of the backfilled 5034 Pit within Kennady Lake.
- Option 7: developing some shallow habitat structures within Kennady Lake around the rim of the Tuzo Pit.
- Option 8: developing a Dyke B habitat structure within Kennady Lake after closure.
- Option 9: constructing impounding dykes to the south of Area 7 to raise Area 8 and Lakes L2, L3, and L13 (would also raise water levels in the remaining portions of Kennady Lake at closure).
- Option 10: widening the top bench of the Tuzo and 5034 mine pits to create shelf areas where they extend onto land.

The proposed fish habitat compensation plan consists of a combination of the compensation options listed above. The preferred options include Options 1b and 1c (raising the water level in lakes to the east of Kennady Lake), Option 2 (raising the level of Lake A3), and Option 10 (widening the top bench of mine pits where they extend onto land. Also included in the proposed compensation plan are Options 3 and 4 (construction of habitat enhancement features in Areas 6, 7 and 8) and Option 8 (the Dyke B habitat structure).

The amount of compensation habitat, in terms of surface area, provided by the proposed compensation plan is summarized in Table 8.10-9. Quantification of habitat gains in terms of HUs, and determination of compensation ratios based on HUs, will be completed as part of the development of a detailed compensation plan to be completed in 2011. More details on the various options and the proposed fish habitat compensation plan are provided in Section 3, Appendix 3.II.

Table 8.10-9 Summary of Fish Habitat Compensation Achieved with the Proposed Conceptual Compensation Plan

Compensation Description	Compensation Habitat Area (ha)	
	During Operations	After Closure
Newly Created Habitat		
Option 1b – Construction of Impounding Dykes F, G, E1, and N14 to the west of Kennady Lake to raise Lakes D2, D3, E1, and N14 to 428 masl elevation	149.7	–
Option 1c – After closure, further raise the water level in Lakes D2, D3, E1, and N14, and the surrounding area, to 429 masl and reconnect the flooded area to Kennady Lake through Lake D1	–	195.9
Option 2 – Construction of Impounding Dyke C between Area 1 and Lake A3, Dyke A3 to the north of Lake A3, and Dyke N10 between Lakes A3 and N10 to raise Lake A3 to 427.5 masl elevation	31.1	31.1
Option 10 – Widening the top bench of pits (to create shelf areas) where they extend onto land	–	13.7
Altered Areas Reclaimed and Submerged at Closure		
Hearne Pit [a]	–	16.0
5034 Pit [a]	–	35.0
Tuzo Pit [a]	–	35.2
Dykes A, B, J, K and N	–	23.8
Road in Area 6	–	4.0
Water Collection Pond Berms CP3, CP4, CP5, and CP6	–	1.3
Mine rock areas [b]	–	25.3
Total	**180.8**	**381.3**
Compensation Ratios (gains:losses)[c]	**0.65**	**1.37**

[a] Areas for these options are entire pit areas, including habitat features along the edges and deep-water areas.
[b] Mine rock piles with final surface elevations between 410.0 and 418.0 masl are considered as compensation habitat.
[c] Calculated based on total area of permanently lost habitat and physically altered and re-submerged habitat (Section 8.10.3.1).

masl = metres above sea level; ha = hectares.

8.10.4.2 Effects of Re-diverting B, D, and E Watersheds to Kennady Lake

At closure, the natural drainage of the B, D, and E watersheds to Kennady Lake will be restored. Dykes F and G will be breached and flow from these watersheds will be re-diverted to Kennady Lake through D1. In the A watershed, Dyke C will be permanent and Lake A3 will continue to flow to the L watershed.

Changes to Lake Levels and Lake Areas

At closure, water levels in the raised Lakes D2-D3 and E1 will decrease relative to operations when the D and E watersheds are re-diverted to Kennady Lake (Table 8.10-10), and D2 and D3 will once again form separate lakes. These changes in lake levels will lead to a decrease in littoral area and lake volume; as a result, there may be corresponding decreases in the availability and suitability of fish habitat in the lakes. However, as the water levels will be returning to pre-Project (i.e., baseline) conditions, the fish and benthic invertebrate communities within the lakes will adjust to the lowered lake levels. As described in Section 8.7.4.3, the restored baseline lake shorelines are expected to remain stable. Habitat conditions for spawning, rearing and overwintering will be similar to pre-Project conditions. As a result, the change would not be expected to have a substantive effect on fish populations within the D and E watersheds. Water levels in Lake A3 will remain the same as during operations. No changes in B1, D1 and D7 will occur from the Project (Table 8.10-10).

Table 8.10-10 Lake Areas and Depths in Diverted Lakes of the A, B, D and E Watersheds by Project Phase

Parameter	Project Phase	Lake						
		A3	B1	D1	D2	D3	D7	E1
Lake area (ha)	Baseline	23.8	8.2	1.9	12.5	38.4	40.2	20.2
	Operations	46.6	8.2	1.9	104		40.2	27.0
	Closure	46.6	8.2	1.9	12.5	38.4	40.2	20.2
	Post-Closure	46.6	8.2	1.9	12.5	38.4	40.2	20.2
Maximum depth (m)	Baseline	12.4	4.1	3.8	1.0	3.0	4.5	3.9
	Operations	15.9	4.1	3.8	3.8	4.6	4.5	4.7
	Closure	15.9	4.1	3.8	1.0	3.0	4.5	3.9
	Post-Closure	15.9	4.1	3.8	1.0	3.0	4.5	3.9

ha = hectare; m = metre.

Changes to Lower Trophic Levels

Total biomass of plankton and benthic invertebrate communities in some lakes in the B, D and E watersheds will decrease due the decreased habitat areas compared to operations. Although productivity of lower trophic communities in these lakes is not expected to be negatively affected by the diversions back to the Kennady Lake watershed, there will be a period of adjustment to the new water level.

Changes to Fish Migrations

In the B, D and E watersheds, the dykes, diversion channels, and other associated infrastructure will be decommissioned. Where possible, the watersheds will be reconnected to Kennady Lake along previous connecting streams. Additional cobble and boulder placement will occur to reduce erosion potential where necessary. These streams will provide fish habitat similar to that currently present in these connecting channels, including Arctic grayling spawning habitat. Fish salvage will be conducted as appropriate during decommissioning the diversion channels (i.e., the connections between the B, D, and E watersheds and the respective lakes in N basin).

Until the water quality in Kennady Lake is deemed suitable for fish, exclusion measures will be taken to limit the initial migration of large-bodied fish from the upper B, D, and E watersheds into Kennady Lake. Mitigation measures will be designed to target large-bodied fish, such as northern pike, burbot, lake trout, and Arctic grayling. However, benthic invertebrates, small forage fish and some juvenile life stages would be expected to pass through the exclusion measures into Kennady Lake. It is anticipated that during the initial period of refilling, some mortality of the incoming small-bodied fish is likely to occur, because of insufficient water depths and possibly elevated levels of turbidity.

During the refilling period, there will be a period of time where the B, D, and E watersheds will be not be connected for fish migration to a large lake (e.g., Kennady Lake or the N lakes). However, similar to Section 8.10.3.3, the stock of most large-bodied fish species is expected to be maintained in the B, D, and E watersheds over this period. Based on lake areas and depths (Table 8.10-10), it is expected that the lakes within the B, D, and E watersheds will provide suitable habitat for fish species, such as Arctic grayling, burbot, and northern pike (i.e., spawning, rearing and overwintering habitat). When the water quality is suitable to support aquatic life, and stable plankton, benthic invertebrate, and forage fish communities have become established, large-bodied fish from the B, D, and E sub-watersheds will be able to freely immigrate to Kennady Lake and become brood stock for recolonization.

The reconnection may also allow fish species not previously present in Kennady Lake to become introduced to Kennady Lake from the N basin. For example, cisco and sucker species from N16 could enter the D and E lakes during operations and then move into Kennady Lake after the connection is restored. More information on the expected re-establishment and recovery of the fish community in Kennady Lake is provided in Section 8.11.

8.10.4.3 Effects of Continued Isolation of Area 8 During Refilling on Fish and Fish Habitat

During refilling of Kennady Lake (i.e., the closure period), Area 8 will remain effectively isolated from the remainder of Kennady Lake. Water quality in Area 8 is predicted to remain stable during refilling the remainder of Kennady Lake (Section 8.8.4.1.1). Discharges from Kennady Lake will not occur until water quality conditions are deemed acceptable for release. As a result, effects to the fish and fish habitat in Area 8 will be similar to those identified in Section 8.10.3.4 above.

8.10.4.4 Effects to Fish and Fish Habitat in Kennady Lake during Post-Closure

The following section describes the effects on fish and fish habitat from reconnection of Kennady Lake to Area 8 and associated changes in water quality. Recovery of the Kennady Lake fish community after refilling is discussed in Section 8.11.

8.10.4.4.1 Effects of Changes in Nutrient Levels

As previously stated, the analysis of potential effects related to nutrients will be submitted following the completion of additional analysis, which is expected to be completed in 2011.

8.10.4.4.2 Effects of Changes to Aquatic Health

Potential effects to aquatic health in Kennady Lake and Area 8 were evaluated for closure and post-closure in the aquatic health assessment (Section 8.9) based on predicted changes in water quality and sediment quality.

For the direct waterborne exposure assessment, total dissolved solids (TDS) was identified as a substance of potential concern (SOPC); however, adverse effects to fish and aquatic invertebrates are not expected at the predicted TDS concentrations in Kennady Lake and Area 8 (Section 8.9.3.2.1). At closure, predicted maximum concentrations of SOPCs in Kennady Lake and Area 8 are below chronic effects benchmarks (CEBs), with the exception of total iron, copper, and strontium. The predicted iron concentrations are not expected to result in adverse effects to aquatic life, and the potential for copper and strontium to cause adverse effects to aquatic life in Kennady Lake and Area 8 was considered to be low (Section 8.9.3.2.1).

For the indirect exposure pathway, predicted fish tissue concentrations in Kennady Lake were projected to be above toxicological benchmarks for only one substance of interest (SOI): silver. However, the potential for the predicted silver concentration to cause effects to fish was considered to be low (Section 8.9.3.2.2).

Based on the aquatic health assessment (Section 8.9), predicted changes to concentrations of all substances considered were projected to result in negligible effects to fish tissue quality and, by association, aquatic health in Kennady Lake. As a result, no effects to fish populations or communities would occur from changes in aquatic health.

8.10.4.4.3 Long-Term Effects

Recovery of Fish Community

The recovery of the fish community in Kennady Lake in post-closure is described in Section 8.11. Physical conditions in the lake at closure include habitat losses due to excavation of the mine pits and habitat enhancement structures built to replace lost habitat in Kennady Lake. The assessment of effects to aquatic health concluded that modelled changes in chemical constituents of water quality will have a negligible effect on the health of aquatic life in the refilled Kennady Lake. The nutrient enhancement is uncertain at this time. As a result, potential effects related to phosphorus have not been presented and will not be available until such time as additional analysis is completed. This information will be provided to the Panel in 2011.

8.11 RECOVERY OF KENNADY LAKE AND ITS WATERSHED

With the physical environment, hydrology and water quality of Kennady Lake returning to stable conditions after Project closure, it is expected that an aquatic ecosystem will develop within Kennady Lake. The uncertainty lies in how long the recovery will take and how similar the aquatic ecosystem will be to baseline conditions.

Under baseline conditions, Kennady Lake ecosystem consists of various aquatic biota, including aquatic plants, phytoplankton, zooplankton, benthic invertebrates, and fish. A three-step process was adopted to evaluate and assess how each of these components of the aquatic ecosystem may develop in Kennady Lake after refilling. The first step involved the completion of a literature review. The literature review was undertaken to develop a summary of the published information relevant to the recovery of lakes after flooding or refilling and to identify, to the extent possible, the main drivers that control the rate and direction of recovery. The specific objectives of the literature review were as follows:

- to summarize the key findings that other researchers have observed on other systems;
- to identify the main drivers that were responsible for the observed changes in each system (to the extent possible); and
- to highlight the management options that have been applied to aid in lake recovery (if presented and/or identified in the reviewed literature).

The second step in the assessment process involved evaluating how the results of the literature review applied to Kennady Lake, given its location and physical structure. The final step in the process consisted of taking the information obtained from the literature review and the evaluation of its suitability to Kennady Lake and using it to project how the aquatic ecosystem in Kennady Lake will likely recover.

A more detailed discussion of the methods used to complete each step of the assessment process is outlined below in Section 8.11.1. The results of the assessment are presented in Section 8.11.2.

8.11.1 Effect of Project Activities on the Long-term Recovery of Kennady Lake

8.11.1.1 Background

As noted in the Key Line of Inquiry: Water Quality and Fish in Kennady Lake (Section 8), some of the aquatic habitat in Kennady Lake disrupted or disturbed by Project activities will be replaced, and the long-term hydrology of Kennady Lake is expected to return to a stable state similar to current conditions. Water quality in the lake is similarly expected to return to existing conditions over time with the potential exception of nutrients and some components of total dissolved solids (TDS). This also takes into account the negligible effects predicted to aquatic health related to potential changes in the chemical constituents of water quality in the refilled Kennady Lake after mine closure. With the physical and chemical environment of Kennady Lake returning to stable conditions, it is reasonable to conclude that an aquatic ecosystem will develop within Kennady Lake. There is uncertainty in how long the recovery may take and what the final aquatic ecosystem will consist of particularly when colonization and trophic change are considered.

Similar to most lakes, Kennady Lake currently contains phytoplankton, zooplankton, benthic invertebrates, aquatic plants, and fish. As outlined in Section 8.11, a three step process was adopted to evaluate and assess how each of these components of the aquatic ecosystem may develop in Kennady Lake after refilling.

A more detailed discussion of the methods used to complete each step of the assessment process for the long-term recovery of Kennady Lake is outlined in Section 10.5.2, and the results of the assessment are presented in Section 10.5.3; the information presented in these two sections is virtually identical to that which appears in Sections 8.11.1 and 8.11.2 of the Key Line of Inquiry: Water Quality and Fish in Kennady Lake. The information is being presented in both locations to ensure that the Terms of Reference (Gahcho Kué Panel 2007) requirement that each key line of inquiry must be a comprehensive stand-alone analysis with only minimal cross-referencing with other parts of the environmental impact statement (EIS) is met.

8.11.1.2 Effects Analysis Methods

8.11.1.2.1 Literature Review

Search Methods

The literature search was conducted with a focus on the following topics:

- impacts of damming on upstream environments;
- flooding of new land and the development of aquatic ecosystems in previously terrestrial habitats (e.g., development of off-stream reservoirs);
- recovery of previously-drained systems; and
- management of lake recovery.

The databases searched included Agricola, Arctic & Antarctic Regions, BIOSIS Previews, Environment Complete, Environmental Abstracts, Genie Catalog, Google Scholar, Scopus, SpringerLink, Web of Science, and Wildlife & Ecology Studies.

The search terms included primary keywords, such as lake recovery, increasing lake volume, impoundments, environments upstream of dams, downstream environments of removed dams, ecosystem establishment, dam formation (focusing on flooding of terrestrial environments), and lake formation. Secondary keywords included cold climates, arctic, subarctic, tundra, and oligotrophic systems. Additional terms were added during the search process. They included “recovery and disturbance and aquatic systems”, “impoundments not dams”, recovery and lentic systems, reservoir aging, and turbidity.

Document tracking was completed using a spreadsheet that outlined the databases searched, the date the searches were conducted, the keywords used, the number of hits and the number of hits sourced for further short-listing.

In addition, Niemi et al. (1990) completed a review of articles on the recovery of aquatic systems after disturbance. The authors focused their efforts on retrieving articles published from 1970 to 1986. As part of the present literature review, the search completed by Niemi et al. (1990) was repeated using similar databases and search terms with a focus on articles published since 1986. A cited references search was also completed using Niemi et al. (1990) as the focus article, and references in all reviewed articles were examined for additional sources relevant to the topic of the current literature review.

Review Procedure

The citations for all retrieved articles were entered into a spreadsheet, and the titles were reviewed for applicability to the topic of lake recovery. A scoring system was applied to short-list the articles to be reviewed. Each citation was scored as 1, 2, or other. A score of 1 meant that the article appeared to be directly applicable to the topic of lake recovery in northern climates, whereas a score of 2 meant that the article contained some relevant material.

Articles that were rated as “other” contained information related to lakes or reservoirs in southern or tropical locations, discussed lake recovery following a spill or other short-term input, or were focused on the recovery of flowing systems (rather than lakes or reservoirs). Articles that provided general background information (e.g., limnology studies that did not necessarily discuss lake recovery) were also generally considered to be non-relevant to the main topic of the literature review. Articles with scores of 1 or 2 were further short-listed by scanning the abstract or, in some cases, the body of the text of short articles. Priority for article review was given to the articles rated as 1, followed by those assigned a rating of 2. The key findings of the articles that were considered relevant to Kennady Lake were brought forward and are discussed in Section 10.5.3

8.11.1.2.2 Assessing Applicability to Kennady Lake

Following the completion of the literature review, key findings were evaluated with reference to their applicability to Kennady Lake. The evaluation involved looking at how the systems described in the reviewed literature compared in size and location to Kennady Lake, as well as assessing whether the drivers identified in the reviewed articles would have equal application to an arctic lake. Of particular focus was the potential role of flooded terrestrial vegetation. Flooded terrestrial vegetation was identified in a number of studies as a key driver that influences initial nutrient dynamics and primary productivity in flooded or refilled systems. An evaluation was, therefore, completed to examine the potential extent of vegetative in-growth into the drawn-down sections of Kennady Lake during the operational life of the Project.

8.11.1.2.3 Forecasting Recovery Rates and the Nature of the Final System

The information obtained from the literature review, balanced by its applicability to Kennady Lake, was used to evaluate how the aquatic ecosystem in Kennady Lake would recover. The evaluation was completed using professional judgement, with due consideration given to the ecological concepts of colonization, natural succession, and trophic interactions, particularly as they apply to small arctic lakes.

Re-establishment of self-sustaining fish populations is the ultimate end-point of the Kennady Lake ecosystem recovery. To assess the re-establishment of fish, it was first necessary to predict the composition, abundance, and distribution of plankton and benthic invertebrate communities expected to re-establish in the lake, because these lower trophic communities form the basis of the food web upon which fish in the lake will depend. Once the predicted recovery of the lower trophic levels was complete, attention was focused on predicting the recovery of the fish community, including both forage and sport fish. As part of the analysis, consideration was given to the potential for restocking Kennady Lake with lake trout and/or round whitefish.

8.11.1.3 Effects Analysis Results

8.11.1.3.1 Summary of Key Findings from Literature Review

Each of the following sub-sections contains a summary of the key information obtained from the literature review with reference to a particular part of the aquatic ecosystem. The first three sub-sections are focused on nutrient dynamics, erosion and turbidity, and the potential release of metals from newly flooded areas. Key findings related to the establishment and growth of bacteria and phytoplankton, zooplankton, benthic organisms, and fish are then outlined in the next four sub-sections.

Each sub-section is organized in a similar fashion, beginning with an introductory paragraph that contains an overall summary of the sub-section contents. The remaining portion of each sub-section is then devoted to a more detailed discussion of the key findings, with relevant examples and citations included in the text.

Nutrient Dynamics

The information obtained from the literature review suggests that nutrient dynamics in a refilled reservoir or flooded lake are driven primarily by the flooding of terrestrial vegetation and, to a more limited extent, soil. Although nitrogen, phosphorus, and carbon are released, not all forms may be equally bioavailable. In particular, phosphorus may be released in a non-bioavailable form, which can lead to the preferential growth of bacteria over that of phytoplankton. The type and quantity of terrestrial vegetation that is flooded can affect the amount and duration of the initial nutrient pulse. Another potential source of nutrients is flooded soil. The benefits of removing terrestrial vegetation or soil prior to flooding to reduce the initial nutrient surge are dependent on site-specific conditions, and can, in some cases, result in some unforeseen detrimental effects, as outlined in greater detail below.

Flooding terrestrial vegetation can result in rapid and dramatic changes in water quality, including a surge in nutrient concentrations (Northcote and Atagi 1997). Following the flooding of a sedge meadow in Sweden, large quantities of terrestrial plant material dominated the detritus pool and supported a system dependent on allochthonous[5] organic matter for five to six years (Danell and Sjoberg 1982). Similarly, following the creation of a new reservoir, Thouvenot et al. (2000) noted that flooding and decomposition of existing terrestrial vegetation released nitrogen and carbon into the system.

Paterson et al. (1997) observed that the concentrations of phosphorus, nitrogen, and dissolved organic carbon in a newly impounded lake increased as a result of vegetative decay. Concentrations of most nutrients were higher in the shallower, flooded peat areas, relative to those measured in the open water areas of the lake — a pattern attributed to the dilution provided by upstream water input from an oligotrophic[6] system.

Although nitrogen, carbon, and phosphorus are released from decaying vegetation, their relative bioavailability can differ. The released forms of carbon and nitrogen are typically bioavailable, whereas the released phosphorus can be in a non-bioavailable form bound to organic particles (Paterson et al. 1997; Thouvenot et al. 2000). This lack of phosphorus or bioavailable phosphorus may initially cause an increase in bacterial biomass over phytoplankton, because phytoplankton require immediately bioavailable phosphorus. In contrast, bacteria can obtain phosphorus from more resilient materials during the decay process.

Geraldes and Boavida (1999) measured higher concentrations of different forms of phosphorus in a newly created reservoir, compared to an old reservoir that had been drained and refilled. The observed variation in phosphorus concentrations between the two systems was attributed to the abundance of terrestrial vegetation in the newer reservoir that was undergoing decay. However, phosphorus concentrations declined after the initial spike post-impoundment, potentially due to an increase in sedimentation rates, the uptake of nutrients by phytoplankton, and/or a reduction in the amount of flooded terrestrial vegetation.

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5 Allochthonous organic matter refers to organic matter that did not originate in the place it was found. In comparison, autochthonous organic matter is derived from sources found within the system, such as plankton debris.

6 Oligotrophic systems are characterized as being poor in nutrients and plant life, and rich in oxygen.

The type and quantity of vegetation entering a system can determine the magnitude and duration of the nutrient surge. The decay of moss-peat in limnocorral[7] experiments initially increased then lowered primary productivity and biomass, because it initially released nutrients (soluble phosphorus and nitrogen) and then lowered some other factor (such as iron or some other essential metal by binding to the increased humic matter) (Guildford et al. 1987). After one year, the moss-peat material no longer released humic material, phosphorus, or nitrogen in sufficient quantities to influence concentrations in the water column (i.e., concentrations in the experimental cells were similar to those in the control cells).

In general, leaves, needles, and other soft parts of trees decay faster than shrubs, brush, and other non-woody vegetation, all of which decay faster than the woody components of large trees (Northcote and Atagi 1997). For example, conifer needle litter can decompose completely within a year, initially by leaching and microbial activity, and then by macroinvertebrate feeding (especially by midge [Chironomidae] larvae) (Crawford and Rosenberg 1984), whereas trees take longer.

Flooded soil can be a source of nutrients to a newly created lake or reservoir, although its input may be minor in comparison to that of flooded vegetation. In experiments with eroded clays, the release of phosphorus from the introduced clays was small, and the increase in phosphorus availability as mainly due to decreased primary productivity, rather than an increase in available phosphorus (Guildford et al. 1987). In contrast, Northcote and Atagi (1997) noted that topsoil removal greatly lowered carbon, nitrogen, and phosphorus levels and reduced phytoplankton growth by over half in a newly flooded system, suggesting that the flooded soil was a major contributor to nutrient release. Hecky et al. (1984) similarly noted an increase in phytoplankton and zoobenthos biomass as a result of the release of nutrients from flooded soils.

McGowan et al*.* (2005) investigated the effects of lowering the water level during the winter on a shallow lake (Wascana Lake) in southern Saskatchewan. They hypothesized that reductions in water level and exposure of sediments to freezing temperatures would increase nutrient release rates. In particular, the rate at which phosphorus was released from the sediment was expected to increase upon refilling, because, based on the work of James et al*.* (2001), oxidation and mineralization of organic phosphates would occur while the sediments were exposed to atmospheric conditions. Sediment desiccation was also expected to increase aerobic nitrification, leading to a build-up of nitrate in

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[7] Large experimental cylinders enclosing a column of water in a lake.

the exposed sediments, as previously noted by Kadlec (1962). However, it was acknowledged that nitrate accumulation rates would be moderated by the increased rates of denitrification that could occur in the underlying anoxic sediments, as per De Groot and Van Wijck (1993).

Water levels in Wascana Lake were reduced by about 50 percent (%) in October, which resulted in most shallow upstream reaches of the lake being completely dry. The following spring, natural runoff restored lake levels. During the subsequent growing season, the authors did not find any evidence of increases in phosphorus release from sediments (McGowan et al. 2005). They speculated that phosphorus was not released, because phosphorus concentrations were naturally high in Wascana Lake and this would have limited diffusion from the sediment. Alternatively, the cold winter temperatures may have limited the rate at which the oxidation and mineralization of organic phosphate occurred.

Changes in the concentrations of nitrogen compounds in the water column were also limited and less than expected. Ammonia levels in Wascana Lake were elevated following lake refilling, but only minor variations were observed in nitrate levels. Overall, McGowan et al. (2005) attributed the lack of a more appreciable response to the winter drawdown to the resilience of the system and the fact that the lower winter water level was within the range of hydrological fluctuations Wascana Lake already experiences.

The benefits of removing terrestrial vegetation prior to flooding to limit the initial nutrient surge are not clear. For example, in Maltañski Reservoir in mid-western Poland, terrestrial vegetation and topsoil were removed prior to refilling the reservoir that had been dry for 10 years. However, post-flooding phosphorus concentrations in the water were higher than expected, suggesting that the preparation step was not effective (Goldyn et al. 2003). The higher than expected phosphorus levels were attributed to external loading of nutrients from incoming water and frequent emptying of the reservoir in the years after the initial refill period[8]. In contrast, Campbell et al. (1975) (as cited in Northcote and Atagi 1997) found phytoplankton densities were 5 to 100 times higher in flooded systems where soil had not been stripped, in comparison to those that had.

Stripping vegetation and topsoil may yield side effects that negate the potential gains to limiting nutrient surge. Soon-to-be-flooded areas around Southern Indian Lake were cleared of timber prior to impoundment. However, the cleared zone was entirely eroded within the first year of impoundment, which resulted in increased suspended sediments in the lake (Hecky et al. 1984). The authors

8 The Polish reservoir was also completely emptied between years.

also noted that the only effective clearing done on Southern Indian Lake was on bedrock shorelines and on protected shorelines without permafrost. In their review, Northcote and Atagi (1997) stated that, from a range of preparation procedures from nothing to complete clearing, the most appropriate procedure(s) for a given site are dependent on the final use of the new reservoir. For example, the purpose of the preparation could range from improving water quality to improving angler and boating access.

There are other benefits to maintaining terrestrial vegetation prior to flooding. Keeping woody debris and other forms of terrestrial vegetation on the flooded lake bed may aid in macrophyte growth; Northcote and Atagi (1997) cite a few studies that found macrophyte colonization was enhanced by inundated trees and brush, because of protection from wave action and erosion of soils. The authors also summarized studies on the Campbell River impoundments on Vancouver Island where high benthic diversity and abundance were associated with flooded trees, brush, and shrubs, compared to lower rates of diversity and abundance in systems where the terrestrial vegetation was nearly completely cleared prior to flooding.

Another possible management option available to limit the initial nutrient surge in newly flooded systems includes the repeated draining and refilling of the lake or reservoir in question. This action will remove the nutrients released from the decaying vegetation and allow for a more rapid establishment of conditions that are in equilibrium with upstream water sources. For example, successive reservoir emptying sped up the change from allochthonous to autochthonous organic matter, which likely caused the changes in unicellular plankton of a newly flooded reservoir (Thouvenot et al. 2000). Nursall (1952) also noted that a flooded oligotrophic lake in the Rocky Mountains was maintained as fundamentally oligotrophic partly because of the rapid replacement of water. Periodic fluctuation of water level (common to hydroelectric reservoirs) and deposition of sediment also contributed to this condition.

Erosion and Turbidity

Site-specific factors (e.g., permafrost, fine-grained sediments) affect shoreline erosion rates in newly created lakes and reservoirs, with the eroded sediment/soil potentially leading to changes in water-column turbidity. Although turbidity can have a profound effect on algae and vegetative growth within a lake or reservoir, the majority of the studies reviewed did not discuss turbidity as being notably higher after impoundment, or having an undue influence on biological development within the newly created systems. There were, however, some notable exceptions (e.g., Southern Indian Lake).

Marzolf (1990) stated that the dominant feature of reservoirs created on the Great Plains of North America is turbidity. However, these reservoirs are typically created by damming a river such that upstream riverbanks are flooded and scoured. Suspended sediment is often kept in the water column by the inflow current and the shallowness of the reservoir relative to its fetch.

Similarly, the distribution of erodible, fine-grained shorelines was the critical difference between the resultant turbidity levels that were measured in a northern Saskatchewan lake (Reindeer Lake) after impoundment and Southern Indian Lake, which is located in northern Manitoba (Hecky et al. 1984). Reindeer Lake is similar to Southern Indian Lake in latitude, magnitude of water level increase, surface area, operating regime, climate, bedrock geology, and pre-impoundment fishery; however, Reindeer Lake did not have turbidity issues, because fine-grained deposits were sparse and erosion was minimal (Hecky et al. 1984).

Southern Indian Lake is located on the Precambrian Shield in a zone of discontinuous permafrost. It is surrounded by boreal forest and experiences high wave action (Newbury and McCullough 1983). A dam constructed at the natural outlet to the lake caused flooding beyond the sub-lake thawed zone into the permafrost-affected upland. Extensive shoreline erosion subsequently altered the sedimentation regime and water quality of Southern Indian Lake (Hecky et al 1984). Pre-impoundment sediment input was about 200,000 tonnes/year compared to a post-impoundment rate of greater than 4,000,000 tonnes/year (Newbury and McCullough 1983).

Shoreline erosion along the edges of Southern Indian Lake continued until bedrock was exposed. The time required for shoreline stabilization was estimated from the frequency of bedrock encounters and the pre-impoundment estimate of how much of the shoreline was bedrock-controlled. From these calculations, it was estimated that it would take 35 years to restore 90% of the shoreline (Newbury and McCullough 1983).

As a consequence of the shoreline erosion, Southern Indian Lake was, on average, a darker, less transparent lake than it was prior to its expansion through impoundment (Hecky et al. 1984). However, primary productivity increased in well-illuminated regions of Southern Indian Lake, due to increased nutrient concentrations resulting from the decay of terrestrial vegetation[9]. Primary productivity did not increase in other areas of the lake, because of low light intensity and increased turbidity. Light extinction in Southern Indian Lake was a

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[9] Phosphate concentrations increased in the water column of Southern Indian Lake after impoundment (C. Anema, unpublished data, cited by Hecky et al. 1984).

linear function of suspended sediments (Hecky 1984), and algal production was limited when mean water column light intensity fell below 5 micro-Einsteins per square metre per minute ($mE/m^2/min$) (Hecky and Guildford 1984). Limnocorral experiments with suspended clays showed that light reduction due to suspended clay and silt depressed primary productivity and phytoplankton biomass (Guildford et al. 1987).

Decreased zooplankton biomass and changes in species composition in major regions of the lake were attributed to lower water temperatures and reduced predation due to poorer transparency (Patalas and Salki 1984). Zoobenthos alternately benefited from, and were depressed by, increased suspended sediments; in some areas, the high concentration of suspended sediments negated the benefit of high input of organic substrate as a source of nutrients and habitat (Hecky et al. 1984).

Fish were negatively affected by the impoundment of Southern Indian Lake. The increased turbidity reduced the ability of fish to locate food, and it may have resulted in reduced embryo survival due to increased rates of sedimentation (Hecky et al. 1984). In addition, the introduced sediments contained mercury, and increased mercury concentrations were observed in fish tissue (Bodaly et al. 1984).

Metals Release

With the exception of mercury, metal release from sediment as a consequence of flooding was not observed or commented upon in the majority of the reviewed literature. Low oxygen conditions in flooded sediment, however, can result in the release of dissolved manganese and iron, as observed in a refilled reservoir in Germany (Nienhuser and Braches 1998).

In contrast to other substances, mercury appears to be a common concern following flooding or impoundment. Increased methyl mercury contamination in fish has been noted in a number of studies, and factors affecting methyl mercury production and its uptake by biological organisms have been identified. This phenomenon is likely due to the inundation and subsequent decomposition of organic material that promotes the microbial methylation of inorganic mercury to organic methyl mercury. It has been well established that (1) mercury in pristine and flooded soils is predominately bound to organic matter, and (2) that mercury methylation is related to organic carbon content of the flooded soil/sediment. Methyl mercury is the most toxic form of mercury and readily accumulates in aquatic organisms.

Three processes can be targeted to mitigate the effect of methyl mercury generation, bioaccumulation through the food chain, and associated environmental and health risks: mercury methylation, mercury bioaccumulation, and fish consumption. Available mitigation options include partial or complete stripping or capping of organic materials and soils, high temperature burning of vegetation and leaf litter, liming, selenium additions to newly created reservoirs and lakes, intensive fishing, fish barriers (screens), restricted access, and/or fish consumption advisories. Of the options available, selenium additions and liming are not widely recommended, and consumption advisors serve only to protect human health without directly addressing mercury concentrations in fish.

Key findings from these studies, as well as that completed by Nienhuser and Braches (1998), are discussed in more detail below.

Iron and Manganese

Nienhuser and Braches (1998) published an account of their difficulties in refilling a drinking water reservoir in Germany. Just after the beginning of refilling, the reservoir became ice-covered for two months. Dissolved oxygen levels in the lower section of the reservoir declined, due to the mineralization of organic matter in the flooded soils/sediments. While the bulk of the terrestrial vegetation was removed prior to refilling, the soil was not, and terrestrial organic matter remaining in flooded soil/sediment decayed. The change in oxygen conditions over the flooded soils/sediment resulted in the development of anoxic conditions within the sediments, which led to the release of dissolved manganese and iron.

Artificial mixing was introduced into the reservoir in an attempt to remedy the situation and prevent further increases in the concentrations of iron and manganese. However, the opposite occurred. Manganese and iron concentrations increased, because the artificial mixing system resulted in the suspension of the bottom sediments/soils in the water column.

Nienhuser and Braches (1998) noted that the rate of oxidation of reduced divalent manganese is slower than that of reduced divalent iron, perhaps because manganese needs a higher redox potential to be oxidized. Therefore, aeration acts faster or more effectively to remove dissolved iron than it does to remove or control dissolved manganese. Manganese oxidation is also influenced by microbial processes and takes between 1 and 100 days at high oxygen levels. Based on their experience, Nienhuser and Braches (1998) concluded that the refilling phase was a critical step in regards to the prevention of future problems with water quality, and they recommend that sediment and all fish are removed prior to refilling. They also suggested that artificial mixing systems be used.

Mercury

Background

Mercury (Hg) concentrations in fish have increased after impoundment in almost all reservoirs in North America and northern Europe. In Canada, various authors (e.g., Verdon et al. 1991; Bodaly and Fudge 1999; St. Louis et al. 2004) reported that reservoir creation often results in fish mercury concentrations that exceed the Canadian human consumption guideline of 0.5 micrograms of mercury per gram (µg Hg/g). In addition, reservoir creation may cause mercury problems in fish in downstream waterbodies (Johnston et al. 1991).

Methyl mercury is the most toxic form of mercury, and it accumulates readily in aquatic organisms (Ullrich et al. 2001). Fish mercury concentrations are thought to increase after flooding in reservoirs because the decomposition of soils and vegetation promotes the microbial methylation of inorganic mercury to organic methyl mercury (Bodaly et al. 1984; Jackson 1988; Hecky et al. 1991; Porvari and Verta 1995). The main pulse of methyl mercury production appears to occur in the first few years following impoundment (St. Louis et al. 2004; Heyes et al. 1998), but even this relatively short period of methyl mercury production has the potential to raise fish mercury concentrations for 20 to 30 years (Hall et al. 2005).

Although all inundated soils and vegetation are sources of organic carbon and potential sites of methyl mercury production, inundated conifer trees, needles, and boughs may be especially important methylation sites (Hecky et al. 1991; Heyes et al. 1998; Hall et al. 2004). Total methyl mercury production is also related to total organic carbon stored in the reservoir. In a study at the Experimental Lakes Area in northern Ontario, the reservoir with the most organic carbon (a flooded wetland) produced the most methyl mercury (Hall et al. 2005). Wetlands store a lot of organic carbon in the form of peat, and in the flooded wetland in the Experimental Lakes Area, 97% of methyl mercury production in the first two years occurred in flooded peat (St. Louis et al. 2004). Peat may cause additional problems in reservoirs, because it can acidify the water (St. Louis et al. 2003), which increases bacterial uptake of mercury for methylation (Kelly et al. 2003). Peat can also float to the surface and create floating peat mats (St. Louis et al. 2004), which can affect turbidity and light penetration. In a reservoir in northern Quebec, the highest concentration of dissolved methyl mercury in water was found under a floating peat mat (Montgomery et al. 2000).

Once methylated in the bottom sediments of a reservoir or lake, methyl mercury may be transferred to biota in a number of ways. There may be passive diffusion of methyl mercury into the water column (Morrison and Thérien 1991) and subsequent uptake into phytoplankton (Plourde et al. 1997). More commonly, flooded soil particles are suspended into the water column by wind or ice-driven erosion. Once in the water column, the soil particles are ingested by zooplankton and benthic invertebrates (Louchouarn et al. 1993; Grondin et al. 1995; Mucci et al. 1995). Plourde et al. (1997) have suggested that passive diffusion of methyl mercury is important in new reservoirs, whereas suspension of flooded soil particles is the most important transfer process in the long term. Ingestion of mercury-contaminated particles by burrowing benthic invertebrates may also be an important route for methyl mercury to enter the food chain. Once in zooplankton and benthic invertebrates, methyl mercury biomagnifies up the food chain to higher concentrations in fish.

Because suspension of sediment is a primary vector by which methyl mercury becomes available to biota, the amount of erosion in a reservoir can significantly impact methyl mercury concentrations in biota. St. Louis et al. (2004) suggested that, if there is little erosion, methyl mercury produced in peat will likely be demethylated. If there is erosion, however, methyl mercury will be rapidly transferred up the food chain. Littoral areas of reservoirs (i.e., the shallow zone where light penetrates to the bottom) are often particularly vulnerable to erosion and, therefore, maybe important sites of methyl mercury transfer. Littoral areas are also usually warmer than pelagic areas (i.e., the deep zones of the lake where light does not penetrate to the bottom), and the rate of mercury methylation increases with increasing temperature (Bodaly et al. 1993).

Once mercury levels are elevated as a result of impoundment, the time required for fish mercury concentrations to return to background levels is dependent on species, fish size, and fish diet. Planktivorous and omnivorous species return to background concentrations sooner than piscivorous species, and smaller fish return to background concentrations sooner than larger fish (Brouard et al. 1990; Verdon et al. 1991; Andersson et al. 1995). Most researchers have estimated that, for piscivorous species, the time to return to background mercury concentrations is 15 to 30 years (Verdon et al. 1991; Andersson et al. 1995; Porvari 1998), whereas those for non-piscivorous species range from 2 to 20 years (Verdon et al. 1991). Northern pike often show the longest recovery time (Jackson 1991; Andersson et al. 1995). The recovery period may be influenced by fish harvesting and reservoir discharges. Higher rates of fish harvesting and high flushing rates reduce the time to return to background concentrations in fish (Verdon et al. 1991).

Management Options

It has been well established that (1) mercury in pristine and flooded soils is predominately bound to organic matter (e.g., Louchouarn et al. 1993; Dmytriw et al. 1995; Tremblay and Lucotte 1997), and (2) mercury methylation is related to organic carbon content of the flooded soil/sediment. To mitigate the effect of methyl mercury generation, bioaccumulation through the food chain and associated environmental and human health risks, there are three processes that can be targeted: mercury methylation, mercury bioaccumulation, and fish consumption. The following identified mitigation options target one or more of these processes (as noted in parentheses):

- partial or complete stripping of organic material and organic soils within the footprint where a new lake or reservoir is to be established, with priority given to those materials/soils that have the greatest potential to contribute to methyl mercury production (e.g., peat and leaf litter) (methylation);
- partial or complete capping of organic material and organic soils within the lake/reservoir footprint, with priority given to those materials/soils that have the greatest potential to contribute to methyl mercury production (methylation);
- high temperature burn of vegetation and leaf litter within the lake/reservoir footprint (methylation);
- adding lime to the newly created lake/reservoir (methylation);
- adding selenium to the newly created lake/reservoir (bioaccumulation);
- intensive fishing (bioaccumulation and fish consumption);
- fish screens (bioaccumulation and fish consumption); and/or
- restricted access/fish consumption advisories (fish consumption).

Each of these mitigation options are discussed in more detail below.

Stripping or Burning

The potential for mercury methylation can be reduced by burning or stripping vegetation and organic soils prior to flooding (Morrison and Thérien 1991). Complete stripping may also reduce methyl mercury transport into the water column. For both burning and complete stripping, it is important that all vegetation, including mosses, lichens, shrubs, leaf litter, and deadfall be burned/stripped, because all of these materials are capable of enhancing mercury methylation (Morrison and Thérien 1991). If partial stripping is used as a mitigation strategy, areas with high organic matter content (e.g., peat) should be targeted, because these materials have a higher potential for methyl mercury production.

A recent investigation of burning before flooding found that burning vegetation and soils (high-temperature burn) reduced post-flood mercury concentrations in water, but not in zooplankton and benthic invertebrates (Mailman and Bodaly 2004). It appeared that zooplankton and benthic invertebrate mercury concentrations were lower in the control treatment than the burned treatment, because high dissolved organic carbon concentrations inhibited mercury bioaccumulation in the control. The effects of pre-flood burning on mercury concentrations in fish tissues are not yet known.

High temperature burning would likely only be effective in areas having leaf litter overlying mineral soils. If burning is employed as a mitigation strategy, high-intensity burning (leaf litter and vegetation) would be more effective at reducing mercury concentrations in water than low-intensity burning (vegetation only) (Mailman and Bodaly 2004).

Capping

Capping of sediment is usually restricted to small areas that have received extensive anthropogenic inputs of heavy metals or organic pollutants (e.g., Zeman 1994; Wiener and Shields 2000). Capping of soils before flooding would isolate organic material and inorganic mercury, and it would relocate the most biologically active part of the sediment to the clean cap materials (Zeman 1994). This should result in reduced mercury methylation, and, if it is a complete cap, reduced methyl mercury transport into the water column.

Both sandy and fine-grained materials have been used for capping contaminated sediment; sandy caps are more resistant to erosion, while fine-grained caps are better at isolating underlying contaminants (Zeman 1994). Problems with capping include erosion, transfer of contaminants through the cap during consolidation, bioturbation[10], diffusion and the impacts on benthic invertebrate colonization (Zeman 1994). These factors are often investigated under laboratory conditions before and during the capping operation, and field monitoring is part of a comprehensive capping program (e.g., Zeman 1994; Wiener and Shields 2000). Similar to partial stripping, partial capping should target areas with high organic matter.

Liming

Mercury concentrations in fish tend to increase with decreasing pH (McMurtry et al. 1989; Grieb et al. 1990; Greenfield et al. 2001). In other words, the more acidic the lake water, the higher the mercury concentrations tend to be in the fish. Flooding of peatlands and soils rich in organic acids may promote more acidic conditions in a given lake or reservoir. Liming involves the addition of high-pH limestone mixtures to the lake and/or surrounding catchment. This mitigation strategy has been successful used to reduce fish mercury concentrations in acidic waters in Sweden (Hakanson et al. 1988; Lindqvist et al. 1991; Andersson

[10] Bioturbation is the process by which aquatic organisms modify the physical and chemical properties of the substrate in which they live. Bioturbation includes mixing of sediment, and solute flux and suspension of sediment into the water column.

et al. 1995). Post-liming pH increases should reduce uptake of mercury by methylating bacteria, reduce direct uptake of mercury across fish gills, increase mercury volatilization, and increase demethylation rates (Ponce and Bloom 1991; Ullrich et al. 2001; Kelly et al. 2003). All of these mechanisms should work to decrease mercury concentrations in fish.

As a mitigation strategy, liming should only be considered if fish mercury problems are being exacerbated by low pH, because not all lakes with fish mercury problems are acidic. Liming requires repeated treatments.

Selenium Additions

Selenium additions can mitigate elevated levels of mercury in fish by disrupting mercury bioaccumulation and methylation. Selenium occurs in both natural and industrial settings, and, at low concentrations, it is an essential nutrient for many organisms. Research has shown that there is a negative relationship between mercury and selenium concentrations in fish tissue and that high selenium concentrations in lakes (either intentional or accidental) can result in low fish mercury concentrations (Turner and Swick 1983; Paulsson and Lundberg 1991; Chen and Belzile 2001). The mechanism through which selenium interferes with mercury bioaccumulation is not fully understood. Selenium may affect mercury biomagnification from food sources (Turner and Swick 1983), the availability of inorganic mercury for methylation (Bjornberg et al. 1988), or the activity of methylating bacteria (Oremland and Capone 1988).

Selenium has been successfully added to lakes in Sweden to reduce fish mercury concentrations (Paulsson and Lundberg 1991). Lakes in the Sudbury area with high selenium levels contain fish with low levels of mercury (Chen and Belzile 2001). However, selenium additions are not often the best mitigation strategy, because high selenium concentrations can be toxic to fish and cause a variety of diseases and deformities (Lemly 1993; Chen and Belzile 2001). Most researchers agree that further studies are required before selenium additions are considered a widely applicable mitigation strategy.

Intensive Fishing

Intensive fishing targets mercury bioaccumulation processes by removing fish with potentially high mercury burdens from the system and reducing mercury bioaccumulation in remaining fish. The removal of the mercury-laden fish should decrease the risk to human health, because sportfish catch-per-unit-effort and mercury concentrations will decrease. Wildlife and raptor mercury concentrations may also decrease, but there is also potential for these organisms to be negatively affected by a reduced food supply. Intensive fishing has proven effective at reducing mercury concentrations in predator fish in Scandinavian and Canadian lakes, and it has been evaluated as a mitigation tool by the

Collaborative Mercury Research Network (COMERN) in partnership with Hydro Québec (Gothberg 1983; Verta 1990; Surette et al. 2003; Tremblay et al. 2004).

There are three possible mechanisms through which intensive fishing reduces predator fish mercury concentrations. They consist of the following:

- increased growth rates of fish due to decreased competition (fish that grow faster have lower mercury);
- changes in feeding to lower-mercury prey; and
- a reduction in the total amount of mercury cycling in the ecosystem (Verta 1990; Surette et al. 2003; Tremblay et al. 2004).

Results indicate that increased growth rates and changes in diet account for most fishing-induced mercury decreases (Verta 1990; Surette et al. 2003). To be effective, a large proportion of the predator fish biomass (about 30 to 50%) must be removed from the lake (Verta 1990; Lindqvist et al. 1991). Also, more than one intensive fishing event may be required. Verta (1990) reported that fish growth rates had declined to pre-fishing levels within five years, and Lindqvist et al. (1991) predicted that fishing-induced decreases in fish mercury levels would last for six to eight years.

Fish Screens, Restricted Human Access, and Fish Consumption Advisories

Increased concentrations of mercury in fish can be avoided by excluding fish from the lake system with fish screens. Fish screens would effectively reduce the risk of both human and wildlife mercury consumption, but they would negate the purpose of creating fish habitat and reduce wildlife and waterfowl presence. To achieve an appropriate balance, fish screens can be used on a short-term basis or as a back-up option, if monitoring results indicate that another mitigation option has not been fully successful.

Fish screens could be employed until mercury concentrations in water and invertebrates decreased to baseline concentrations (about three to five years after impoundment), after which fish could be re-introduced into the system. If installed in response to post-flooding monitoring results, fish screens may be especially useful in decreasing mercury concentrations in fish if combined with an intensive fishing program.

Restricted human access and fish consumption advisories are intended to reduce human consumption of mercury-contaminated fish. Fish consumption advisories would address only human health risks. They would be developed by determining sportfish mercury concentrations after impoundment and relating them to the Canadian human consumption guideline. The efficacy of consumption advisories, however, is not always high. A study in Maine showed that only 25% of anglers who were aware of fish consumption advisories changed their fishing behaviour (MacDonald and Boyle 1997). Also, it has been shown that knowledge and understanding of fish consumption advisories can vary greatly with ethnicity, age, income, education, and whether the person is a resident of the area (Burger 1998; MacDonald and Boyle 1997).

A fish advisory approach could be effective for addressing human health risks if access to the lake can be effectively controlled. Restricted access does not mitigate the risk to wildlife health or the time required for mercury concentrations in fish to return to background concentrations.

Bacteria and Phytoplankton

Nutrient dynamics in a refilled reservoir or flooded lake are driven primarily by the flooding of terrestrial vegetation and, to a more limited extent, soil. Although nitrogen, phosphorus, and carbon are released, not all forms may be equally bioavailable. In particular, phosphorus may be released in a non-bioavailable form, which can lead to the preferential growth of bacteria over that of phytoplankton (i.e., algae). However, a predominance of bacteria does not always occur, since sufficient bioavailable phosphorus may be released to support active phytoplankton growth. The type and quantity of terrestrial vegetation that is flooded can affect the magnitude and duration of the initial nutrient pulse; it can also affect the potential for bacteria to initially dominate the lowest trophic level.

As the source of organic matter switches from allochthonous to autochthonous, a shift in dominance typically occurs, with phytoplankton replacing bacteria as the dominant planktonic organism. In other words, when an area is first flooded, the organic matter in the system or entering the system tends to originate from primarily external sources, such as flooded terrestrial vegetation or other materials entering the system through runoff or tributary inflow. The characteristics of these materials tend to favour bacterial growth over phytoplankton. However, over time, the external material decays and is replaced with organic matter that originates primarily from within the reservoir, be it in the form of dead and decaying phytoplankton, zooplankton, fish, or other internal material (e.g., fish feces). The characteristics of the internal materials tend to favour phytoplankton growth over that of bacteria, which leads to a shift in dominance between these two groups. The period over which the shift from bacterial to phytoplankton dominance occurs is dependent on site-specific conditions. However, in some studies, plankton community structure returned to that of oligotrophic environments within three years of flooding. Key findings from studies that document the factors affecting the dominance of bacteria and phytoplankton are discussed in more detail below.

Paterson et al. (1997) observed a brief increase in phytoplankton photosynthesis after the flooding of an experimental lake. Phytoplankton biomass and total phosphorus concentrations were highest nearest the shore over the flooded peat, suggesting that the higher nutrient concentrations in this area of the lake contributed to the increase in phytoplankton biomass. However, the increased rate of phytoplankton growth was short-lived.

In the same system, Paterson et al. (1997) also observed a large sustained increase in bacterial biomass. Bacterial biomass was higher over the flooded peat areas than the open waters, consistent with the patterns observed with phytoplankton. Bacterial size structure and morphology were also affected in that mean individual biovolume increased from 0.1 to 0.3 cubic micrometres (μm^3). Large increases in methane and CO_2 production that occurred after flooding also indicated increased bacterial production (Kelly et al. 1997). The dominance of bacteria in the plankton community for the first year after flooding was also observed in a newly-created, oligo-mesotrophic reservoir in France (Thouvenot et al. 2000).

Both studies (i.e., Paterson et al. 1997 and Thouvenot et al. 2000) found that high bacterial growth coincided with low phytoplankton growth. Paterson et al. (1997) noted that the proportion of bacteria to phytoplankton changed from pre-flood conditions. Before flooding, average bacterial biomass was 27% of average phytoplankton biomass; after flooding, bacterial biomass exceeded that of phytoplankton by nine times. The proportional change resulted both from increasing bacterial biomass and changes in phytoplankton abundance. For example, phytoplankton biomass declined by 70% from the pre-flooding average of 0.45 milligrams per litre (mg/L) to a post-flood average of 0.13 mg/L. The same parameter was 0.40 mg/L in the upstream lake at the same time (Paterson et al. 1997). The observed decline in phytoplankton biomass was not due to dilution by deepening of the water column, because the low levels of algal biomass persisted throughout the first summer of impoundment until drawdown in the fall.

The high phosphorus concentrations, low phytoplankton concentrations, and high bacterial biomass observed by Paterson et al. (1997) suggest that the majority of the phosphorus released after impoundment was not in a bioavailable form that could be easily used by phytoplankton. The authors suggested that the majority of the phosphorus present immediately after impoundment may have been bound to organic complexes that were unavailable to phytoplankton but usable by bacteria. Phytoplankton growth rates following impoundment may also have been affected by limiting amounts of other essential elements. For example, high levels of dissolved organic carbon (DOC) could have resulted in essential metals being bound within organic complexes that rendered them inaccessible to phytoplankton (Guildford et al. 1987). Finally, bacteria may have out-competed phytoplankton for phosphorus. Bacteria predators, such as ciliates and nanoflagellates, were grazed down by *Daphnia rosea*, and the DOC released after flooding was likely highly labile and readily available to the bacteria. These mechanisms may have removed any competitive advantage previously experienced by the phytoplankton (Paterson et al. 1997).

Throughout the four-year study by Paterson et al*.* (1997), the algal community consisted of small (less than 30 micrometres [µm]) cryptophytes, chrysophytes, and chlorophytes that could be consumed by zooplankton. Whereas species composition changed after flooding, proportions of edible algae did not.

Similar to Paterson et al*.* (1997), Thouvenot et al*.* (2000) suggested that the low abundance of autotrophic algae and cyanobacteria observed in the newly created Sep Reservoir in France was the result of restrictions in phosphorus bioavailability, which favoured bacteria growth over that of phytoplankton. No relationship was observed between the concentrations of dissolved organic matter in the water column, which were elevated one year after flooding, and phytoplankton biomass, as estimated from chlorophyll *a* concentrations (Jugnia et al. 2007). The lack of a notable relationship suggests that the dissolved organic matter did not come from autochthonous photosynthetic sources (Jugnia et al. 2007).

In the same system, higher bacterial biomass production after the first year of flooding was correlated to higher concentrations of dissolved free carbohydrate. Bacterial biomass decreased in the second year after flooding, coincidental with an observed decrease in the concentrations of allochthonous dissolved organic matter (Jugnia et al. 2007). Jugnia et al. (2007) also determined that bacterial production was controlled by the type of substrate available, in that it depended on sources of substrate other than phytoplankton exudates and most likely on allochthonous dissolved organic matter. The ratio of bacterial production to primary production (as measured by photosynthesis activity) was also higher than expected, suggesting that bacteria were out-producing phytoplankton (Jugnia et al. 2007).

The shift between allochthonous to autochthonous sources of organic matter and its effect on bacterial versus phytoplankton dominance was also observed in the Sep Reservoir (Thouvenot et al*.* 2000). In the first year after flooding, the reservoir's plankton community was dominated by bacteria, gradually shifting to mixotrophic flagellates (algae with whip-like appendages), heterotrophic flagellates, and finally autotrophic phytoplankton, which are species similar to that found in humic lakes where allochthonous organic matter dominates (Jansson et al. 1996). The high initial abundance of bacteria suggested that high allochthonous organic matter stimulated bacterial production (Thouvenot et al. 2000). As the allochthonous organic matter decreased, bacteria became dependent on autochthonous carbon (e.g., carbon produced by phytoplanktonic excretion, cell lysis, and sloppy feeding). As such, they were no longer in direct competition for phosphorus with other planktonic organisms, such as autotrophic algae and cyanobacteria, which accounted for 67% of the total unicellular plankton biomass by the end of the study. While the structure of the plankton communities immediately after flooding resembled that of environments rich in allochthonous matter, the community structure returned to that of oligotrophic environments within three years (Thouvenot et al. 2000).

Thouvenot et al. (2000) determined that the low abundance of autotrophic algae and cyanobacteria observed immediately after the creation of a new reservoir in France was not caused by heavy predation by large zooplankton, because zooplankton biomass was low. The authors also suggest that the high proportion of mixotrophic organisms present after flooding may have been indirectly due to the high dissolved organic matter content of the water, which was exploited either directly by adsorption of dissolved organic matter or indirectly through the consumption of bacteria. Pigmented flagellates, which feed on bacteria, were also commonly observed after flooding. The dominant species of pigmented flagellates (Chrysophyceae and Cryptophyceae) were similar to those occurring in humic lakes, further suggesting that the high dissolved organic matter contributed to the observed species composition immediately after flooding. Pigmented flagellates, such as *Dinobryon* sp., and *Cryptomonas ovata,* could have been affected directly by competition for phosphorus and obtained phosphorus by ingestion of bacterial prey (Thouvenot et al. 2000).

Zooplankton

Information obtained from the reviewed studies suggests that an increase in zooplankton abundance is likely to occur after flooding. Bacterial growth, fuelled by decomposition of terrestrial vegetation and the release of nutrients from flooded soil, will likely stimulate production of rotifers and cladocerans that graze on bacteria. Rotifers typically dominate the zooplankton community initially, because they can colonize new environments faster than cladocerans and copepods. Lower fish predation, due to lower fish densities and more hiding places in the flooded vegetation, will also encourage this production. As the allochthonous organic matter dissipates, there will be a shift to larger-sized cladocerans and copepods. If persistent turbidity depresses bacterial and phytoplankton growth, then zooplankton biomass likely will decline and changes in species composition will be more strongly influenced by fish predation, as outlined in the following section. Key findings from studies that document these changes in the zooplankton community are discussed in more detail below.

According to Northcote and Atagi (1997), zooplankton biomass generally increases in newly flooded reservoirs, with flooded herbaceous vegetation or grasses supporting large populations of cladocerans and rotifers. The large observed increase in zooplankton biomass and productivity was one of the most dramatic responses noted by Paterson et al. (1997) following the impoundment of an experimental lake in northern Ontario. High food availability and low mortality rates contributed to the high zooplankton abundance post-impoundment. Thouvenot et al. (2000) similarly noted an increase in zooplankton biomass in a newly-created reservoir in France.

In the study completed by Paterson et al. (1997), bacteria were likely the primary food source for the zooplankton, because the production of zooplankton was frequently equal to or exceeded that of phytoplankton. Based on the available zooplankton, phytoplankton, and bacteria data, Paterson et al. (1997) mapped the dominant pathway of carbon flow in their system. Prior to impoundment, they postulated that the zooplankton fed primarily on phytoplankton and not bacteria. In the year after impoundment, zooplankton switched to feeding on bacteria, because the high biomass and cell size of bacteria increased their availability. In the second year after impoundment, bacterial biomass declined, although larger cell size was maintained. At the same time, phytoplankton production increased, leading to uncertainty as to the relative importance of bacteria and phytoplankton to zooplankton.

Low mortality rates of zooplankton post-impoundment were either due to lower fish densities or to the increased occurrence of refugia (hiding places) where zooplankton could escape predation. The refugia included the flooded peat sections of the expanded lake where dissolved oxygen concentrations were low (Paterson et al. 1997). The authors noted a shift in dominance from small species (e.g., *Bosmina longirostris*) to larger species (e.g., *Daphnia rosea*). This pattern is consistent with decreased predation by fish, which preferentially select larger prey species, after impoundment.

In general, rotifers initially dominate the zooplankton community in the first year after impoundment (Pinel-Alloul et al. 1989; Thouvenot et al. 2000). Rotifers have a short generation time, but high fecundity. They can, as a result, colonize new environments faster than cladocerans and copepods, which have lower fecundity but longer generation times (Thouvenot et al. 2000). Rotifers also benefit from the increased level of bacterial production commonly observed following impoundment of new reservoirs (Knauer and Buikema 1984, as cited in Pinel-Alloul et al. 1989).

Polyarthra sp. was the most abundant rotifer observed by Thouvenot et al. (2000). It accounted for 24 to 50% of the zooplankton biomass measured immediately after the flooding of a reservoir in France. *Hexarthra mira* was the next most abundant, accounting for 18 to 20% of the total zooplankton biomass.

In contrast, *Conochilus* sp. and *Kellicottia* sp. were the co-dominant species of rotifers observed in a newly created subarctic reservoir in northern Quebec in the first year after impoundment (Pinel-Alloul et al. 1989). *Conochilus* are detritus-bacteria feeders, while *Kellicottia* sp., are microfilter-feeders that consume nanoplankton and, to some extent, bacteria and detritus. Therefore, the relative abundance of these two rotifers immediately after flooding is reflective of the high availability of detritus and bacteria in the newly created system. Species that feed more on nanoplankton and microflagellates, such as *Polyarthra vulgaris*, became more abundant after several years once phytoplankton production increased (Pinel-Alloul et al. 1989).

Cladocerans typically become the dominant species of zooplankton after rotifers (Paterson et al. 1997; Thouvenot et al. 2000; Pinel-Alloul et al. 1989). Thouvenot et al. (2000) observed a switch from rotifers to cladocerans two years after the initial flooding of a reservoir, with larger-sized species, such as *Daphnia longispina* and *Eudiaptomus gracilis*, being evident.

In a subarctic reservoir, Pinel-Alloul et al. (1989) noted that the “inefficient” microfilter-feeder, *Bosmina longirostris*, dominated the cladoceran community in the first two years after impoundment; “inefficient” referred to the optimum food particle size of this species as being below 2 to 5 µm, which is why bacteria and detritus dominate its diet. After the initial two year period, more efficient microfilter feeders, such as *Daphnia longiremis*, *Skistodiaptomus oregonensis*, and *Leptodiaptomus minutes*, became more prominent. The shift in the composition of the cladoceran community coincided with a shift in the dominance of phytoplankton over bacteria.

The performance of the zooplankton community in Southern Indian Lake was notably different from those outlined above. In this lake, zooplankton biomass decreased by 30 to 40% after flooding, with cladocerans and small cyclopoid copepod species being most heavily affected (Patalas and Salki 1984). Calanoid copepods were less affected, with larger species actually being more abundant and widespread after impoundment. *Mysis relicta* went from rare to common (Hecky et al. 1984), a change attributed to this species’ preferences for lower water temperatures and to reduced whitefish predation due to poorer transparency (Patalas and Salki 1984). As previously noted, Southern Indian Lake experienced high rates of shoreline erosion following impoundment, which resulted in high levels of turbidity and reduced water temperatures. These changes to turbidity levels and water temperature were most likely the agents responsible for the observed performance of the zooplankton community.

Benthic Invertebrates

Similar to zooplankton, benthic invertebrates tend to be abundant in new impoundments, because the flooded terrestrial vegetation provides structural habitat and a food source. Generally, midges (Chironomidae) colonize new impoundments first, and are usually more abundant than other benthic organisms. However, other groups of benthic invertebrates can initially dominate, depending on how the new lake or reservoir is formed. For example, early colonizers in a reservoir created by damming a river are riverine species, which are gradually replaced with species that prefer standing water. The succession of benthic invertebrate species varies among case studies, due to differences in the quality and quantity of terrestrial vegetation contained within the newly flooded systems and the dispersal abilities of the local benthic species, as discussed in greater detail below.

Increased benthic invertebrate abundance in newly created lakes and reservoirs was reported in virtually all of the reviewed studies that included a benthos component (Nursall 1952; Danell and Sjoberg 1982; Voshell and Simmons 1984; Hecky et al. 1984; Northcote and Atagi 1997). Hecky et al. (1984) attributed the increased post-impoundment densities in Southern Indian Lake primarily to the input of nutrients and organic material via the flooded shorelines, although reduced predation by adult whitefish also may have been a contributing factor. The coincidental shoreline erosion that occurred in Southern Indian Lake resulted in increased suspended sediment concentrations, which negated the benefits of the nutrient and organic inputs in some areas of the lake. As a result, benthic invertebrate densities were not consistent across the lake, and it was not until the third year following impoundment that benthic invertebrate densities returned to pre-impoundment levels in some regions of the lake (Wiens and Rosenberg 1984).

In most other studies, including Northcote and Atagi (1997), the presence of flooded terrestrial vegetation was identified as the key driver that led to the increased abundance of benthic invertebrates. The flooded vegetation provided habitat and increased food availability.

Midges were commonly reported as one of the earliest and most abundant colonizers of new impoundments, due in large part to the availability of decomposing terrestrial vegetation (e.g., Nursall 1952; Danell and Sjoberg 1982; Hecky et al. 1984; Voshell and Simmons 1984; Northcote and Atagi 1997). Midges and the amphipod *Hyalella azteca* were the most abundant benthic invertebrates detected in Lake Anna a year after it was created (Voshell and Simmons 1984). Abundant genera of midges in Lake Anna included *Glyptotendipes*, *Dicrotendipes,* and *Chironomus*. High midge populations were similarly observed in Southern Indian Lake in areas containing flooded terrestrial vegetation (Hecky et al. 1984). Black spruce (*Picea mariana*) needles were shown to be readily used as a major source of organic substrate by midges (Crawford and Rosenberg 1984).

In a flooded sedge meadow in Sweden, midges were the early invertebrate colonizers, likely because many species of this group could tolerate the rather extreme habitat conditions present in the newly created lake (Danell and Sjoberg 1982). For example, the new lake would experience regular bottom-freezing during the winter, drastic variations in water temperature and low oxygen levels. Danell and Sjoberg (1982) note that species possessing haemoglobin and having large-size larvae that are able to survive on a wide range of food items tend to be more successful that other species of benthic invertebrates in newly created lakes and reservoirs.

Cantrell and McLachlan (1977) studied midge competition and distribution in a newly flooded lake in Northumberland, England. The lake basin lacked any terrestrial vegetation prior to filling, with the bottom substrate consisting primarily of boulder clay. It only received water from rainfall, effectively isolating the basin from invertebrate drift. The study focused on two species of midges: *Chironomus plumosus* and *Tanytarsus gregarious*.

C. plumosus is often the first species to colonize temperate impoundments, because of its extended period of emergence during the summer months and the presence of haemoglobin in its body fluids; the haemoglobin allows this organism to withstand low concentrations of dissolved oxygen for extended periods of time (Cantrell and McLachlan 1977). In contrast, another early colonizer midge species, *T. gregarious*, is unable to withstand low dissolved oxygen levels and is phototaxic (i.e., attracted to light) (Cantrell and McLachlan 1977).

Cantrell and McLachlan (1977) found that *T. gregarious* was more abundant toward the edges of the lake, because the larger size of *C. plumosus* effectively excluded it from the sediment in offshore areas. *T. gregarious* reacted positively to the light and moved into the shallower water present along the edge of the lake. *T. gregarious* was able to effectively colonize these shallower areas, because of a lower amount of sediment compared to the lake centre and a preference of deeper sediment by the competitively superior *C. plumosus*.

In Barrier Reservoir, which was created by damming the Kananaskis River in the Rocky Mountains of Alberta, *Pentapedilum* sp. was the first among the midges to become established, mainly because it was among the first benthic invertebrates to arrive in the newly created reservoir (Nursall 1952). The dominance of *Pentapedilum* sp. and other lotic species in the reservoir, however, was short lived. The inability of these organisms to survive in the standing waters of the reservoir resulted in a notable decline in their abundance by the end of the first summer.

The following spring, the leaf litter present along the bottom of Barrier Reservoir was completely buried with riverine sediment that was washed in during a heavy spring runoff event. As a result, the eutrophic conditions that were previously present in the reservoir disappeared, and a shift in the benthic invertebrate community occurred. *Tanytarsus* sp., a midge commonly found in oligotrophic systems, became dominant by the following year (Nursall 1952).

A similar pattern was observed by Voshell and Simmons (1984) following the creation of Lake Anna in the south-eastern United States. Initially, the benthic invertebrate community was dominated by facultative species originating from the upstream river. By the second year of impoundment, most of the terrestrial vegetation that had been flooded was gone, and the bottom substrate of the lake had changed. The fertile topsoil that was originally flooded was being replaced or covered with finer silty sediments that washed in from upstream sources. Plankton debris and feces was also accumulating on the lake bottom. The change in bottom substrate and the shift from allochthonous to autochthonous organic matter facilitated the replacement of the first colonizers with species that prefer standing water, such as aquatic worms (Oligochaeta).

Midges and *H. azteca* were the most abundant benthic invertebrates detected in Lake Anna a year after it was created (Voshell and Simmons 1984). Snails (Gastropoda) were the third most abundant organisms in the first year after impoundment, with the genera *Physa*, *Ferrissia* and *Helisoma* being abundant. Other abundant organisms included the mayfly (Ephemeroptera) *Caenis amica*, and caddisflies (Trichoptera) of the genus *Oecetis*.

Benthic invertebrate density and composition were similar in the second and third years after impoundment, likely because of the uniformity of the pre-impoundment basin and the use of artificial substrates for sampling (Voshell and Simmons 1984). However, for the reasons outlined above, the fauna in these years was considerably different compared to that present in the first year following impoundment. Midges overtook *H. azteca* as the most common benthic invertebrate, with *Glyptotendipes* sp., *Procladius* sp., the tribe Tanytarsini, *Ablabesmyia* sp., *Chironomus* sp., and *Cryptochironomus* sp. making up most of this group. *Dicrotendipes* sp. and *Endochironomus* sp. became less common. Aquatic worms appeared in the second year, as well as flatworms (Turbellaria) and the phantom midge *Chaoborus* sp. Different species of caddisflies and dragonflies/damselflies (Odonata) became established in the second year. In contrast, abundances of *H. azteca*, *C. amica*, and snails declined substantially.

In the third year, caddisflies became notably more abundant, particularly *Cernotina spicata* and *Cyrnellus fraternus*, along with a burrowing mayfly, *Hexagenia munda*. *Hexagenia* species are considered to be a major benthic macroinvertebrate in lentic habitats in temperate areas (Edmunds et al. 1976, as cited in Voshell and Simmons 1984).

Danell and Sjoberg (1982) studied benthic invertebrate succession in a lake created by flooding meadowland that had been dry and dominated by sedges for approximately 20 years. They reported the dates of occurrence and relative biomass of different benthic groups starting from the third year after flooding to the eighth year. As observed in other studies, midges were dominant in the flooded lake and occurred in every sample, although they declined in abundance during the study period. Other early colonizers included some species of aquatic beetles (Coleoptera), aquatic sow bugs (Isopoda), and water bugs (Heteroptera), whereas caddisflies, mayflies, and dragonflies/damselflies became more prevalent six to seven years after flooding. Other invertebrates, such as molluscs (Mollusca; mainly the snail *Gyraulus* sp.), did not appear until the sixth year after flooding, likely due to their lower capacity for dispersal. Danell and Sjoberg (1982) noted that the shift from allochthonous to autochthonous production of organic matter occurred five to six years after flooding, which is longer than that noted in other studies. The prolonged period over which the flooded terrestrial vegetation exerted an influence on the lake system resulted in a longer than expected succession of benthic species, compared to that reported by others (e.g., Voshell and Simmons 1984).

The effects of draining a shallow prairie lake over the winter months were studied by McGowan et al. (2005). The study was completed on Wascana Lake, which is located in southern Saskatchewan. It was expected that the complete exposure and desiccation of bottom sediments would reduce the diversity and abundance of benthic invertebrates. However, no substantial effects were observed during the next summer after spring melt refilled the lake. The results of this study suggest that benthic invertebrate populations living in northern climates may be resilient to variation in water level and subsequent exposure to harsh winter conditions.

Fish

Summary articles highlight the positive and negative effects of new reservoir development on fish (i.e., outline general effects to fish). However, few articles obtained in the literature review specifically discussed effects to fish (i.e., fish were not typically included as one of the test organisms under detailed study). Fish were either removed prior to reservoir development or were not part of the study design. When studied, the abundance and diversity of the resident populations are dependent on the fish species and the extent to which the species can take advantage of the new environment. Upstream and downstream fish populations helped re-establish populations in newly-created or enlarged lake systems. Juvenile fish populations recovered quickly, because of the availability of new habitat and food sources. In contrast, older and larger adult age classes generally were reduced. Fish abundance tended to be higher in lakes containing flooded vegetation compared to those with little or no vegetation. Fish abundance in new impoundments with increased concentrations of suspended sediments tended to be lower than those in systems without high turbidity, because high turbidity levels prevented effective feeding and resulted in reduced growth and egg survival rates. Methyl mercury accumulation in fish tissues tend to be higher in these highly turbid systems, as discussed in more detail below.

According to O'Brien (1990), the creation and operation of reservoirs can affect fish through several mechanisms. Fluctuations in water level and changes in substrate composition can affect spawning success. Spawning success can also be negatively affected by the presence of unstructured shoreline and a scarcity of littoral zone vegetation, particularly in steep-sided reservoirs. Development of littoral zone vegetation may be hindered by wave action, turbidity, or large fluctuations in water level. Increased turbidity levels that may result from shoreline erosion can limit feeding success. They can also directly affect growth and survival rates if turbidity levels are sufficiently high to result in gill abrasions and loss of spawning habitat through sedimentation.

Conversely, the increases in zooplankton productivity that typically occur after impoundment can provide a larger food source to resident fish. Flooded terrestrial vegetation can also provide spawning and rearing habitat to certain fish species. The net effect of reservoir creation on the abundance and diversity of the resident fish community, therefore, is dependent on the make-up of the fish community and to what extent it can adapt to, or take advantage of, the new environment created within the reservoir.

For example, Lindström (1973) observed that when the littoral zone in a reservoir is lost, the fish community shifts from one dominated by littoral fish to one dominated by largely pelagic fish (i.e., fish that prefer to reside in deeper water). From the fisherman's point of view (at least as defined by Lindström [1973]), there may be a general decline in the numbers and size of "good fishing" species and an increase in undesirable fish. However, it should be noted that Lindström (1973) focused on systems that experience severe fluctuations in water levels, which tend to destroy littoral habitat.

In north-eastern Belgium, fish densities were drastically reduced after draining and refilling a lake, as detailed by Van de Meutter et al. (2006). However, the studied lake was connected to a number of neighbouring lakes through a series of streams and channels. The connections among the lakes provided a migratory conduit, so that fish could rapidly re-colonize the lake. Within two years of refilling, the number of juvenile fish had recovered to pre-disturbance levels due to a combination of dispersal and increased survival of young-of-the-year fish. Overall fish density, however, had not fully recovered within two years of refilling, with older fish being under-represented in the lake.

Paller (1997) observed a similar trend in a South Carolina reservoir. Within nine months of refilling, the fish community had re-established itself. The number of species present, their relative abundance, and overall fish biomass was similar to pre-disturbance conditions. However, the age-class structure was skewed. The lake contained more juvenile and fewer older fish compared to the age-class structure present prior to disturbance.

The faster recovery observed by Paller (1997), relative to that observed by Van de Meutter et al. (2006), may have been due to the presence of seed organisms in the refilled reservoir Paller (1997) studied. In addition, the reservoir Paller (1997) studied was not completely drained prior to refilling, unlike the Belgian lake that Van de Meutter et al. (2006) examined.

Some studies have found fish populations to be numerous in the first years of the existence of a reservoir, potentially from increased reproduction rate brought about by secure spawning grounds, production of fry afforded by flooded vegetation, or increased food availability (Legault et al. 2004). At the time the La Grande complex reservoirs were impounded in Quebec, overall abundance for all species dropped substantially but then rose over the next three years before decreasing slightly up to the tenth year (DesLandes et al. 1995).

Northcote and Atagi (1997) reviewed the importance of submerged vegetation to fish in reservoirs. In terms of providing spawning habitat, the reproductive success of species, such as lake whitefish, lake trout, northern pike, and walleye, is generally unaffected by the flooding of terrestrial vegetation. However, inundated terrestrial vegetation is often associated with higher abundance of young-of-the-year fishes, because it directly provides rearing habitat and indirectly provides increased food supply through coincidental increases in zooplankton abundance. If the flooded vegetation is structurally complex (i.e., contains lots of branches, leaves and cross-connections), then it can provide valuable habitat for adult fish, it terms of providing rich feeding sites and providing shelter and protection from ambush predators, such as bass and northern pike. Overall fish abundance also tends to be higher in areas with flooded vegetation, compared to that generally observed in lakes or reservoirs that were cleared prior to flooding or that contain little to no vegetation.

In the case of Southern Indian Lake, the abundance of young-of-the-year northern pike (*Esox lucius*) was initially high in the first year following impoundment (Bodaly and Lesack 1984); however, this trend did not persist, and spawning success declined in subsequent years. The initial year-class was also slower growing and in poorer condition than other year-classes (Bodaly and Lesack 1984). Northern pike is also a species that generally does well in reservoirs (Legault et al. 2004). In the first few years of a reservoir's creation, the abundance and growth of northern pike usually increase (Machniak 1975 cited in Legault 2004).

As previously noted, Southern Indian Lake is located in northern Manitoba on the Precambrian Shield in a zone of discontinuous permafrost. It is surrounded by boreal forest and experiences high wave action (Newbury and McCullough 1983). A dam constructed at the natural outlet to the lake caused flooding beyond the thawed zone under the lake into the permafrost-affected upland, which was cleared of timber prior to flooding. Extensive shoreline erosion subsequently occurred, leading to elevated turbidity levels and increased rates of sedimentation within the lake (Hecky et al. 1984).

The increased turbidity levels present in the lake post-impoundment reduced light penetration and visibility. Observed declines in the catch-per-unit-effort of lake whitefish (*Coregonus clupeaformis*) on traditional fishing grounds was attributed to reduced visibility affecting feeding success, either by triggering a redistribution of the fish stocks within the lake or by affecting schooling behaviour. Lake whitefish continued to spawn on their old spawning grounds, but in situ experiments suggested that increased sedimentation of clay and silt negatively affected egg survival (Fudge and Bodaly 1984). Lake trout populations generally are low in Quebec's reservoirs despite the fact that reservoirs present abiotic and biotic factors considered suitable for the species; however, drawdown effects may be a factor (Legault et al. 2004).

The flooding of Southern Indian Lake and the subsequent introduction of large quantities of soil and sediment coincided with a notable increase in mercury concentrations in the muscle tissue of all commercial fish, including northern pike and walleye (*Sander vitreus*) (Bodaly et al. 1984). Similar increases in mercury tissue concentrations were not observed in surrounding, undisturbed lakes over the same period. The source of the mercury was determined to be bacterial methylation of naturally occurring mercury in the flooded soils and the suspension of sediments (Bodaly et al. 1984).

Once methylated in the bottom sediments of a reservoir or lake, methyl mercury may be transferred to biota in a number of ways. There may be passive diffusion of methyl mercury into the water column (Morrison and Thérien 1991) and subsequent uptake into phytoplankton (Plourde et al. 1997). More commonly, flooded soil particles are suspended into the water column by wind or ice-driven erosion. The soil particles are ingested by zooplankton and benthic invertebrates (Louchouarn et al. 1993; Grondin et al. 1995; Mucci et al. 1995). Once in zooplankton and benthic invertebrates, methyl mercury biomagnifies up the food chain to higher concentrations in fish.

Because suspension of sediment is a primary vector by which methyl mercury becomes available to biota, the amount of erosion in a reservoir can substantially impact methyl mercury concentrations in biota. St. Louis et al. (2004) suggested that, if there is little erosion, methyl mercury produced in peat will likely be demethylated. If there is erosion, however, methyl mercury will be rapidly transferred up the food chain. In Southern Indian Lake, mercury levels in fish increased quickly after impoundment, and continued to be high eight years after the lake was flooded (Bodaly et al. 1984).

Once mercury levels are elevated as a result of impoundment, the time required for fish mercury concentrations to return to the background level is dependent on species, fish size, and fish diet. Mercury levels in tissues of planktivorous and omnivorous species return to background concentrations sooner than in piscivorous species, and levels in smaller fish return to background concentrations sooner than in larger fish (Brouard et al. 1990; Verdon et al. 1991; Andersson et al. 1995). Most researchers have estimated that, for piscivorous species, the time to return to background mercury concentrations is 15 to 30 years (Verdon et al. 1991; Andersson et al. 1995; Porvari 1998), whereas those for non-piscivorous species range from 2 to 20 years (Verdon et al. 1991). The persistence of high mercury levels in fish tissues in Southern Indian Lake, as reported by Bodaly et al. (1984), is consistent with these projections.

Summary and Conclusions

Flooding terrestrial vegetation can result in a surge in nutrient concentrations, particularly of nitrogen, carbon, and phosphorus. However, the released phosphorus may be in a non-bioavailable form, which encourages the growth of bacteria over that of phytoplankton. Herbaceous vegetation generally decomposes faster than woody vegetation, and thus the type and amount of flooded vegetation affects the magnitude and duration of the nutrient surge.

Flooded soil can also be a source of nutrients to a newly created lake or reservoir. However, this input may not be as substantial as that originating from flooded vegetation. Removing terrestrial vegetation and soil prior to impoundment may limit the magnitude and duration of the nutrient surge, but the overall net benefits that result from this management option are dependent on site-specific conditions. Keeping the vegetation in place can enhance macrophyte growth, zooplankton abundance, and benthic invertebrate diversity. The removal of the terrestrial vegetation can also lead to increased shoreline erosion in the newly created lake or reservoir. Another management option available to limit or stabilize nutrient levels in a newly created system involves the repeated draining and refilling of the system.

Most of the reviewed studies did not discuss turbidity as a major driver for ecosystem recovery. Site-specific factors, however, can lead to erosion and increased levels of turbidity in newly created lakes and reservoirs. In a well-studied lake impoundment in northern Manitoba, extensive and ongoing erosion of fine-grained shorelines contributed to a sustained increase in turbidity levels, which has had a notable effect on the aquatic ecosystem.

With the exception of mercury, release of metals from sediment as a consequence of flooding was not observed or commented upon in the majority of the reviewed literature. Low oxygen conditions in flooded sediment, however, can result in the release of dissolved manganese and iron, as observed in a refilled reservoir in Germany (Nienhuser and Braches 1998).

In contrast to other substances, it is common for mercury concentrations in fish to increase following impoundment. This phenomenon is likely due to the inundation and subsequent decomposition of organic material that promotes the microbial methylation of inorganic mercury to organic methyl mercury. It has been well established that (1) mercury in pristine and flooded soils is predominately bound to organic matter, and (2) that mercury methylation is related to organic carbon content of the flooded soil/sediment. Methyl mercury is the most toxic form of mercury and readily accumulates in aquatic organisms.

To mitigate the effect of methyl mercury generation, bioaccumulation through the food chain and associated environmental and health risks, there are three processes that can be targeted: mercury methylation, mercury bioaccumulation, and fish consumption. Available mitigation options include partial or complete stripping or capping of organic materials and soils, high temperature burning of vegetation and leaf litter, liming, selenium additions to newly created reservoirs and lakes, intensive fishing, fish barriers (screens), restricted access, and/or fish consumption advisories. Of the options available, selenium additions and liming are not widely recommended, and consumption advisories serve only to protect human health without directly addressing mercury concentrations in fish.

The surge in nutrients that typically occurs following the creation of a new lake or reservoir generally leads to a brief increase in phytoplankton growth and photosynthesis, but bacterial growth quickly dominates. High bacterial growth coincides with low phytoplankton growth, suggesting that bacteria out-compete phytoplankton for nutrients.

As the source of organic matter switches from external to internal, a shift in dominance typically occurs, with phytoplankton replacing bacteria as the dominant planktonic organism. In other words, when an area is first flooded, the organic matter in the system or entering the system tends to originate primarily from external sources, such as flooded terrestrial vegetation or other materials entering the system through runoff or inflow. The characteristics of these materials tend to favour bacterial growth over phytoplankton; over time, the external material decays and is replaced with organic matter that originates primarily within the lake, from dead and decaying phytoplankton, zooplankton, fish, or other material (e.g., fish feces). The characteristics of the internal materials tend to favour growth of phytoplankton over that of bacteria, which leads to a shift in dominance between these groups of organisms. The period over which the shift from bacterial to phytoplankton dominance occurs is dependent on site-specific conditions. However, in some studies, plankton community structure returned to that characteristic of oligotrophic environments within three years of flooding.

Zooplankton biomass is generally high initially in new impoundments, with the possible exception of systems that experience notable shoreline erosion and turbidity. The high biomass is due to high food availability, in the form of abundant bacterial or phytoplankton growth, and low mortality rates, due to low fish densities and the availability of refugia in flooded vegetation. Initially, rotifers typically dominate the zooplankton community, because they are able to colonize new environments faster than cladocerans and copepods. Rotifers also benefit from the initial high level of bacterial production commonly observed following impoundment of new reservoirs.

Cladocerans typically become the dominant species of zooplankton after rotifers, possibly within two to three years of impoundment. Changes in the zooplankton community generally coincide with the shift from bacteria to phytoplankton dominance in the lowest trophic level. If persistent turbidity occurs following impoundment, then zooplankton biomass will likely decline and changes in species composition will be more strongly influenced by fish predation.

Similar to zooplankton, benthic invertebrates tend to be abundant in new impoundments, because the flooded terrestrial vegetation provides structural habitat and a food source. Generally, midges colonize new impoundments first, and they are usually more abundant than other benthic organisms. However, other groups of benthic invertebrates can initially dominate, depending on how the new lake or reservoir is formed. For example, early colonizers in a reservoir created by damming a river tend to originate from the river. They are then gradually replaced with species that prefer standing water. The rate at which succession within the benthic community occurs is dependent on the time required for flooded terrestrial vegetation to decay and dissipate, as well as the dispersal abilities of the local benthic populations. In general, succession will occur more quickly in systems where the flooded vegetation quickly dissipates and invertebrate drift from nearby standing waters occurs.

Key findings of the literature review for fish suggest that the net effect of reservoir/lake creation on the abundance and diversity of the resident fish population is dependent on the make-up of the fish community and the extent to which it can adapt to, or take advantage of, the new environment created within the lake. Flooded or refilled systems that are connected to surrounding waterbodies can experience rapid colonization and/or recovery, although the age-class structure post-impoundment tends to be biased towards a greater abundance of juvenile fish relative to older fish. Fish abundance also tends to be higher in lakes or reservoirs containing flooded vegetation, compared to that generally observed in lakes or reservoirs that were cleared prior to flooding or that contain little to no vegetation.

Fish abundance in new impoundments with increased concentrations of suspended sediments tend to be lower than those in systems without turbidity issues. High levels of turbidity can negatively affect fish through reduced feeding success. High levels of suspended sediment can also cause gill abrasions and the associated sedimentation can reduce egg survival rates. In addition, mercury levels in fish tissues tend to be higher in more turbid systems.

8.11.1.3.2 Applicability of Literature Review Findings to Kennady Lake

There are some important differences between Kennady Lake and the systems that have been reported in the available literature. Key areas of difference include the following:

- the potential influence of terrestrial vegetation on the refilled lake;
- the potential for erosion;
- the amount of organic matter present initially after refill that may influence methyl mercury production;
- increased nutrient concentrations in the refilled lake; and
- the rate at which recovery may occur.

These key areas of difference are discussed in more detail below.

Terrestrial Vegetation

The presence of terrestrial vegetation was identified in a number of studies as a key driver that influences initial nutrient dynamics, methyl mercury production, and primary productivity in flooded or refilled systems. Unlike many of these studies, Kennady Lake refilling does not involve flooding of surrounding terrestrial vegetation. During refilling, the water level of Kennady Lake will return to its baseline elevation and not higher. However, during the operations phase, terrestrial vegetation could colonize the dewatered lake bed. Given the physical characteristics of Kennady Lake and its geographical location, notable in-growth of terrestrial vegetation is unlikely. Kennady Lake is situated in the sub-arctic and is surrounded by tundra vegetation, which consists largely of dwarf, upland woody vegetation interspersed with grasses, sedges, moss, and lichen. The lake itself contains three categories of aquatic habitat, which include the following (as outlined in Section 8.3):

- shallow, nearshore habitat within the zone of freezing and ice scour (i.e., less than 2 metres [m] deep);
- nearshore habitat deeper than the zone of ice scour where wave action prevents excessive accumulation of sediment (i.e., greater than 2 m but less than 4 m); and
- deep, offshore habitat with substrate usually consisting of a uniform layer of loose, thick organic material and fine sediment (i.e., greater than 4 m).

The lack of fine sediment around the periphery of the lake, and the consistent presence of boulder and cobble through the shallow areas of the lake, will effectively limit colonization of the lakebed by terrestrial vegetation through vegetative propagation (i.e., root growth). Vegetation is more likely to be established through seed dispersal and subsequent germination, with the seeds being dispersed across the nearshore rocky habitat to colonize the fine sediments that are currently located in the deeper sections of the lake. Vegetation is expected to establish slowly and coverage would be patchy. Initial colonizers are thought to be graminoids (grasses and sedges).

The size of the boulder/cobble barrier that separates the tundra vegetation from the fine lake sediments is expected to increase as a result of dewatering. During the latter part of the dewatering process, re-suspension of the bed sediments is projected to occur. Re-suspension of the bottom sediments will occur, because, as water levels in Kennady Lake decline, the portion of the lake affected by wind-driven scouring will change. It will move from the current shallow nearshore, boulder/cobble habitat into what is now the deeper fine sediment areas. The fine sediment located in these areas will become entrained in the water column and discharged to the Water Management Pond (WMP) in Area 3, where it will either settle out of solution or be removed. The net result will be an extension of the boulder/cobble habitat that currently separates the surrounding tundra vegetation from the fine sediments in Kennady Lake, which will increase the difficulty for terrestrial vegetation that relies on vegetative propagation to become established in the dewatered portions of Kennady Lake.

Based on the above, the degree to which terrestrial vegetation becomes established within the dewatered sections of Kennady Lake is expected to be limited.

Erosion

In some refilled lakes or flooded areas, extensive erosion of the shoreline was noted. A similar trend is not expected to occur when Kennady Lake is refilled, because water levels are going to return to existing elevations. The surrounding tundra is not going to be inundated, and the existing shoreline consists almost entirely of rocky substrate, which is resistant to erosion. Consequently, effects associated with erosion are not expected to occur in Kennady Lake, such as prolonged periods of poor water clarity and the associated limitations on phytoplankton development.

Methyl Mercury Production

Results of the literature review indicate that the presence of organic matter is a key driver that controls methyl mercury production in a flooded or refilled area. The decomposition of the organic matter promotes the microbial methylation of inorganic mercury to organic methyl mercury, with the main pulse of methyl mercury production generally occurring in the first few years following flooding or refilling. Although all inundated soils and vegetation are sources of organic carbon and potential sites of methyl mercury production, inundated conifer trees, needles, and boughs appear to be especially important methylation sites, as noted in the literature review.

Conifer trees, needles, and boughs will not be present in Kennady Lake upon refilling. Terrestrial vegetation that may be present will likely consist of grasses and other weedy species, and the abundance of the terrestrial vegetation in Kennady Lake is expected to be limited. As noted above, the shallow zones of Kennady Lake consist almost exclusively of rocky substrate, which will prevent the vegetative propagation of the surrounding tundra vegetation. The size of the rocky zone is also expected to increase during the latter phases of drawn-down, further increasing the distance between the existing tundra vegetation and the fine lake bottom sediments.

Although flooded soils can provide the organic material necessary to support methyl mercury production, this mechanism is of little relevance to Kennady Lake. Refilling activities will be limited to the lake itself. The surrounding soils will not be inundated, and the bed sediments in the refilled lake will effectively be the same as those that currently exist, with one possible exception. Organic materials in the bed sediment exposed to the atmosphere during the operational life of the Project may undergo degradation. In other words, the organic content of the bed sediments may decline over the life of the Project, because of increased exposure to aerobic conditions.

The potential for methyl mercury production to occur in Kennady Lake after refilling, therefore, is expected to be limited, because a new source of organic matter is unlikely to be present. The in-growth of terrestrial vegetation will likely be limited by the rocky substrate that dominates the shallow zones of Kennady Lake, and the organic materials contained in the existing bed sediments may experience a greater level of aerobic decay than currently occurs while the lake is dewatered. Without a large organic carbon source to support the process, it is unlikely that methyl mercury production will be of concern in Kennady Lake once refilled.

Increased Nutrient Levels

Following the creation of a new lake or reservoir, there is typically a surge in nutrients, which leads to a brief increase in phytoplankton growth and photosynthesis. Water quality model results currently indicate that a longer-term increase in nutrient levels may occur in the refilled Kennady Lake, which could result in a more prolonged influence on phytoplankton growth and photosynthesis that has been observed in new lakes and reservoirs. However, De Beers is currently evaluating a variety of environmental design features and mitigation measures that will limit the amount of phosphorus that is released into the refilled Kennady Lake, so the temporal extent of any initial nutrient surge or increase in nutrient levels is uncertain.

Recovery Time

In several of the reviewed studies, recovery times for different components of the aquatic ecosystem were noted, with some being as short as two to three years. Most of the lakes described in the literature review are located at lower latitudes and have different species composition, greater species richness, higher productivity, and more complex food-webs than Kennady Lake under baseline conditions. These factors have a direct bearing on recovery rates and suggest a slower recovery in Kennady Lake.

Summary

Although some of the key findings from the literature review are not directly applicable to Kennady Lake, the overall trends documented in the reviewed studies provide evidence that an aquatic ecosystem will re-establish itself within Kennady Lake after refilling. The expected trajectory of recovery is outlined below.

8.11.1.3.3 Predicted Recovery of Kennady Lake

At the end of operations, some of the aquatic habitat in Kennady Lake physically altered during Project operations will be resubmerged. Habitat enhancement structures (e.g., finger reefs and habitat structures on the decommissioned mine pits/dykes) will be constructed. Refilling of Areas 3 through 7 will begin, using natural runoff from the upland watershed and waters diverted from Lake N11. During this time, Area 8 will continue to receive only natural runoff from the surrounding area.

After approximately 8 years, Areas 3 to 7 of Kennady Lake will be full of water. Thereafter, once water quality meets regulatory requirements, dyke A will be removed. Kennady Lake will once again consist of five interconnected basins.

The hydrology of the reconnected system is expected to be fairly similar to existing conditions as soon as dyke A is removed and pumping from Lake N11 ceases. The natural drainage of the B, D, and E watersheds to Kennady Lake will be restored; however, in the A watershed, Lake A3 will continue to flow to the N watershed. Water quality in the refilled lake is expected to return to conditions suitable to support aquatic life over time. The physical and chemical environment in Kennady Lake, therefore, will be in a state that will allow re-establishment of an aquatic ecosystem, although the re-established communities may differ from pre-development communities.

The predicted recovery of the aquatic ecosystem in Kennady Lake is outlined below, with reference to the key components of the system. These components include lower trophic communities (phytoplankton, zooplankton, benthic invertebrates) and fish.

Lower Trophic Levels

Development of lower trophic communities is expected to reflect the key factors identified in the literature review and the quality of water used to refill the lake. Because Kennady Lake does not support a substantial aquatic plant community due to physical factors and climate, it is unlikely to do so in the future. Therefore, the discussion of lower trophic levels is restricted to the development of plankton and benthic invertebrate communities.

Growth of terrestrial vegetation within Areas 3 through 7 during the period of exposure will be limited, based on the anticipated low rate of seed dispersal and slow vegetative growth that currently occurs around the margins of the lake in the tundra region. The dry lakebed will be surrounded by a margin of boulder and cobble, which will act as a barrier to vegetative propagation into the lake from the surrounding tundra. In addition, the amount of dried up organic sediments present on the exposed lake bottom will likely be reduced during the period of exposure by oxidation. Overall, the amount of organic material present on the exposed lake bottom upon refilling is expected to be lower than typically present when creating new reservoirs in the more southern locations described in the literature review, and potentially lower than currently exists in Kennady Lake.

Nutrient supply may be higher than under baseline conditions, and may result in rapid development of phytoplankton in re-filled areas of Kennady Lake. Because the amount of flooded organic material in Kennady Lake is anticipated to be low, its contribution to an initial trophic upsurge will likely be minor and short-lived. Nevertheless an initial period of upsurge may occur due to additional nutrient inputs from re-flooded sediments. Phytoplankton productivity likely will peak during this period, although the magnitude of the peak compared to the long-term level of productivity may be reduced in comparison to those observed in other systems. The initial upsurge may be followed by a period of bacterial dominance, until allochthonous (i.e., external) sources of dissolved organic matter are exhausted. In Kennady Lake, external sources are primarily represented by the terrestrial vegetation (e.g., grasses and weedy species) that has invaded the lakebed. The shift from allochthonous to autochthonous (i.e., internal) carbon sources is expected to occur during the filling period (8 years) and may be complete by the time the lake is fully refilled.

The rapid shift from external to internal sources of carbon will likely facilitate the development of the phytoplankton community in Areas 3 through 7, with the community becoming established during the refilling period. The development of the phytoplankton community in Areas 3 through 7 will also be facilitated by the arrival of phytoplankton from upstream sources (i.e., B, D, and E watersheds) and from Lake N11, which will be used as a water source to shorten the filling time. As a result, a phytoplankton community is expected to develop in Areas 3 through 7 by the end of the refilling period or shortly thereafter (i.e., within five years).

The phytoplankton community of Area 8 will remain similar during the refilling period. Breaching of dyke A will result in greater flow-through in Area 8 and a possible change in phytoplankton community structure, as water from Areas 3 through 7, which may contain higher nutrient levels, mix with Area 8 water.

Overall, the expected time frame for recovery of the phytoplankton community is estimated to be approximately five years after refilling is complete, taking into consideration that the phytoplankton community will begin to develop during the eight year refilling period. This time frame expectation will be reviewed when additional analysis of post-closure nutrient concentrations is available.

Zooplankton community development is predicted to closely follow recovery of the phytoplankton community. During the initial upsurge, zooplankton biomass is expected to peak, although this peak would also be less pronounced compared to that reported for zooplankton communities at other locations. It would then gradually decline to the level characteristic of the long-term nutrient concentrations in Kennady Lake. Colonization sources will be the same as those for phytoplankton and include the upstream watershed, N11 and the WMP. The zooplankton community of the refilled lake is expected to be different from baseline due to a potential increase in nutrient levels. The expected time frame for the development of the zooplankton community is longer than that of phytoplankton (i.e., likely within about five to ten years of Kennady Lake being completely refilled).

Recovery of the benthic invertebrate community is expected to be slower than for the plankton communities. In studies of newly-created reservoirs, benthic invertebrate community development was frequently found to be related to the availability of structural habitat and food provided by flooded terrestrial vegetation. As noted above, establishment of terrestrial vegetation in exposed areas of Areas 3 through 7 is anticipated to be minimal. Limited dispersal abilities of non-insect benthic invertebrates (e.g., worms, mollusks), which lack a winged adult life stage, represent another factor accounting for the prediction of slower community development.

Benthic invertebrate density is anticipated to be higher than existing levels during the first few years of refilling, provided that turbidity does not limit phytoplankton productivity. Following this period, densities are predicted to stabilize at a level characteristic of the long-term nutrient concentrations of Kennady Lake.

The succession of benthic invertebrate species varies among case studies, largely due to differences in the amount and type of terrestrial vegetation present within newly flooded areas and the dispersal abilities of local benthic invertebrate species. As in the case of plankton, upstream surface waters (i.e., B, D and E watersheds), N11, and the WMP will represent sources of colonization via drift to Areas 3 through 7. However, aquatic insects can also colonize from adjacent watersheds by deposition of eggs by winged adults. Most colonization studies found that midges (Chironomidae) were the initial colonizers, followed by slower establishment of other groups. Under existing conditions, Kennady Lake benthic communities consist mostly of midges, fingernail clams (Sphaeriidae), aquatic worms (Oligochaeta) and roundworms (Nematoda), with about half of the total abundance contributed by midges. A greater dominance by midges and aquatic worms is likely after refilling, reflecting the elevated nutrient levels predicted, which may result in reduced dissolved oxygen concentrations during winter.

The Area 8 benthic invertebrate community is likely to change after reconnection to the other basins, consistent with predicted changes in water quality and the plankton community. A gradual potential increase in phosphorus concentrations could result in increased plankton abundance and biomass, and ultimately, higher benthic invertebrate abundance and biomass compared to pre-development conditions.

The estimated time to recovery for the benthic community in Kennady Lake is about ten years after refilling is complete, consistent with accounts of lake recovery and lake creation described by previous studies. At the end of the recovery period, the benthic invertebrate community will be different from the currently existing community in Kennady Lake and surrounding lakes. The new community will likely be of higher abundance and biomass, depending on final nutrient levels in the refilled system. In terms of composition, it will likely consist largely of the same groups that exist under pre-development conditions (i.e., midges, fingernail clams, aquatic worms, and roundworms). However, their relative proportions may differ from baseline, because of interactions among invertebrate species, the influence of fish predation and the different abilities of invertebrate species in these groups to take advantage of potential increases in food supply and other changes that may occur as a result of potentially altered nutrient levels.

Fish

Kennady Lake is currently a nutrient limited, oligotrophic lake containing a relatively simple food web. The dominant food chain consists of lake trout as the top predator, feeding primarily on round whitefish. Round whitefish, in turn, feed on zooplankton and benthic invertebrates. Burbot and northern pike are the only other piscivorous fish species present in Kennady Lake, but they are found in much lower abundance than lake trout. Arctic grayling, lake chub, ninespine stickleback, and slimy sculpin (i.e., other fish species present in Kennady Lake) are generally benthivorous and serve as secondary prey items for lake trout. Young-of-the-year lake trout feed almost exclusively on zooplankton, but undergo an ontogenetic diet shift to fish and benthic invertebrates as they grow (Martin and Olver 1980). Therefore, zooplankton are an important link in the dominant Kennady Lake food chain, in that they support the growth and recruitment of lake trout.

The re-establishment of the fish community within Kennady Lake, and the speed at which it will occur, will depend on the ability of fish to re-colonize the refilled lake, the habitat conditions within the refilled lake, and how succession among the top predators takes place within the refilled system after it has been fully connected to the surrounding environment. These aspects of recovery are outlined below, as well as a discussion of the potential for non-resident fish species to enter Kennady Lake, and of the time required for a stable fish community to become established within the refilled lake.

Location of Potential Migrants and Initial Re-colonization

Fish are present in the upper Kennady Lake watershed, including in the A, B, D and E sub-watersheds. These sub-watersheds will be diverted away from Kennady Lake during the operational life of the Project. However, the B, D, and E watersheds will be reconnected to the lake once refilling begins. Fish populations, including Arctic grayling, northern pike, burbot, lake chub, slimy sculpin, and ninespine stickleback, are expected to persist in these watersheds during Project operations.

At closure, the B, D and E sub-watersheds will be rediverted back to Kennady Lake. During refilling, exclusion measures will be used to limit the initial migration of fish from the upper sub-watersheds into Kennady Lake. The mitigation measures will target large-bodied fish, such as northern pike, burbot, lake trout, and Arctic grayling. Small-bodied fish, such as lake chub, slimy sculpin, and ninespine stickleback, will likely pass through the exclusion devices, as will the young-of-the-year of large-bodied fish. It is anticipated that the smaller fish species will move quickly into Kennady Lake. The smaller cyprinids (i.e., minnows) and younger age classes of large-bodied fish species tend to be more mobile and prone to downstream immigration in comparison to larger fish (Binns 1967; Avery 1978; Olmsted and Cloutman 1978).

During the initial period of refilling, some mortality of the incoming small-bodied fish is likely to occur, because of insufficient water depths and possibly elevated levels of turbidity. As conditions improve, and water depths increase, the early migrants will become permanently established, feeding on the plankton and benthic invertebrate communities that are themselves becoming established in the refilled lake. Nutrient levels in the refilled Kennady Lake may be higher than under existing conditions. A potential increase in primary productivity from nutrients may also result in increased growth and production of these small-bodied forage fish species.

Development of self-sustaining populations of the small-bodied fish species in Kennady Lake is unlikely to occur until the lake is completely refilled. Prior to complete refilling, access to suitable spawning and rearing habitat will be limited, as it is primarily in the upper 3 to 4 m of the lake. Based on the current refill scenario, which assumes that remaining space in the Tuzo pit will be refilled first, the upper 3 to 4 m of Kennady Lake will likely only contain sufficient water depths to support spawning and rearing near the end of the refill period. Small-bodied forage fish species (e.g., lake chub, slimy sculpin, and ninespine stickleback), are less specific with respect to habitat; as such, they will likely recolonize and establish self-sustaining populations within Kennady Lake over time.

Area 8 will be a second potential source of migrants. Area 8 will be separated from the dewatered basins of Kennady Lake during the operational life of the Project by dyke A, and it is anticipated that Area 8 will contain residual populations of lake chub, slimy sculpin, ninespine stickleback, Arctic grayling, northern pike and burbot, all of which are relatively hardy fish species. Area 8 is not expected to contain residual populations of lake trout or round whitefish because of overwintering habitat limitations. Area 8 is shallow, and will provide limited overwintering habitat to these cold-water fish species.

Lake I1 is another potential source of migrant fish. Lake I1 drains into Area 8; lake trout, Arctic grayling, slimy sculpin and ninespine stickleback have been captured in the lake. Due to the depth of Lake A1 (maximum depth of 11 m), the ephemeral nature of the outlet stream, and the presence of both adult and juvenile lake trout, it is likely that this lake has a self-sustaining population of lake trout. Juvenile fish in Lake I1 disperse downstream to Area 8 in spring, likely to alleviate density-dependent factors, such as competition for limited food resources and to escape predation.

Migrants from Area 8, and potentially from Lake I1, will complement downstream migration from the upper B, D, and E sub-watersheds after Kennady Lake has been completely refilled and dyke A has been removed. Prior to the removal of dyke A, the colonization of Kennady Lake by small-bodied fish will occur exclusively through the downstream migration of fish from the upper B, D and E sub-watersheds. Once dyke A has been removed, the migration of fish from Area 8 into the rest of Kennady Lake is expected to be rapid, due to proximity and the increased productivity that is expected from nutrient enrichment in Kennady Lake and Area 8.

Large-bodied fish from the B, D, and E sub-watersheds will be allowed to freely immigrate to Kennady Lake once conditions in the lake are acceptable, i.e., water levels have been re-established, water quality is suitable to support aquatic life, and stable plankton, benthic invertebrate, and forage fish communities have become established. Immigration of fish from downstream lakes may also occur, although to a lesser extent. Lakes in the L watershed generally are too shallow to support populations of large-bodied fish species, but lakes in the M watershed, particularly Lake M4 and Lake M3, are deep enough and large enough to support populations of lake trout, round whitefish, Arctic grayling, northern pike, and burbot. Both Arctic grayling and northern pike have been documented migrating upstream from these lakes. The upstream migration occurs in spring when Arctic grayling are migrating into streams to spawn and northern pike are migrating into streams to access flooded riparian areas. It is unclear how far upstream these fish currently travel, but some may eventually find their way into Kennady Lake.

Immigration of lake trout and round whitefish from downstream lakes is less likely to occur. Lake trout and round whitefish are fall spawners and typically spawn in lakes. They do not, as a result, have an inherent need to migrate into streams to complete their life cycle. However, these species may make movements into streams for feeding or rearing; for example, lake trout have been observed moving into the Kennady Lake outlet (Stream K5) in spring to feed on spawning Arctic grayling. In addition, there are numerous barriers present in the streams that connect Kennady Lake to the lakes in the M watershed. Upstream passage over these barriers is only possible during the spring freshet, not during the fall spawning period when lake trout and round whitefish may be traveling through the streams.

The partially dewatered areas of Kennady Lake, including the WMP, will not be a source of migrant fish. Turbidity levels are expected to be high and habitat will be unsuitable for all fish species present in the existing lake.

Although lake trout and round whitefish will be able to access the refilled Kennady Lake, it is not known at this time to what extent the overwintering habitat in Kennady Lake at post-closure may become more limited than pre-Project conditions as a result of potential changes in nutrient levels and limnological characteristics. The analysis of nutrient levels in the refilled lake is on-going, with results expected in 2011.

Establishment of Large-bodied Fish in the Refilled Kennady Lake

Northern pike, Arctic grayling, and burbot are likely to be large-bodied fish species that readily re-establish in the refilled Kennady Lake, as they are hardy species and are found to inhabit a wide range of lake conditions. These species are likely to enter the refilled Kennady Lake initially as juveniles from the D and E sub-watersheds.

Burbot will also likely enter Areas 3 to 7 of Kennady Lake from Area 8 once dyke A is removed. Burbot are expected to become established early in the recovery of Kennady Lake as they are relatively tolerant of turbid water (Chen 1969; Hatfield et al. 1972 cited in McPhail 2007) and are omnivorous and voracious feeders (Kahilainen and Lehtonen 2003). As a result, burbot are likely to be able to quickly take advantage of the forage fish and benthic invertebrates available in the lake, particularly in the absence of other large predators (e.g., northern pike and lake trout).

Arctic grayling are also expected to establish earlier than northern pike, because, like burbot, they are relatively tolerant of turbid water (McLeay et al. 1983, 1984, 1987), and have very broad feeding preferences (McLeay et al. 1984; Scott and Crossman 1973; Birtwell et al. 2005). Arctic grayling show considerable low oxygen tolerance for salmonids (Eriksen 1975 as cited in Hubert et al. 1985). Spawning habitat for Arctic grayling will be available in streams in the reconnected B, D, and E watersheds and downstream of Area 8.

Northern pike is expected to re-establish self-sustaining populations later in the refilled Kennady Lake. Northern pike are dependent on aquatic vegetation for spawning and rearing. Although aquatic vegetation is expected to eventually become re-established in the lake, re-colonization of aquatic vegetation is expected to be slow especially as the presence of aquatic vegetation in Kennady Lake is currently limited. As a result, recruitment of northern pike in Kennady Lake will occur for some time primarily through migration from lakes in the D and E sub-watersheds, and to a lesser extent from downstream of Area 8.

The establishment of self-sustaining populations of lake trout and round whitefish are more dependent on the final nutrient and limnological characteristics that develop in the lake. The analysis of nutrient levels in the refilled lake is on-going, with results expected in 2011. Conclusions with respect to the potential for self-sustaining populations of lake trout and round whitefish to become established in the refilled Kennady Lake will be put forward at that time.

Non-native Species

The possibility exists for non-native species to become established in Kennady Lake. Kennady Lake does not currently contain cisco or sucker species. One longnose sucker was captured moving downstream out of Kennady Lake in the spring of 2000. However, longnose sucker have never been captured in Kennady Lake, despite the extensive gillnetting efforts that have occurred since 1996. Cisco are present in Lake 410 and Lake M4, which are located downstream of Kennady Lake, and in Lake N16 in the adjacent N watershed. Longnose sucker[11] are similarly present in Lake N16 and in the small lakes and streams immediately north of Kennady Lake in the N watershed. Furthermore, cisco and longnose sucker from N16 could enter the D and E lakes during operations and then move into the refilled Kennady Lake after the connection is restored.

It is unclear why these species do not currently reside in Kennady Lake. Cisco co-exist with round whitefish in Lake N16 and Lake 410, indicating that these two closely-related coregonid species occupy niches different enough to allow them to co-exist in the same lake. Physical habitat is unlikely to preclude cisco from Kennady Lake, because they spawn over rocky substrates in nearshore areas (similar to round whitefish). Cisco differ from round whitefish in their food preferences and feeding behaviour; cisco are pelagic planktivores, whereas round whitefish are typically bottom-feeding benthivores (Scott and Crossman 1973; Richardson et al. 2001). Plankton communities in Lake N16 and in Kennady Lake are currently similar; therefore, food availability is unlikely to be the reason for the absence of cisco from Kennady Lake. Although cisco may be able to access Kennady Lake in post-closure, this species is unlikely to become permanently established in Kennady Lake once refilled due to overwintering habitat limitations.

Known populations of longnose sucker are located further from Kennady Lake than cisco, but are more likely to eventually access Kennady Lake than cisco. Longnose sucker have an inherent instinct to migrate into streams in spring to spawn. Longnose sucker were found to move between all lakes and streams between Lac de Gras and Kodiak Lake during springtime (Low 2002). This finding suggests that longnose sucker can make extensive migrations between lakes and could eventually move from lakes in the N watershed to Kennady Lake in time. It is unclear whether longnose sucker could become established in Kennady Lake, should they be able to access it. Longnose sucker feed on benthic invertebrates and prefer cold, oligotrophic lakes (Scott and Crossman 1973; Richardson et al. 2001). Currently, habitat and food availability appear to

[11] White sucker was also recorded in Lake N16 in 1999. This is the only reported instance of white sucker in the watershed upstream of Kirk Lake and may potentially be a misidentification.

be suitable for longnose sucker in Kennady Lake; however, based on catch data, it appears that a longnose sucker population does not exist in the lake. Conditions in the refilled Kennady Lake will be different than what currently exists, and it is possible that due to changes in prey abundance, habitat conditions and predators, that a population of this species will become established.

The Effect of Habitat Modifications on Fish Recovery

The mine rock piles in Areas 5 and 6 will be designed and constructed in a way to ensure long-term stability. The Fine PKC Facility in Areas 1 and 2 will be reclaimed during mine operations, including covering with coarse PK and mine rock and grading. The mine pits will be reclaimed once mining has been completed. 5034 will be backfilled with mine rock and Hearne will be backfilled with fine PK. The Tuzo Pit will not be backfilled with material, but instead will be allowed to flood following operations. There will be some permanent losses of habitat in Kennady Lake due to mine rock piles, PK storage, and mine pits; however, compensation habitats will be constructed in the Kennady Lake watershed to offset losses. As identified in the Conceptual Compensation Plan (CCP, Section 3, Appendix 3.II), options for fish habitat compensation within Kennady Lake itself include construction of finger reefs, construction of habitat structures on the decommissioned mine pits/dykes, and widening of bench pits.

The refilled sections of the mine pits are not expected to hinder or prevent the recovery of the Kennady Lake fish community. Although the refilled areas will be in the order of 300 m deep, the loss of productive lake bottom within the pit is expected to be small (less than 10% of the lake area). There is no evidence to suggest that fish avoid deep-water pits where they contain sufficient dissolved oxygen. The upper level of the Tuzo pit will likely provide additional summer thermal refuge for fish. As observed during the 2010 hydroacoustic study, when Areas 4 and 6 are thermally stratified in summer, lake trout seek deeper water areas with cooler water.

Restocking Program

As previously noted, lake trout and round whitefish are expected to persist in Lake I1 throughout the operational life of the Project. These fish species may eventually immigrate into the refilled Kennady Lake, if conditions are suitable. If it is determined that Kennady Lake would provide suitable habitat for these fish species, restocking may be used to supplement the natural migration process and speed the time to recovery for lake trout and round whitefish. Restocking is a biologically viable and technically feasible option to re-establish more sedentary fish species, such as lake trout and round whitefish. Stocking is a well-established fisheries management technique that has been used in a variety of locations in Canada, particularly in Ontario (Powell and Carl 2004). It has been used to develop “put-and-take” sport-fisheries, to introduce new species to barren lakes, to supplement existing stocks, and to rehabilitate extirpated or reproductively suppressed fish stocks.

If stocking is determined to be appropriate, lake trout would not be transplanted into Kennady Lake until a self-sustaining population of round whitefish or other suitable prey species was established, which, in-turn, would require the re-establishment of the lower trophic levels. As such, monitoring of the lower trophic communities and forage fish populations in the refilled lake would be undertaken to determine if and/or when a restocking program should be undertaken. Kennady Lake would be stocked with lake trout from lakes within the Lake 410 or Kirk Lake watersheds to maximize the likelihood of transferring fish with similar genetic make-up to those currently residing in Kennady Lake. Stocking success is increased if the source population has genetic traits that have adapted it to habitat similar to habitat present in the lake to be stocked. Any stocking program proposed for Kennady Lake would require acceptance and input from local Aboriginal communities and from federal and territorial agencies.

Prediction of the Re-established Fish Community in Kennady Lake

It is expected that a fish community will become re-established in Kennady Lake. The physical habitats in the reconnected lake are expected to be similar to those that currently exist. Water quality will also be somewhat similar, with the exception of nutrient-related parameters. Density and biomass of zooplankton and benthic invertebrates are expected to increase in Kennady Lake.

The final fish community of Kennady Lake will likely once again be characterized by low species richness (less than 10 species), containing a small-bodied forage fish community (e.g., lake chub, slimy sculpin, ninespine stickleback) and large-bodied species, such as northern pike, Arctic grayling, burbot, and possibly longnose sucker. Total lake standing stock and annual production may be increased over what currently exists in the lake. However, the composition of the fish community is highly dependent on the nutrient and limnological characteristics that develop in the refilled lake. The analysis of nutrient levels in the refilled lake is on-going, with results expected in 2011. Conclusions with respect to the nature of the fish community in the refilled Kennady Lake will be put forward at that time.

Predicted Duration of the Recovery

Recovery of aquatic ecosystems after "press"[12] disturbances that last for some time is difficult to estimate (Niemi et al. 1990). It is clear from the available data that recovery times from "press" disturbances are longer than those from "pulse"[13] disturbances, and that the longest recovery times are typically associated with "press" disturbances that include long-term alterations of physical habitat (Niemi et al. 1990). Project activities at Kennady Lake constitute a "press" disturbance.

There are dependent and independent factors that can reduce the recovery time of fish communities following "press" disturbances (Niemi et al. 1990). The independent factors that can reduce recovery times of fish communities include the following:

- persistence of fish in the disturbed area;
- persistence of fish in refugia upstream or downstream of the disturbed area; and
- absence of barriers to fish movement.

Kennady Lake will have the benefit of having persistent fish populations in refugia upstream and downstream, and there will be no barriers to immigration of fish to the lake once dykes and fish exclusion measures are removed. Habitat enhancement features will also be constructed to replace habitat disturbed during Project operations. Potential increases in nutrient levels may also increase primary productivity within the lake. These attributes should minimize recovery times.

Dependent factors that can reduce recovery times of fish communities include the following (Niemi et al. 1990):

- colonizing fish species with quick generation times;
- fish species with resistant life stages;
- fish species with a high propensity to disperse; and
- influx of species with minimal competition and predation interactions.

[12] "Press" disturbance is a disturbance of long duration and often involving changes in the watershed or stream channel (e.g., timber harvesting, mining, channelization, drought).

[13] "Pulse" disturbance is a disturbance of limited and easily definable duration, which has little effect on the surrounding watershed (e.g., chemical spills, floods).

While these dependent factors influence recovery times, there is little that can be done to manipulate these factors. They are inherent to the characteristics of the fish species located in the area.

Overall, it is the life history attributes of Arctic grayling, northern pike and burbot that will ultimately determine the duration of the primary recovery of the Kennady Lake aquatic ecosystem.

Burbot and Arctic grayling are expected to establish self-sustaining populations in the refilled Kennady Lake earlier than northern pike. The northern pike population in Kennady Lake is currently small, likely limited by the lack of suitable habitat (i.e., lack of aquatic plants for spawning and rearing). Re-establishment of a stable, self-sustaining northern pike population is expected to take a long time (i.e., approximately 50 to 60 years following the complete refilling of Kennady Lake). This is based on the following rationale:

- The time frame for recovery of the plankton communities and benthic invertebrate communities after refilling is complete is expected to be between 5 and 10 years.
- The time frame for recovery of the forage fish community after recovery of the lower trophic communities is expected to be an additional five years.
- Kennady Lake will have cool summer water temperatures (maximum of 17 degrees Celsius [°C]), and a short growing season (less than four months).

Although data are limited, recovery times range from 5 to greater than 52 years for fish communities recovering from “press” disturbances in studies compiled by Niemi et al. (1990). Most (greater than 70%) of these studies dealt with disturbances to streams, and few were located in cold climate zones. Streams can be expected to recover faster than lakes, because streams are more dynamic than lakes. Arctic systems usually recover slower than temperate or tropical systems, because of colder temperatures, shorter growing seasons, and low nutrient availability. Although nutrient availability may not be a limiting factor for the recovery of Kennady Lake, a longer recovery compared to temperate zone lakes remains likely due to Arctic climate-related factors. As a result, the estimated time to full recovery is expected to fall between 50 to 60 years following the complete refilling of Kennady Lake, or 60 to 76 years from the end of Project operations. The average life span of northern pike is 10 to 12 years in fast-growing southern Canadian populations and in slow-growing Arctic populations as high as 24 to 26 years (Scott and Crossman 1973). Maximum age for burbot is probably between 10 and 15 years (Scott and Crossman 1973).

Allowing fifteen years for development of the supporting food web, the estimate of 50 to 60 years is expected to allow for the completion of two life cycles of these slower growing predators.

If lake trout return to be the dominant piscivore in Kennady Lake, it is expected that this species will require the longest time to re-establish a stable, self-sustaining population. Lake trout are slow-growing, have the longest time to first maturity (eight to nine years) of any fish in the area, and typically spawn only once every two years. Restocking may also be required to supplement the natural migration process. As a result, if conditions in the lake are suitable, the re-establishment of a stable, self-sustaining lake trout population is anticipated to take approximately 60 to 75 years following the complete refilling of Kennady Lake.

8.11.1.4 Summary

An aquatic ecosystem will develop within Kennady Lake after refilling and reconnection of its basins. There will be some permanent losses of habitat in Kennady Lake due to mine rock piles, PK storage and mine pits; however, compensation habitats will be constructed within the Kennady Lake watershed to offset losses. The long-term hydrology of Kennady Lake is expected to return to a state similar to current conditions and water quality in the refilled lake is expected to return to conditions suitable to support aquatic life over time. The physical and chemical environment in Kennady Lake, therefore, will be in a state that will allow re-establishment of an aquatic ecosystem, although potential increases in nutrient concentrations may result in re-established communities differing from pre-development communities.

The expected time frame for recovery of the phytoplankton community is estimated to be approximately five years after refilling is complete, taking into consideration that the phytoplankton community will begin to develop during the eight year refilling period. A potential increase in nutrient levels in the refilled Kennady Lake may also facilitate community development and may result in a more productive phytoplankton community in the refilled lake compared to the pre-development community.

Zooplankton community development is predicted to follow recovery of the phytoplankton community. Colonization sources will be the same as those for phytoplankton and include the upstream watershed (i.e., the B, D, and E watersheds), Lake N11, and the WMP. The zooplankton community of the refilled lake may also be more productive than the existing community. The expected time frame for the development of the zooplankton community is longer than that of phytoplankton (i.e., likely within five to 10 years of Kennady Lake being completely refilled).

Recovery of the benthic invertebrate community is expected to be slower than that of the plankton communities. The estimated time to recovery for the benthic community in Kennady Lake is about 10 years after refilling is complete. At the end of the recovery period, the benthic invertebrate community in Kennady Lake may be different from the community that currently exists in Kennady Lake and in surrounding lakes, depending on nutrient levels in the refilled system.

The re-establishment of the fish community within Kennady Lake, and the speed at which it will occur, will depend on the ability of fish to re-colonize the refilled lake, the habitat conditions within the lake, and how succession takes place within the refilled system after it has been fully connected to the surrounding environment. It is expected that a fish community will become re-established in Kennady Lake. However, potential increases in nutrient concentrations, may contribute to the possibility that the resulting fish community composition is different than what exists currently.

Fish populations, including Arctic grayling, northern pike, burbot, lake chub, slimy sculpin, and ninespine stickleback, are expected to persist in the B, D, and E watersheds during Project operations. These watersheds are likely to be the primary source of initial migrants into Areas 3 to 7 of Kennady Lake. During refilling, exclusion measures will be used to limit the initial migration of large-bodied fish, such as northern pike, burbot, lake trout, and Arctic grayling, from entering the lake. It is anticipated that during the initial period of refilling, some mortality of the incoming small-bodied fish is likely to occur, because of insufficient water depths and possibly elevated levels of turbidity. As conditions improve, and water depths increase, the early migrants will become permanently established, feeding on the plankton and benthic invertebrate communities that are themselves becoming established in the refilled lake. Nutrient levels in the refilled Kennady Lake may be higher than under existing conditions, which may result in increased primary productivity and increased growth and production of these small-bodied forage fish species.

Following the removal of dyke A, migrant fish will also enter Areas 3 through 7 of Kennady Lake from Area 8, which is expected to contain residual populations of lake chub, slimy sculpin, ninespine stickleback, Arctic grayling, northern pike, and burbot. The migration of fish from Area 8 into the rest of Kennady Lake is expected to be rapid, due to proximity and the potential for increased productivity in Kennady Lake and Area 8.

The final fish community of Kennady Lake will likely once again be characterized by low species richness (less than 10 species), containing a small-bodied forage fish community (e.g., lake chub, slimy sculpin, ninespine stickleback) and large-bodied species, such as northern pike, Arctic grayling, burbot, and possibly longnose sucker. Total lake standing stock and annual production may be increased over what currently exists in the lake. However, the composition of the fish community is highly dependent on the nutrient and limnological characteristics that develop in the refilled lake. The analysis of nutrient levels in the refilled lake is on-going, with results expected in 2011. Conclusions with respect to the nature of the fish community in the refilled Kennady Lake will be put forward at that time.

8.12 RELATED EFFECTS TO WILDLIFE AND HUMAN USE

8.12.1 Overview

This section presents a summary of the effects of changes to water quantity, water quality, and fish in the Kennady Lake watershed on wildlife and human health. The summary of residual effects is based on assessments presented in other sections of the environmental impact statement (EIS). The assessment of effects to wildlife for all pathways, including changes in water quantity, water quality, and fish are provided in the following other sections of the EIS:

- Key Line of Inquiry: Caribou (Section 7);
- Subject of Note: Carnivore Mortality (Section 11.10);
- Subject of Note: Other Ungulates (Section 11.11); and
- Subject of Note: Species at Risk and Birds (Section 11.12).

Potential pathways for effects to wildlife associated with changes in water quality, water quantity, and fish in the Kennady Lake watershed include:

- effects to wildlife health resulting from changes in water quality and fish tissue quality;
- effects of dewatering Areas 2 to 7 of Kennady Lake on riparian vegetation and related effects to wildlife; and
- effects to wildlife resulting from a decrease in lake area resulting from the dewatering of Areas 2 to 7 of Kennady Lake, isolation of Area 8, and changes to small lakes in the watershed.

The only potential pathway for effects to human health relevant to Section 8 is associated with changes in water quality and fish tissue quality.

A summary of the residual effects for each of these pathways is provided below.

8.12.2 Summary of Residual Effects

8.12.2.1 Wildlife

8.12.2.1.1 Effects of Changes in Water Quality and Fish Tissue Quality to Wildlife Health

An ecological risk assessment was completed to evaluate the potential for adverse effects to individual animal health associated with exposure to materials released from the Project. The result of the assessment indicated the potential for effects to occur to aquatic-dependant birds (i.e., waterfowl and shorebirds) as a result of boron levels in Kennady Lake after refilling. No other impacts were predicted to birds or other wildlife, including caribou, muskoxen and moose.

The ecological risk assessment was completed using water quality predications that were developed assuming that there was no isolation of the fine PKC material located at the base of the Fine PKC Facility, and that all waters travelling over the facility would come into contact with this material, which is the predominate source of boron to the refilled lake. Processes that would modify the degree of contact between the fine PK and the runoff waters were not considered, including the aggradation of permafrost and/or the application of cover material to limit infiltration. In addition, the water quality predications used in the risk assessment were developed by setting parameters concentrations in the runoff waters to the maximum concentrations observed in the geochemical investigations completed in support of the EIS. Consequently, the results of the risk assessment correspond to an extreme condition that has a low likelihood of occurring.

De Beers is committed to further study of this potential issue in 2011, and will incorporate mitigative strategies into the Project design to the extent required to maintain boron levels in Kennady Lake below those that may be of environmental concern, including the potential application of less permeable cover material to limit infiltration through the Fine PKC Facility. Given these commitments and the low likelihood of the assessed situation actually occurring, overall potential effects to wildlife were deemed to be environmentally insignificant. However, the predictions of environmental significance with respect to water birds are dependent on the execution of further study of the ingestion pathways discussed in Section 11.2 and the commitment that mitigative strategies will be incorporated into the Project design to the extent required to invalidate these pathways.

8.12.2.1.2 Effects of Dewatering Areas 2 to 7 on Riparian Vegetation and Related Effects to Wildlife Habitat

Riparian vegetation around the edges of Kennady Lake is currently limited, and primarily restricted to sheltered bays and streams. Most of this riparian vegetation will be lost when Areas 2 to 7 are dewatered. However, dewatering of Kennady Lake will result in the exposure of a portion of the lake-bed. There is the potential for vegetation to establish on the exposed lake-bed sediments. This type of habitat would likely be favoured by grasses, sedges, and possibly, invasive weedy species, and would create habitat for wildlife. In Area 8, higher concentrations of nutrients may increase riparian habitat.

Changes in abundance and composition of vegetation associated with dewatering will be localized, and will have a minor influence on the quantity of forage available for wildlife, relative to baseline conditions. Consequently, changes to forage quantity, resulting from the dewatering of Areas 2 to 7, are expected to be a minor pathway that would not contribute to effects to wildlife.

8.12.2.1.3 Effects of a Decrease in Open Water Area to Wildlife Habitat

During operations, a reduction in the surface area of open water in the Kennady Lake watershed will result primarily from the dewatering of Areas 2 to 7, and to a lesser extent from the loss of small lakes. This will be partially offset by the raising of lakes in the A, D and E watersheds, and resultant increase in the surface area of lakes A3 (22.8 hectares [ha]), D2 and D3 (53.1 ha combined), and E1 (6.8 ha).

After closure, once Kennady Lake has been refilled and the lakes in the D and E watersheds have returned to their pre-disturbance levels, a reduction in the surface area will persist due to the loss of Kennady Lake area through the development of the West and South Mine Rock Piles and Fine Processed Kimberlite Containment (PKC) Facility, and several small lakes (e.g., Lakes A1 and A2). This will be offset to a small degree due to the permanent raising of Lake A3.

The overall decrease in the surface area of open water in the Kennady Lake watershed through operations and closure will primarily affect habitat for water birds (e.g., waterfowl, loons, and grebes) and shore birds whose important habitats include vegetation communities with a wetter moisture regime including shallow and deep water, sedge wetlands, and riparian habitats. Approximately 68% of the Project footprint is aquatic habitat and 32% is terrestrial habitat. The baseline Local Study Area (LSA) is approximately 200 square kilometres (km^2) (Section 11.12.2.1, Figure 11.12-2), centered on Kennady Lake; it was selected to assess direct effects (e.g., habitat loss) to individuals from the Project footprint. The baseline Regional Study Area (RSA) is much larger at 5,700 km^2 (Section 11.12.2.1, Figure 11.12-2); it was selected to capture indirect effects of the Project.

At the local scale, the Project footprint will alter 4.4% of the wildlife baseline LSA. Direct effects from the Project footprint are expected to decrease the surface area of open water in the wildlife baseline LSA by 2.2%. However, there will be a less than 1% decrease in sedge wetland and riparian shrub relative to baseline values in the wildlife LSA. These local changes are expected to influence individuals that occupy or travel through habitats within and adjacent to the Project.

At the population level, the Project is expected to affect less than 1.4% of highly suitable habitat for water birds and shore birds (i.e., deep water, shallow water, sedge wetland, riparian habitat) in the wildlife baseline RSA. The greatest reduction in highly suitable habitat is to deep water (446 ha). The magnitude of the incremental decrease in habitat quantity caused by the footprint was predicted to be low. A less than 1.4% loss of habitat is well below the 40% threshold value for habitat loss associated with predicted declines in bird and mammal species (Andrén 1994, 1999; Fahrig 1997; Mönkkönen and Reunanen 1999). Therefore, the direct effect of the Project on the population size and distribution of water birds and shore birds is predicted to be low in magnitude.

8.12.2.2 Human

8.12.2.2.1 Effects of Changes in Water Quality and Fish Tissue Quality to Human Health

A human health risk assessment was completed to evaluate how the predicted changes to air and water quality in the Kennady Lake watershed could potentially affect human health. Emission sources considered in the assessment included fugitive dust, air emissions, site runoff and seepage and exposed lakebed sediments. Potential exposure pathways included changes in air, water, soil, vegetation and fish tissue quality.

The results of the assessment indicate that individuals living at the Project site could experience health issues should they consume fish, as predicted changes in metal levels in water could affect fish tissue quality. However, individuals working at the Project site will not be allowed to fish and, therefore, will not consume fish from the Kennady Lake watershed. In addition, individuals do not currently live at the Project site, and it is unlikely that non-workers would do so in the future. This exposure scenario was used to provide a conservative evaluation of potential effects to individuals using the area for traditional purposes, because traditional purposes typically involve a temporary presence on the land near the Project site. The human health assessment was also completed using the conservative water quality predictions described herein, which included the free and complete contact between site runoff waters and the materials contained in the mine rock piles, the Coarse PK Pile and the Fine PKC Facility.

De Beers is currently evaluating a variety of environmental design features and mitigation measures to limit contact between site runoff waters and the fine PK located within the Fine PKC Facility and other potential sources. The effectiveness of these environmental design features and mitigation measures is uncertain and requires further analysis. This analysis is expected to be completed in 2011. Once complete, De Beers will update the human health assessment to reflect the effects of these measures. De Beers is also committed to implementing additional environmental design features and mitigation measures to the extend required to protect human health.

As a result, human health is not expected to be detrimentally affected by Project activities, in the Kennady Lake watershed or in downstream systems. However, this statement is contingent on the results of further study and the implementation of mitigation strategies to the extent required to maintain exposure levels below those that would be of concern.

8.13 RESIDUAL EFFECTS SUMMARY

The potential environmental effects related to the valid pathways identified for water quality and fish in Kennady Lake is provided below for the following components:

- hydrology;
- water quality;
- aquatic health;
- fish and fish habitat; and
- recovery

8.13.1 Hydrology

8.13.1.1 Construction and Operations

The dewatering of Kennady Lake Areas 2 through 7 will begin after the construction of Dyke A. All discharge during construction will be by direct discharge to Lake N11 and Kennady Lake Area 8. A Water Management Pond (WMP) will be established in the dewatered Areas 3 and 5. Plant makeup water will be withdrawn from the WMP and fresh water supply for potable water (60,000 cubic metres per year [m^3/y] during construction and 28,000 m^3/y during operation) will be withdrawn from Area 8. It is expected during construction and operation that the dewatering process will not result in effects to natural channel or bank stability; however, the exposed lake-bed within the dewatered Kennady Lake may be subject to erosion, depending on the bed substrate. All runoff and water retained in collection ponds within the Kennady Lake watershed will be managed to prevent its release to the natural receiving environment if it does not meet specific water quality guideline criteria.

The diversion of drainage from watersheds A, B, D and E away from Kennady Lake will be achieved with the construction of saddle dykes on the outlets of lakes A3, B1, D2, and E1. The dykes will raise water level in lakes A3 (3.5 metres [m]), D2 (2.8 m), D3 (1.6 m) and E1 (0.8 m) and block the existing outlet of Lake B1 with no change in water levels, and cause the cessation of flows downstream of the dykes for most of the year. The lake surface areas will increase by 96% in Lake A3 (to 0.47 square kilometres [km^2]), 102% in lakes D2 and D3 (to 1.03 km^2) and 33% in Lake E1 (to 0.27 km^2); however, the mean annual water level variation is expected to be similar or reduced from pre-diversion conditions. The increase in water levels will result in the inundation of lake shoreline zones, but because of the natural armouring afforded by cobble and boulder substrate, and the preparation of the shoreline zone to be inundated if required, erosion potential and sediment sourcing will be minimized. The diversion channels constructed in watersheds A, B, D and E to convey the reversed flows to the N watershed will have similar annual hydrograph characteristics to the natural lake outflows, and will also be designed to prevent erosion and maintain stability in permafrost. Raised lake filling in the D watershed is expected to take 3 years, and in the A watershed is expected to take 11 years.

Project activities in the Kennady Lake watershed will include the development of project surface infrastructure (camp and plant site, processing facilities, sewage treatment plant, explosives management facilities, airstrip and site roads) as well as the West and South Mine Rock Piles, Coarse PK pile and Fine PKC Facility.

Watersheds A, Ka, Kb and Kd are tributaries to Areas 2 to 7 that include project surface infrastructure. All runoff from these watersheds will be conveyed to the WMP by the site water management system (e.g., the Project mechanism to which all elements of site contact and mine contact water, potable and plant water supply, pumped inflows and discharges, and natural inflows and outflows are managed and facilitated). Watersheds H, I and Ke are tributaries to Area 8 that include project surface infrastructure. All infrastructure within these watersheds will be free-draining and no measurable effect on the quantity of inflow to Area 8 of Kennady Lake is anticipated. Project surface infrastructure is not expected to have any measurable effect on natural channel or bank stability, because no natural lakes will be affected, and constructed ditches will incorporate erosion and sediment control measures.

Mine rock piles will be located entirely within the controlled area boundary and all drainage will be managed as part of the closed-circuit site water management system. Lake Ka1 will be covered by the West Mine Rock Pile and a portion of the tributary area to the Lake F1 outlet channel, downstream of the lake, will be occupied by the South Mine Rock Pile. No effects on natural channel or bank stability are anticipated, because runoff around the mine rock pile perimeters and in the diverted Lake F1 will be managed to prevent channel erosion.

The Coarse PK Pile will be located entirely within the controlled area boundary and all drainage will be managed as part of the closed-circuit site water management system. Construction and operation of the Coarse PK Pile will result in the permanent loss of Lake Kb4 as a waterbody. No effects on natural channel or bank stability are anticipated, because runoff from the Coarse PK Pile and upstream areas will be managed with internal and perimeter ditches to prevent channel erosion.

The Fine PKC Facility will be located entirely within the controlled area boundary and all drainage will be managed as part of the closed-circuit site water management system. Construction and operation of the Fine PKC Facility will result in the permanent loss of the northern portion of Kennady Lake (Area 2) as a waterbody, as well as lakes A1, A2, A5 and A7 and their outlet channels. No effects on natural channel or bank stability are anticipated, because runoff from the Fine PKC Facility and upstream areas will be managed with internal and perimeter ditches to prevent channel erosion.

The effects of altered discharge regimes to the water level in Area 8 will vary depending on the Project phase. During construction, dewatering flows through Area 8 from Area 7 will be generally increased from baseline conditions, with the duration of the flood flow extended through to September (with residual flows in extending into October). However, flows will be limited so that dewatering discharge will not exceed the 1:2 year flood discharge volume. During operation, flows through Area 8 will be generally decreased from baseline conditions, due to the closed-circuiting of the watershed upstream of Dyke A. The alterations in water levels in Area 8 will correspond with the flow changes, with the largest changes for open water discharge expected to occur in September for dewatering (+0.190 m) and in July during operation (-0.158 m). Because water levels in Area 8 and corresponding discharges in its outlet (Stream K5) will be managed not to exceed 1:2 year flood flows, no adverse effects to channels or bank stability are anticipated.

8.13.1.2 Closure

At closure, the dykes on the isolated and diverted upper watersheds (B, D and E) will be removed and surface flows restored to Kennady Lake. The diversion of Lake A3 to Lake N9 will be permanent. The restored watersheds will then contribute to the natural refilling of Kennady Lake, which will be supplemented by the diversion of water from Lake N11. The Kennady Lake refill time is expected to take approximately 8 to 9 years. Water levels in Kennady Lake will rise during refilling as a function of cumulative inflow less lake evaporation. No effects on channel or bank stability are expected during refilling, and erosion will be prevented at the refilling discharge points by armouring of the outfalls in Area 3, and the use of diffusers at the discharge points. No water from the refilled Areas 3 through 7 will be released to Area 8 until the water level is at the naturally armored shoreline elevation and water quality meets specific criteria.

During the refilling of Kennady Lake, flows at the Area 8 outlet will be reduced due to the removal of 77% of the upper natural drainage area (i.e., Areas 3 through 7 and their associated upper watersheds). The mean monthly water levels in Area 8 during refilling for June to October are expected to be 0.10 m to

0.16 m lower than median baseline flow conditions. No erosion effects are expected under these flow scenarios because flow levels will be below baseline values.

At closure, the Kennady Lake watershed will have been altered as a result of the Project development. That is, the watershed area will decrease by 2.6% (32.46 km^2 to 31.62 km^2), due to the permanent diversion of the A3 watershed, with a net decrease in lake surface area, including Kennady Lake tributaries, of 14.1% (11.29 km^2 to 9.70 km^2). The reduction in lake surface area will correspond to a decrease in lake proportion of the watershed from 34.8% to 30.7%. As a consequence, the water balance will change for the Kennady Lake watershed resulting in the increase of mean annual water yield by 8.9%. The reduction in the surface area of Kennady Lake of 14.1% (8.15 km^2 to 7.19 km^2) means that flood peak discharges will increase post-closure due to less storage in the lake.

8.13.2 Water Quality

8.13.2.1 Construction and Operation

Residual effects to water quality during construction and operations include effects of the deposition of dust and metals from air emissions and acidifying air emissions to waterbodies within the Kennady Lake watershed. Several pathways associated with deposition of Project air emissions in Area 8 and smaller waterbodies in the Kennady Lake watershed were assessed:

- deposition of total suspended particulates;
- deposition of trace metals; and
- deposition of acidifying emissions.

Effects of Deposition of Dust and Metals from the Project

The effects of dust and associated metal deposition on water quality were evaluated for 19 lakes within the Kennady Lake watershed, of which 12 are fish bearing. Changes to total suspended solids and trace metals concentrations in these lakes from deposition of total suspended particulates and metals will potentially exceed average baseline concentrations by greater than 100%. However, the spatial extent of dust and metal deposition is anticipated to be restricted to localized areas within and close to the active mine area. Maximum deposition is expected to occur near haul roads along the southern, western and eastern boundary of the development area, and primarily reflect winter fugitive road dust emissions. In general, no concentration of total suspended particulates (TSP) above the NWT air quality standard is predicted beyond approximately

2 km from the development area boundary (Section 11.4, Subject of Note: Air Quality).

Based on annual cumulative loading of TSS and metals, predicted maximum concentrations of aluminum, cadmium, chromium, copper, iron, mercury, and silver are anticipated to be above water quality guidelines in two or more lakes adjacent to the Project area during construction and operations. However, the estimated maximum changes in TSS and metal concentrations in lakes within the Kennady Lake watershed are based on air quality modelling results representing peak production periods during mine operation (i.e., Years 1 and 5). As a result, the level of conservatism built into the air quality assessment means that predictions of TSS and metal concentrations are likely to be higher than can be realistically expected.

The period of elevated TSS and metal concentrations in affected lakes is expected to be relatively short. During construction and operations, the largest load of suspended sediments to surface waters during the year will occur during spring freshet, when dust deposited to snow during winter and eroded materials enter surface waters. During the freshet period, elevated TSS and metals concentrations are naturally elevated above average baseline conditions due to the peak watershed runoff through the lakes. Sediment inputs during other times of the year are anticipated to be sporadic and too small to result in measurable changes in TSS and metal concentrations in lakes, except in localized areas near stream mouths during and immediately after precipitation events.

The length of the freshet period is estimated to range from approximately two days for small lakes to a maximum of one to two weeks based on the length of the freshet for Kennady Lake. This would be followed by a period of settling, estimated as less than a month based on observations at Snap Lake (De Beers 2010), by which time TSS concentrations in lake water are expected to be similar to background concentrations. Therefore, the effects on TSS and metal concentrations are expected to be localized in the immediate vicinity of the Project and temporally restricted to the period during and after freshet.

Effects of Acidifying Emissions from the Project

Predicted net PAI values representing peak emissions during construction and operations are below the critical loads for the 19 lakes included in the evaluation of Project-related effects. The annual deposition of nitrogen during construction and operations was less than 5 kilograms per hectare per year (kg/ha/y) for all lakes. Based on these results, Project-related deposition of sulphate (SO_4) and nitrate (NO_3) in the Kennady Lake watershed is not predicted to result in lake acidification.

8.13.2.2 Closure

Water quality in Kennady Lake is projected to vary over time as the lake is refilled after closure. At the end of the Project operations, Kennady Lake will be filled as quickly as possible (approximately 8 to 9 years) by restoring the upper diverted watersheds and augmenting natural watershed inflows with additional inflow from Lake N11.

To estimate the water quality in Kennady Lake and Area 8 through the closure phase, a dynamic, mass-balance water quality model was developed in GoldSim™. For this assessment, 1:2 year (median) wet conditions were assumed, which represents a close to average climate scenario, which is appropriate for assessing long-term water quality conditions in a lake environment.

Modelling of water quality in Kennady Lake during and after refilling was evaluated in two periods of time in the closure phase, which follow on from construction and operation:

- Closure period – the Tuzo Pit will be filled and once Tuzo Pit is full, the dewatered Areas 3 to 7 will be refilled; and
- Post-closure period – when Areas 3 to 7 are filled to the same elevation as Area 8, and water quality is acceptable, dyke A will be removed and the refilling of Kennady Lake will be completed and flow will occur between Areas 3 through 7 and Area 8.

The focus of this residual effects summary is on water quality in the refilled Kennady Lake and Area 8 after the removal of dyke A (post-closure) because this is when Kennady Lake will be physically restored and recovery of the aquatic ecosystem can begin.

After refilling, Tuzo and Hearne pits represent new waterbody features within the restored Kennady Lake. The bottom of Tuzo pit will be about 295 metres (m) below the surface of Kennady Lake, and Hearne Pit will be approximately 120 m deep, creating deep depressions within the lake. During and after refilling of Tuzo pit, saline groundwater inflow will collect in the bottom of the pit forming a higher density, more saline (TDS concentration of up to 400 mg/L) layer, which is referred to as a monimolimnion layer. The monimolimnion layer will be separated from the overlying freshwater layer in what is referred to as meromictic conditions. A long-term analysis evaluated the stability of meromictic conditions for 15,000 years, and concluded that the saline bottom layer will remain stable and will not overturn. The water quality in Kennady Lake above Tuzo Pit will, therefore, will be primarily determined by the upper 20 m of fresh water, which will be subject to temperature and wind-driven summer seasonal stratification.

Hearne pit will be partially backfilled with fine PK and process water, but will not be initially filled with saline water as will occur for Tuzo pit. Therefore, meromixis is assumed not to occur in Hearne Pit, and water in this pit will be fully mixed with water in Area 6. This assumption is a conservative prediction, because if meromixis does occur in Hearne Pit, the deeper water in contact with the fine PK will be isolated and the input of the diffusive flux of metals and nutrients from the bottom of Hearne pit to the water quality in Area 6 will be unlikely.

Water quality in Kennady Lake during refilling will be influenced by the following sources:

- natural watershed runoff with a background surface water quality;
- supplemental water pumped from Lake N11 with a background water quality;
- seepage from the Fine PKC Facility, and contact water from the Coarse PK Pile and the mine rock piles, and minor contribution from site runoff;
- contact water from the exposed pit walls during refilling of the Tuzo pit basin and Hearne pit; and
- diffusion from fine PK in the bottom of Hearne Pit.

After refilling is complete and the lake is restored to pre-mine levels, water quality in Kennady Lake will be influenced by:

- natural watershed runoff with a background surface water quality; and
- seepage from the Fine PKC Facility, and contact water from the Coarse PK Pile and the mine rock piles, and minor contribution from site runoff;
- contact water from the exposed pit walls during refilling of the Tuzo Pit basin and Hearne; and
- diffusion from PK material in the bottom of Hearne Pit.

Water quality in the surface water of Tuzo Pit will be influenced by water pumped from Lake N11 and contact water from the exposed pit walls. As water levels in the pit rise and exposed pit walls are flooded, mass loading from contact water will decrease.

During refilling of the Tuzo Pit, natural runoff and contact water will collect in the WMP and low points in the dewatered lake-bed of Areas 3 through 7. Once the Tuzo Pit is filled, the refilling of Areas 3 through 7 will begin and the Tuzo Pit basin becomes part of Area 4 and the Hearne pit will be part of Area 6.

Contact water from the exposed pit walls in the Tuzo Pit basin and Hearne pit will be negligible after flooding. Seepage from the Fine PKC Facility and contact water from mine rock piles are the primary source of mass loadings that will affect water quality in Kennady Lake during and after refilling. Water quality parameters in runoff that comes into contact with the mine rock and PK material will include TDS and major ions, metals and nutrients (e.g., phosphorus, nitrate, and ammonia).

Water quality in Area 8 will remain similar to background conditions during the refill period, before the removal of dyke A, because this Area will remain isolated from Kennady Lake. Water quality in Area 8 during the post-closure phase will be driven by the water flowing from Kennady Lake after Dyke A is breached, with additional dilution from the Area 8 sub-watershed.

Concentrations of all modelled constituents are predicted to increase when Dyke A is breached. In nearly all cases, concentrations are predicted to peak within five years of Dyke A being breached, as water in Area 8 is replaced with water from the refilled Kennady Lake. Concentrations are generally predicted to decline with time. In a few cases, concentrations are predicted to increase during the post-closure period and reach a long-term steady state concentration within a few decades.

8.13.2.2.1 Total Suspended Solids

There will be no influx of TSS above background concentrations to the refilling Tuzo Pit basin and Areas 3 through 7. Natural drainage from the restored upper watersheds and supplemental water pumped from Lake N11 will not be a source of additional TSS, with concentrations consistent with background water quality.

8.13.2.2.2 Total Dissolved Solids and Major Ions

Concentrations of TDS and major ions in Areas 3 to 7 are projected to increase during the operations phase (approximately 400 milligrams per litre [mg/L]), primarily due to saline groundwater discharged from the mining pits to the WMP. During the closure phase, TDS concentrations are predicted to decrease as higher TDS water is drained from the lake to Tuzo Pit and fresh water is imported from Lake N11 (approximately 150 mg/L). The main constituents of TDS during the two periods include calcium and chloride. This major ion dominance is consistent with the composition in background water quality.

In the post-closure period, concentrations are predicted to continue to decline as Kennady Lake receives fresh water inflows (i.e., natural drainage) from the basin and Dyke A is breached. In one to two decades of post-closure, concentrations are predicted to approach steady state at slightly less than 100 mg/L TDS. Calcium, chloride, magnesium and sodium are predicted to mirror the trends displayed by TDS.

The long-term results presented for the post-closure period reflect a reasonable degree of conservatism. Concentrations of TDS and major ions are predicted to remain elevated above background levels because loading of these constituents from the Fine PKC Facility, contact with mine rock and diffusion from PK material in the bottom of Hearne Pit are assumed to continue in the long-term. The loading of TDS from this facility to Kennady Lake is expected to reduce with the establishment of permafrost through the fine PK material.

Concentrations of TDS and major ions in Area 8 are predicted to follow the general trends described for Kennady Lake. All major ions follow this trend, except potassium and sulphate, which are predicted to increase following closure.

There are no CCME guidelines for TDS or any of the major ions. To put the predicted concentrations into context, TDS and all major ions are predicted to remain above background conditions but below levels that would affect aquatic health.

8.13.2.2.3 Nutrients

During the refilling of Tuzo Pit, ammonia and nitrate concentrations are projected to generally increase, primarily due to inputs from blasting residue. These are expected to decrease during the closure phase as higher concentration water is transferred to Tuzo Pit and fresh water is imported from Lake N11. By the time Dyke A is removed, modelled nitrogen and ammonia concentrations are expected to be at, or below, water quality guidelines and decline thereafter to near background levels. In Area 8, all forms of nitrogen are expected to peak in concentration in Area 8 within five years of breaching Dyke A, then return to near-background concentrations.

Concentrations of phosphorus are predicted to increase in Areas 3 to 7 during the operations phase due to loading from process water and runoff from mine rock and fine PK. Concentrations are predicted to decrease during the closure phase. Post-closure modelling results suggest that there is a potential for phosphorus levels to increase, relative to pre-project conditions, in Kennady Lake as a result of runoff from the reclaimed mine site. The runoff waters mobilize phosphorus from the mine rock, coarse PK and fine PK as they travel through the external structures, with the fine PK being the largest source of phosphorus. However, the modelling analysis was completed assuming free and complete contact between the runoff waters and the materials contained in the mine rock piles, the Coarse PK Pile and the Fine PKC Facility.

De Beers is currently evaluating a variety of environmental design features and mitigation measures to limit contact between site runoff waters and the fine PK located within the Fine PKC Facility and other potential sources. These environmental design features and mitigation measures include, for example:

- Promotion of permafrost development in the Fine PKC Facility.
- Use of low permeability cover material to limit infiltration into key areas, such s the Fine PKC Facility.

The effectiveness of these environmental design features and mitigation is uncertain and requires further analysis. Accordingly, the amount of phosphorus that may be released into the environment is uncertain at this time. As a result, potential effects related to phosphorus have not been presented and will not be available until such time as additional analysis is completed. This analysis will be provided to the Panel in 2011.

8.13.2.2.4 Trace Metals

Of the 23 trace metals that were modelled for this assessment, chromium, cobalt, iron, lead, manganese, mercury, selenium, silver, thallium, uranium and zinc are predicted to increase in concentration during the operations phase, then steadily decline in concentration as the lake is flushed during the post-closure period. With the exception of thallium, the primary loading source of these metals to Kennady Lake is groundwater from the active mine pits, hence the decline once pit dewatering is finished. Thallium has two primary loading sources, namely, groundwater and mine rock runoff. Because the concentrations of these metals will be mainly groundwater-driven, the dissolved fraction of these metals is predicted to comprise the majority of the total concentrations. Chromium and iron are projected to exceed water quality guidelines in the post-closure phase

Aluminum, antimony, arsenic, cadmium, copper, nickel and vanadium will be influenced by a combination of sources throughout the operations phase. These metals are predicted to increase mainly due to inputs from groundwater and mine rock runoff, with secondary loading sources through runoff infiltration and contact with fine PK and process water. These metals are predicted to increase in concentration relatively steadily throughout the operations phase, rise or fall during the closure period, then remain fairly constant throughout the post-closure period. The lack of reduction in post-closure concentrations of these metals is due to the geochemical loading through runoff contact that will occur from the remaining mine rock and fine PK in and near Kennady Lake. Because the primary loading sources of these metals is groundwater and geochemical flux, the majority of these metals will be in the dissolved form. Cadmium and copper are projected to exceed water quality guidelines in the post-closure period.

Barium, beryllium, boron, molybdenum and strontium are predicted to increase in the post-closure period. Concentrations of these metals will mainly be driven by loadings through runoff infiltration and contact with mine rock, coarse PK and fine PK. Because these storage facilities will be present in the post-closure period, concentrations of these metals are predicted to increase after closure, reach steady state conditions in Kennady Lake within about 40 years. Because geochemical sources are the primary contributors of these metals, the majority of total concentrations will be in the dissolved form. None of these five metals are projected to exceed water quality guidelines in the post-closure phase.

Concentrations of trace metals in Area 8 are predicted to follow the general trends described above for Kennady Lake. After the initial period of approximately five years to approach Kennady Lake concentrations, trace metal concentrations are then predicted to decrease, remain relatively constant or decrease. Of the 23 modelled trace metals, cadmium, chromium and copper are projected to exceed water quality guidelines in the post-closure period.

Comparison to water quality guidelines is provided for reference only. Effects of trace metal concentrations on human health have been evaluated and are discussed in Section 8.12. Effects of trace metal concentrations on the health of aquatic life are summarized in the following residual effects summary for Aquatic Health.

8.13.3 Aquatic Health

Potential effects to aquatic health could occur as a result of changes to water quality and/or the deposition of dust and metals. Aerial deposition of sulphate and nitrate could also lead to changes in aquatic health through acidification of waterbodies. However, Project-related deposition of sulphate and nitrate is not predicted to result in acidification in the Kennady Lake watershed.

During construction and operation, predicted maximum concentrations of suspended solids and some metals may increase above water quality guidelines because of dust and metal deposition in some lakes, some of which are fish-bearing lakes. However, the predicted concentrations were derived using very conservative assumptions, and hence are likely conservative estimates of the maximum potential concentrations. Most of the deposition will impact the affected lakes during the short period of freshet, when dust deposited to snow enters surface waters. The length of the freshet period is estimated to be relatively short; therefore, the period in which aquatic life will be exposed to the elevated suspended solids and metals concentrations will be short. Given the conservatism in the predicted concentrations, and the length of the exposure to elevated concentrations, the potential for adverse effects from dust and metals deposition is considered to be low. Follow-up monitoring will be undertaken to confirm this evaluation.

At the end of operations, the Project is no longer a notable source of dust and metal deposition. Therefore, the incremental effect of the Project on metals in the affected lakes is anticipated to cease with a consequential return to existing (i.e., post-Project) conditions.

As a result of Project activities, changes to water quality in Kennady Lake and Area 8 during closure and post-closure are expected, that is, after refilling is complete in Kennady Lake and after breaching of Dyke A. The potential effect of these changes on aquatic health was evaluated by considering both direct waterborne exposure and accumulation within fish tissues.

In regards to direct waterborne exposure, predicted maximum concentrations for most substances of potential concern (SOPCs) were lower than the corresponding chronic effects benchmark (CEB), with the exception of total copper, iron, and strontium.

Despite the predicted exceedances of the CEB, the potential for copper to cause adverse effects to aquatic life in Kennady Lake and Area 8 is considered to be low. The CEB for copper is based on the CCME guideline, which is intended to be conservative and protective of the most sensitive species. Predicted copper concentrations are only slightly greater than the CEB, indicating the possibility (but not necessarily the likelihood) of effects to the most sensitive species. However, the CCME guideline does not consider the potential for other water quality characteristics (e.g., dissolved organic carbon) to reduce bioavailability and ameliorate copper toxicity. Furthermore, the CCME guideline is based on toxicity tests with native and sensitive organisms, whereas organisms inhabiting Kennady Lake are unlikely to be highly sensitive to copper, given that baseline sediment copper concentrations exceed the CCME interim sediment quality guideline. Given the small magnitude by which predicted maximum concentrations exceed the CEB, and given the potential for ameliorating factors discussed above, the potential for adverse effects from copper is considered to be low. Follow-up monitoring will be undertaken to confirm this evaluation.

The potential for iron to cause adverse effects to aquatic life in Kennady Lake is considered to be low. Maximum total and dissolved iron concentrations in Kennady Lake after refilling and Dyke A is removed are predicted to be slightly above the corresponding CEB. The CEB for iron is based on the CCME guideline, which is intended to be conservative and protective of the most sensitive species. Iron concentrations similar to the CEB have been reported by some authors to elicit sublethal effects on cladocerans (Dave 1984). However, other authors have reported effects thresholds for the same species more than an order of magnitude higher than the CEB (Biesinger and Christensen 1972). Lethal effects on cladocerans and effects on fish and other taxa have only been reported at much higher iron concentrations, greater than the CEB and greater than all predicted iron concentrations in Kennady Lake. Thus, the predicted iron concentrations are not expected to result in adverse effects to aquatic life. Follow-up monitoring will be undertaken to confirm this evaluation.

Strontium is conservatively projected to be higher than the CEB in Kennady Lake and Area 8 during closure and post-closure conditions. However, the CEB is highly conservative, and the actual likelihood of adverse effects to aquatic life is therefore highly uncertain. The CEB was based on a single study of rainbow trout embryos (Birge et al. 1979) that reported effects at strontium concentrations several orders of magnitude lower than any other study, including studies with rainbow trout and other fish species. Given the high level of uncertainty in the toxicity reported by Birge et al. (1979), and given that the maximum predicted strontium concentrations in Kennady Lake are orders of magnitude lower than all other effects concentrations in the toxicity dataset, the potential for adverse effects from strontium is considered likely to be low. Follow-up monitoring will be undertaken to confirm this evaluation.

Predicted fish tissue concentrations are below toxicological benchmarks for all substances considered in the assessment except silver. However, fish tissue silver concentrations are predicted to increase only marginally above baseline conditions as a result of the Project. Also, the selected silver tissue benchmark is based on a no-effect concentration, and thus is a highly conservative basis for assessing the potential for predicted silver concentrations to cause effects to fish. Given the modest predicted increase, and that both baseline and predicted tissue concentrations only marginally exceed the available no-effect concentration, the potential for predicted silver concentrations to cause effects to fish is concluded to be low.

Based on the above results, changes to concentrations of all substances considered in this assessment are predicted to result in negligible effects to aquatic health in Kennady Lake.

8.13.4 Fish and Fish Habitat

Effects to fish and fish habitat are predicted to occur in Kennady Lake and its watershed during mine construction and operations, and closure (including post-closure), as a result of physical changes to habitat, and changes to hydrology and water quality. Flow changes in the Area 8 outlet channel (Stream K5) affecting fish migration into and out of Area 8 are assessed in Section 9.10.

8.13.4.1 Construction and Operations

Changes to Fish Habitat from Project Footprint

Changes to fish habitat will occur in Kennady Lake and the Kennady Lake watershed due to the development of the Project. The affected habitat areas include portions of Kennady Lake and adjacent lakes within the Kennady Lake watershed that will be permanently lost, portions that will be physically altered after dewatering and later submerged in the refilled Kennady Lake, and portions that will be dewatered (or partially dewatered) but not otherwise physically altered before being submerged in the refilled Kennady Lake. The affected habitat areas were quantified in the Conceptual Compensation Plan (CCP) (Section 3, Appendix 3.II).

The permanently lost areas are those affected by the following:

- The Fine PKC Facility (Areas 1 and 2, Lake A1, Lake A2, Lake A5, Lake A6, Lake A7);
- The Coarse PK Pile (Area 4 and Lake Kb4);
- West Mine Rock Pile (Area 5 and Lake Ka1);
- South Mine Rock Pile (Area 6); and
- Dykes C, D, H, I and L.

The Project will result in the permanent loss of 194.56 ha of lake area of 0.51 ha of watercourse area in tributaries to Kennady Lake.

Fish habitats that will be physically altered during operations and then submerged in the refilled Kennady Lake include the following:

- Part of Kennady Lake Area 3 (affected by Dyke B);
- Part of Kennady Lake Area 4 (affected by Tuzo Pit, Dyke B, Dyke J, and CP6 Berm);
- Part of Kennady Lake Area 6 (affected by Hearne Pit, 5034 Pit, Dyke K, Dyke N, Road between Hearne Pit and Dyke K, CP3 Berm, CP4 Berm, and CP5 Berm); and
- Part of Kennady Lake Area 7 (affected by Dyke A and Dyke K).

The Project will result in 83.32 ha of lake area being physically altered and re-submerged at closure.

The areas that will be dewatered (or partially dewatered) but not otherwise altered before being re-submerged include the following:

- Portions of Kennady Lake Areas 3 through 7 (those parts that are not either permanently lost or physically altered);
- Lake D1; and
- Streams D1, D2, and E1.

The Project will result in approximately 435.90 ha of lake area and 0.23 ha of watercourse area in tributaries to Kennady Lake being dewatered and re-submerged at closure but that will remain otherwise unaltered.

The CCP (Section 3, Appendix 3.II) describes the various options considered for providing compensation, and presents a proposed fish habitat conceptual compensation plan to achieve no net loss of fish habitat according to DFO's Fish Habitat Management Policy (DFO 1986; 1998; 2006).

Effects of Dewatering on Fish and Fish Habitat

Effects of dewatering the main basins of Kennady Lake during mine operations included the direct effects of dewatering activities on the fish population of Kennady Lake, the temporary effect of habitat loss, and the effects of the dewatering discharge on flows, water levels, and channel/bank stability in Area 8.

To minimize the waste of fish caused by dewatering activities, fish salvage will be conducted to remove fish from Areas 2 to 7 before and during dewatering. A combination of gear types would be used to maximize capture efficiency. Dewatering will result in the temporary loss of fish habitat within Areas 2 to 7 of Kennady Lake. However, it is expected that a self-sustaining fish population will be present in Kennady Lake post-closure (Section 8.13.5). Estimated water levels in Area 8 will be slightly augmented relative to baseline conditions during Kennady Lake dewatering; however, this would not have any effect on fish habitat or shoreline stability, as it would be within the natural variability of the basin.

Effects of Diversions on Fish and Fish Habitat

To reduce the volume of runoff entering the controlled areas of Kennady Lake, the A, B, D, and E watersheds will be diverted to the adjacent N watershed. Habitat downstream of the dykes will be dewatered and lost to fish residing in upstream lakes. The loss of fish habitat resulting from the placement of the dykes and the dewatering of downstream stream segments and lakes is included in the CCP (Section 3, Appendix 3.II). Raising water levels in lakes A3, D2, D3, and E1 will result in increased lake habitat area. The raised water levels will likely create a benefit to fish residing in these lakes during mine construction and operations through additional space and increased amount of overwintering habitat. Populations of northern pike and ninespine stickleback are also likely to benefit from the increased spawning and rearing habitat in areas with flooded vegetation. Changes in water levels and lake areas are also expected to increase habitat area available for plankton and benthic invertebrates, which will result in increased total biomass of plankton and benthic invertebrates, after a period of adjustment to the new water levels.

Raising lake levels in Lakes A3, D2, D3 and E1 will create new shorelines at higher elevations than the existing shorelines, which can result in shoreline erosion and an increased sediment load into the lakes. However, increases in total suspended solids (TSS) concentrations in the raised lakes are expected to be low due to the composition of substrate materials; as a result, negligible effects on fish and fish habitat would be expected.

Dykes in streams A3, B1, D2, and E1 will interrupt the movements of fish between Kennady Lake and waterbodies upstream of the dykes. This effect will be permanent for the A watershed, but will be limited to the period of mine operations for the B, D, and E watersheds. Loss of access to the lowermost streams in the A, B, D, and E watersheds is likely to affect Arctic grayling which currently use these stream habitats for spawning and rearing. Persistence of this species will depend on whether Arctic grayling use habitat constructed in the diversion channels and any immigration of Arctic grayling from the N watershed. Although the dykes will isolate the northern pike populations within the B, D, and E watersheds for the duration of mine operations (and permanently in Lake A3), it is likely that the isolated populations will be self-sustaining. Life history requirements for small populations of burbot, slimy sculpin and ninespine stickleback can be fulfilled in the diverted watersheds, without the need to access Kennady Lake. Prevention of downstream out-migration of juvenile and young-of-the-year fish to Kennady Lake is expected to have a minor effect on fish populations in lakes upstream of the dykes.

Populations of small-bodied fish, such as ninespine stickleback and slimy sculpin, are likely to persist in diverted watersheds during mine operations because suitable spawning, rearing, and foraging habitat for each species will be available and there is no critical habitat in Kennady Lake that any of these species require to complete their life histories. Aquatic vegetation exists in lakes A3, D2, D3, D7, and E1 and these lakes will continue to provide suitable habitat for northern pike and ninespine stickleback throughout mine operations. Although lake trout have been captured in the lakes of the diversion watersheds, it is likely that they are using them seasonally for feeding. The lakes in the B, D, and E watersheds likely do not currently support self-sustaining lake trout populations; therefore, it is not expected that lake trout will persist in these lakes during operations. Lakes A3, D3 and D7 will likely continue to provide the same amount of habitat for burbot that currently exists. The persistence of Arctic grayling in the diverted watersheds will be dependent on the suitability and use of spawning and rearing habitat constructed in the diversion channels and the use of this new habitat by Arctic grayling, as well as by potential immigration of Arctic grayling from the neighboring lakes in the N watershed. The diversion channels will be designed to provide spring spawning and rearing habitat for Arctic grayling and allow the seasonal passage of fish between lakes that approximates natural conditions.

Effects of Isolation on Area 8 on Fish and Fish Habitat

Isolation of Area 8 during operations and closure from the remainder of Kennady Lake was predicted to result in a slight increase in nutrient concentrations. Although the change is not expected to alter the trophic status of Area 8 from oligotrophic, it is expected to result in a slight increase in productivity of plankton and benthic invertebrate communities, without notable changes in community composition or dissolved oxygen concentration.

The residual fish community in Area 8 of Kennady Lake is anticipated to consist of small-bodied fish species (i.e., lake chub, ninespine stickleback, and slimy sculpin), as well as Arctic grayling, northern pike and burbot. As a result of the existing overwintering limitations in Area 8 and the elimination of alternative overwintering refugia in Areas 2 through 7 during operations, lake trout and round whitefish may not continue to persist in Area 8 throughout the operational period, as they are less tolerant of low dissolved oxygen concentrations.

Effects of Dust Deposition on Fish and Fish Habitat

Windborne dust from Project facilities and exposed lake bed sediments, and air emissions from Project facilities, may result in increased deposition of dust in the surrounding area. Effects of TSS from dust and particulate deposition on fish and fish habitat are expected to be localized in the immediate vicinity of the Project and temporally restricted to the period during and after freshet. The potential for adverse effects to aquatic health from dust and metals deposition was considered in the aquatic health assessment to be low (Section 8.13.3) therefore, no effects to fish populations or communities are expected to occur from changes in aquatic health.

8.13.4.2 Closure and Post-Closure

Effects of Development of Fish Habitat Compensation Works to Fish and Fish Habitat

To compensate for habitat permanently lost or altered due to proposed mine development, and eliminate potential adverse effects due to changes in habitat area, the Project includes a habitat compensation plan designed to create new fish habitat (CCP, Section 3, Appendix 3.II). As per the CCP, the preferred options for the proposed compensation plan include:

- raising the water level of some lakes to the west of Kennady Lake (in the D, E, and N watersheds);
- additional raising of the water level in the flooded area created by the above option after mine closure;
- raising Lake A3 to a higher elevation than planned for the development of the Project; and
- widening the top bench of the Tuzo and 5034 mine pits to create shelf areas where they extend onto land.

Also included in the proposed compensation plan are:

- constructing finger reefs in Areas 6 and 7;
- developing habitat enhancement structures in Area 8; and
- developing a Dyke B habitat structure within Kennady Lake after closure.

The amount of compensation habitat, in terms of surface area, provided by the proposed compensation plan is 180.8 ha developed during operations and 381.3 ha developed after closure. This corresponds to a compensation ratio (gains:losses calculated based on total area of permanently lost habitat and physically altered and re-submerged habitat) of 0.65 for operations and 1.37 for closure.

Effects of Restoring the B, D, and E Watersheds to Fish and Fish Habitat

At closure, the natural drainage of the B, D, and E watersheds to Kennady Lake will be restored. Where possible, the watersheds will be reconnected to Kennady Lake along previous connecting streams. Water levels in the raised D2 and D3, and E1 lakes will return to baseline levels. The fish and lower trophic communities within the lakes will adjust to the new lake levels and the restored lake shorelines are expected to remain stable. Habitat conditions for spawning, rearing and overwintering will be similar to pre-Project conditions. As a result, the change would not be expected to have a substantive effect on fish populations within the D and E watersheds. Until the water quality in Kennady Lake is deemed suitable for fish, measures will be taken to limit the initial migration of large-bodied fish from the upper B, D, and E watersheds into Kennady Lake.

Effects of Continued Isolation of Area 8 During Refilling to Fish and Fish Habitat

During refilling of Kennady Lake, Area 8 will remain effectively isolated during this period; effects on Area 8 will be similar to those described above.

Effects to Fish and Fish Habitat in Kennady Lake during Post-Closure

After reconnection of the refilled Kennady Lake to Area 8, concentrations of nutrients may be higher than during pre-development conditions. The assessment of potential effects related to nutrients will be submitted following the completion of additional analysis, which is expected to be completed in 2011.

The Project is expected to have low or negligible effects on aquatic health in Kennady Lake and Area 8 from changes in chemical constituents of water quality (Section 8.13.3); therefore, no effects to fish populations or communities are expected to occur from changes in aquatic health.

8.13.5 Recovery of Kennady Lake

An aquatic ecosystem will develop within Kennady Lake after refilling and reconnection of its basins. There will be some permanent losses of habitat in Kennady Lake due to mine rock piles, PK storage and mine pits; however, compensation habitats will be constructed within the Kennady Lake watershed to offset losses. The long-term hydrology of Kennady Lake is expected to return to a state similar to current conditions and water quality in the refilled lake is expected to return to conditions suitable to support aquatic life over time. The physical and chemical environment in Kennady Lake, therefore, will be in a state that will allow re-establishment of an aquatic ecosystem, although predicted nutrient concentrations indicate that the re-established communities may differ from pre-development communities.

The expected time frame for recovery of the phytoplankton community is estimated to be approximately five years after refilling is complete, taking into consideration that the phytoplankton community will begin to develop during the refilling period (approximately 8 to 9 years). The potential increase in nutrient levels in the refilled Kennady Lake may also facilitate community development and could result in a more productive phytoplankton community in the refilled lake compared to the pre-development community.

Zooplankton community development is predicted to follow recovery of the phytoplankton community. Colonization sources will be the same as those for phytoplankton and include the upstream watershed (i.e., the B, D, and E watersheds), Lake N11, and the WMP. The zooplankton community of the refilled lake may also be more productive than the existing community. The expected time frame for the development of the zooplankton community is longer than that of phytoplankton (i.e., likely within five to 10 years of Kennady Lake being completely refilled).

Recovery of the benthic invertebrate community is expected to be slower than that of the plankton communities. The estimated time to recovery for the benthic community in Kennady Lake is about 10 years after refilling is complete. At the end of the recovery period, the benthic invertebrate community in Kennady Lake will be different from the community that currently exists in Kennady Lake and in surrounding lakes. The community may be of higher abundance and biomass, reflecting the potentially more productive nature of the lake, and will likely be dominated by midges and aquatic worms.

The re-establishment of the fish community within Kennady Lake, and the speed at which it will occur, will depend on the ability of fish to re-colonize the refilled lake, the habitat conditions within the lake, and how succession takes place within the refilled system after it has been fully connected to the surrounding environment. It is expected that a fish community will become re-established in Kennady Lake.

Fish populations, including Arctic grayling, northern pike, burbot, lake chub, slimy sculpin, and ninespine stickleback, are expected to persist in the B, D, and E watersheds during Project operations. These watersheds are likely to be the primary source of initial migrants into Areas 3 to 7 of Kennady Lake. During refilling, exclusion measures will be used to limit the initial migration of large-bodied fish, such as northern pike, burbot, lake trout, and Arctic grayling, from entering the lake. It is anticipated that during the initial period of refilling, some mortality of the incoming small-bodied fish is likely to occur, because of insufficient water depths and possibly elevated levels of turbidity. As conditions improve, and water depths increase, the early migrants will become permanently established, feeding on the plankton and benthic invertebrate communities that are themselves becoming established in the refilled lake. Nutrient levels in the refilled Kennady Lake may be above the those found under existing conditions. The potential increase in primary productivity from nutrient availability may also result in increased growth and production of these small-bodied forage fish species.

Following the removal of dyke A, migrant fish will also enter Areas 3 through 7 of Kennady Lake from Area 8, which is expected to contain residual populations of lake chub, slimy sculpin, ninespine stickleback, Arctic grayling, northern pike, and burbot. The migration of fish from Area 8 into the rest of Kennady Lake is expected to be rapid, due to proximity and potentially from increased productivity resulting from increased nutrient levels in Kennady Lake and Area 8.

The final fish community of Kennady Lake will likely once again be characterized by low species richness (less than 10 species) containing a small-bodied forage fish community and large-bodied species. Total lake standing stock and annual production may be increased over what currently exists in the lake. However, the composition of the fish community is highly dependent on the nutrient and limnological characteristics that develop in the refilled lake. As the amount of phosphorus potentially released is currently uncertain, the full assessment of the potential effects on the Lake Kennady fish community has not been presented.

The estimated time to full recovery of fish populations is expected to fall between 50 to 60 years following the complete refilling of Kennady Lake, or 60 to 76 years from the end of Project operations.

8.14 RESIDUAL IMPACT CLASSIFICATION

The Gahcho Kué Project (Project) activities will result in changes to the hydrology, water quality, and aquatic communities of the Kennady Lake watershed. As summarized in Section 8.13, the changes are projected to occur during construction and operations, and closure, with changes to water quality and the persistence of fish in Kennady Lake that will continue after closure for the long-term. To assess the environmental significance of the projected changes, a residual impact classification system was developed and applied to the VCs considered in the key line of inquiry. For this key line of inquiry, the VCs consist of water quality, and specific fish species, i.e., Arctic grayling, lake trout, and northern pike, and wildlife and human health (refer to Section 8.5).

In the EIS, the term “effect”, used in the effects analyses and residual effects summary, is regarded as an “impact” in the residual impact classification. Therefore, in the residual impact classification for this section, all residual effects are discussed and classified in terms of impacts to water quality and fish in Kennady Lake.

The residual impact classification focused on VCs, because they represent the components of the aquatic ecosystems in the Kennady Lake watershed that are of greatest interest or concern (as outlined in the Terms of Reference). Projected impacts to VCs also incorporate, or account for, changes to other important key components, such as groundwater quality, groundwater flow, hydrology, fish habitat, and aquatic life occupying lower trophic levels in the ecosystem (e.g., aquatic plants, plankton, zooplankton, benthic invertebrates, forage fish species). Notable changes in water flows, for example, will contribute to changes in water quality, and the quantity and quality of habitat available for Arctic grayling, lake trout, or northern pike. The classification of impacts to water quality and the three valued fish species, therefore, incorporates the classification of impacts to hydrology and key components, according to their influence on the VCs.

The classification was carried out on residual impacts (i.e., impacts with environmental design features and mitigation considered). The environmental design features and mitigation were incorporated in the engineering design or the management plans, and were incorporated in the Project as it evolved (i.e., as the engineers received input from various scientists and traditional knowledge holders, the design evolved).

8.14.1 Methods

The pathways to effects to VCs and assessment endpoints were analyzed in Section 8.6. The pathways that were identified as primary pathways (i.e., likely to result in a measurable environmental change that could contribute to residual effects on a VC relative to baseline or guideline values) were considered and aggregated under their respective biophysical environment (i.e., hydrology, water quality, aquatic health, or fish) in effects statements (e.g., changes to water quality as a result of Project activities during construction and operations). These effects statements set the direction for the residual effects analysis (Sections 8.7 to 8.12), which considered the key Project activities (i.e., diversion of the upper Kennady Lake watersheds, dewatering of Kennady Lake, close circuiting Areas 2 through 7, refilling Kennady Lake) during the phases of the Project (i.e., construction and operations, or closure), to determine the extent of the change to the biophysical environment, and ultimately to the VCs.

The objective of each effects analysis was to determine how Project activities would affect an individual measurement endpoint or a given set of measurement endpoints for a given biophysical environment, e.g., the amount of habitat available to lake trout during operations, or metals concentrations in Area 8 after reconnection with Areas 3 and 7 of Kennady Lake in closure. The measurement endpoints are, in turn, connected to the broader-scale assessment endpoints, which represent the ultimate properties of the system that are of interest or concern.

The residual impact classification focuses on the assessment endpoints because these are statements of what is most important to future generations. The four assessment endpoints relevant to the Key Line of Inquiry: Water Quality and Fish in Kennady Lake, as outlined in Section 8.5, include the following:

- suitability of water quality to support a viable aquatic ecosystem;
- persistence and abundance of desired population(s) of Arctic grayling;
- persistence and abundance of desired population(s) of lake trout; and
- persistence and abundance of desired population(s) of northern pike.

Residual effects to the fifth assessment endpoint, “suitability of water and fish for human and wildlife consumption”, through changes in water quality and fish tissue quality to human health and wildlife health are summarized along with the key findings of the terrestrial wildlife and habitat assessments, in Section 8.12.

The effects analyses (Sections 8.7 to 8.11) and residual effects summary (Section 8.13) presented the incremental changes from the Project on water quality and fish, including the key components of these VCs. Incremental effects represent the Project-specific changes relative to baseline conditions (i.e., 1996 and 2010), through construction and operation of the Project (and into the future, i.e., closure and beyond closure). For this key line of inquiry, the primary focus of Project-specific effects during each Project phase is to the Kennady Lake watershed, which is a requirement in the Terms of Reference. Therefore, the spatial boundary of the assessment is limited to the local study area for the Project. This approach was also adopted to achieve consistency in the scales used to evaluate geographic extent across the key lines of inquiry that focus on aquatic ecosystems.

Residual impacts to each assessment endpoint were classified based on the results of the effects analyses and their linkage to these endpoints. For example, the results of the water quality and aquatic health assessments completed in Sections 8.8 and 8.9 were used to classify residual impacts to the first assessment endpoint (i.e., suitability of water quality to support a viable aquatic ecosystem). Similarly, the results of the analysis of effects to fish and fish habitat, and the projection of the recovery of Kennady Lake described in Sections 8.10 and 8.11, respectively, were used to classify residual impacts to the abundance and persistence of desired population(s) of key fish species.

The residual impact classification describes the residual impacts of the Project on the water quality and fish in Kennady Lake using a scale of common words (rather than numbers and units). The use of common words or criteria is a requirement in the Terms of Reference for the Project. The following criteria are used to describe impacts of the Project on the VCs:

- direction;
- magnitude;
- geographic extent;
- duration;
- reversibility;
- frequency;
- likelihood; and
- ecological context.

Generic definitions for each of the residual impact criteria are provided in Section 6.7.2.

The predicted scales for the impact criteria are also considered in the impact classification. The scales used to assign values (e.g., high, moderate, or low) to each of the classification criteria are outlined in Tables 8.14-1 and 8.14-2. The rating system for magnitude is presented separately in Table 8.14-2, because the scales used to define magnitude are specific to each assessment endpoint, whereas the scales defined for the remaining classification criteria are common across all five assessment endpoints. The results from this impact classification are then used to determine environmental significance of impacts from the Project on water quality and fish (Section 8.14.2).

To provide transparency in the EIS, the definitions for these scales were ecologically or logically based on aquatic environments. Although professional judgment is inevitable in some cases, a strong effort was made to classify impacts using scientific principles and supporting evidence. The scale for the residual impact criteria for classifying effects from the Project are specifically defined for water quality and fish, and definitions for each criterion are provided in Table 8.14-1.

As existing and planned projects in the NWT are located outside of the Kennady Lake watershed, there is no opportunity for the releases of those projects to interact with those of the Project within the Kennady Lake watershed. Consequently, there is no potential for cumulative effects to fish or water quality in Kennady Lake or small lakes and streams in the Kennady Lake watershed.

Table 8.14-1 Definitions of Scales for Seven of the Eight Criteria Used in the Residual Impact Classification

Direction	Geographic Extent	Duration	Frequency	Reversibility	Likelihood	Ecological Context
Neutral: no measurable change to a VC from existing conditions **Negative:** the Project will result in an adverse effect to a VC **Positive:** the Project will result in a beneficial effect to a VC	**Local:** projected impact is confined to watersheds upstream of the outlet of Lake 410; small scale direct and indirect impacts from the Project (e.g., footprint, dust deposition, dewatering) **Regional:** projected impact extends beyond Lake 410 to the inlet to Aylmer Lake; the predicted maximum spatial extent of combined direct and indirect impacts from the Project that exceed local scale effects **Beyond Regional:** projected impact extends into Aylmer Lake and beyond; cumulative local and regional impacts from the Project and other developments extend beyond the regional scale	**Short-term:** projected impact is reversible by the end of construction **Medium-term:** projected impact is reversible upon completion of refilling Kennady Lake (i.e., end of closure) **Long-term:** projected impact is reversible some time after the refilling of Kennady Lake is complete (i.e., beyond closure) or not reversible	**Isolated:** projected impact occurs once, with an associated short-term duration (i.e., is confined to a specific discrete period) **Periodic:** projected impact occurs intermittently, but repeatedly over the assessment period **Continuous:** projected impact occurs continually over the assessment period	**Reversible:** projected impact will not result in a permanent change from existing conditions or conditions compared to 'similar'[(a)] environments not influenced by the Project **Not reversible:** projected impact is not reversible (i.e., duration of impact is unknown or permanent)	**Unlikely:** projected impact is likely to occur less than one in 100 years **Possible:** projected impact will have at least one chance of occurring in the next 100 years **Likely:** projected impact will have at least one chance of occurring in the next 10 years **Highly Likely:** Projected impact is very probable (100% chance) within a year	**High:** projected impact relates to a valued component of the aquatic ecosystem

(a) "similar" implies a waterbody that is similar in size, shape, location, and general characteristics to that affected by the Project (e.g., Kennady Lake).

Table 8.14-2 Definitions Used to Rate the Magnitude of Projected Residual Impacts

Scale	Assessment Endpoint				
	Suitability of Water Quality to Support a Viable Aquatic Ecosystem	Abundance and Persistence of Desired Population(s) of Key Fish Species			Suitability of Water and Fish for Human or Wildlife Consumption
		Abundance of Lake Trout	Abundance of Arctic Grayling	Abundance of Northern Pike	
Negligible	results of the aquatic health and productivity assessments indicate that no measurable change to the overall health of the aquatic ecosystem will occur	no measurable change to the abundance of lake trout, relative to existing conditions	no measurable change to the abundance of Arctic grayling, relative to existing conditions	no measurable change to the abundance of northern pike, relative to existing conditions	results of the human and/or wildlife health assessments indicate that the consumption of water and/or fish from the affected waterbody(ies) will result in no measurable effects to the health of human users and/or wildlife
Low	results of the aquatic health and productivity assessments indicate that a measurable change to the aquatic community may occur, but no notable changes in community structure or overall health of the system are expected	no measurable change in the abundance of lake trout, but population statistics (such as age-class structure) may differ from existing conditions	no measurable change in the abundance of Arctic grayling, but population statistics (such as age-class structure) may differ from existing conditions	no measurable change in the abundance of northern pike, but population statistics (such as age-class structure) may differ from existing conditions	-[a]
Moderate	results of the aquatic health and productivity assessments indicate that a measurable change to the aquatic community, including a notable shift in community structure may occur, but no effect to the overall health of the system is expected	projected decrease in abundance of lake trout; however, the species is expected to persist	projected decrease in abundance of Arctic grayling; however, the species is expected to persist	projected decrease in abundance of northern pike; however, the species is expected to persist	-[a]
High	results of the aquatic health and productivity assessments conclude that the overall health of the aquatic ecosystem could be affected	projected decrease in the abundance of lake trout is sufficient to result in a complete loss of the species in question (i.e., will not persist)	projected decrease in the abundance of Arctic grayling is sufficient to result in a complete loss of the species in question (i.e., will not persist)	projected decrease in the abundance of northern pike is sufficient to result in a complete loss of the species in question (i.e., will not persist)	results of the human and/or wildlife health assessments indicate that the consumption of water and/or fish from the affected waterbody(ies) will negatively affect the health of human users and/or wildlife

[a] - = not applicable.

8.14.2 Classification Time Periods

Due to the overall nature of how the Project will affect the Kennady Lake watershed, residual impacts were classified for two specific time periods. The first period extended from the initiation of the Project to 100 years later. This time frame incorporated the construction and operations, and closure phases of the Project, and the expected recovery period in which the aquatic ecosystem would be in a stable and productive state (i.e., taking into account the duration of the Project during construction, operations, and closure, and recovery during post-closure). The recovery period was conservatively based on the amount of time that northern pike will re-establish to a stable, self-sustaining population in Kennady Lake following the complete refilling of Kennady Lake. Northern pike are expected to require a long time to re-establish (i.e., 50 to 60 years). As well, once suitable habitat conditions develop for lake trout in the refilled lake, it is expected that this species would also require a long time to re-establish a stable, self-sustaining population (i.e., approximately 60 to 75 years following the complete refilling of Kennady Lake).

The second period focused on future conditions after 100 years from Project initiation. Rather than classifying one snapshot in time, the classification in this period focussed on the ability of the affected ecosystems to recover to a steady state.

8.14.3 Results

8.14.3.1 Residual Impacts to Suitability of Water Quality to Support Aquatic Life

In Section 8.8 and 8.9, the effects of the Project on water quality and aquatic health in the main basins of Kennady Lake (i.e., Areas 3 through 7, Area 2 is incorporated into the Fine PKC Facility during operations) and Area 8 resulting from the pathways of physical changes to Kennady Lake as a result of diversions, dewatering, and refilling activities were assessed for construction and operations, and for closure (including post-closure). The residual effects were summarized in Section 8.13. As noted in Sections 8.8 and 8.13, the potential effects of changes to nutrient levels in Kennady Lake have not been presented. They are the subject of continuing evaluation and are therefore not included at this time in the classification of potential effects for this assessment endpoint. Once the continued analysis is complete, the classification results outlined herein will be updated as appropriate and required.

During construction and operations, predicted maximum concentrations of suspended solids and some metals may increase above water quality guidelines because of dust and metal deposition in some fish-bearing lakes within two kilometres (km) of the Project. However, given the conservatism in the predicted concentrations, and the potential for exposure to elevated concentrations being limited to the peak watershed flows associated with the freshet, the potential for adverse effects from dust and metals deposition is considered to be low. At the end of operations, a return to existing (i.e., pre-development) conditions is anticipated.

Potential effects to aquatic health in the main basins of Kennady Lake and Area 8 were evaluated for closure and post-closure periods based on predicted changes in water quality. For the direct waterborne exposure assessment, total dissolved solids (TDS) and several metals were identified as substances of potential concern (SOPCs). A total of four metals in the main basins of Kennady Lake (and three in Area 8) are expected to exceed water quality guidelines for the long term. These metals are cadmium, chromium, copper, and iron, each of which has been measured above guideline concentrations during existing conditions.

With respect to predicted TDS concentrations in the main basins of Kennady Lake and Area 8, adverse effects to fish and aquatic invertebrates are not expected. Predicted maximum concentrations of SOPCs in Kennady Lake and Area 8 are below chronic effects benchmarks (CEBs), with the exception of total iron, copper, and strontium (strontium does not exceed water quality guidelines, but does exceed a conservative CEB [Section 8.9]). The predicted iron concentrations are not expected to result in adverse effects to aquatic life, and the potential for copper and strontium to cause adverse effects to aquatic life in Kennady Lake and Area 8 was considered to be low. For the indirect exposure pathway, predicted fish tissue concentrations in Kennady Lake were projected to be above toxicological benchmarks for only one SOPC: silver. However, as the predicted increase in silver concentration is modest, and baseline and predicted tissue concentrations only marginally exceed the available no-effects benchmark, the potential for the predicted silver concentration to cause effects to fish was considered to be low. Therefore, predicted changes to concentrations of all substances considered were projected to result in negligible effects to fish tissue quality and, by association, aquatic health in Kennady Lake.

Based on the above, projected impacts of the Project on the suitability of water within the Kennady Lake watershed to support a viable and self-sustaining aquatic ecosystem are negative in direction and moderate in magnitude during the first 100-year period. During this period there are both positive and negative effects to aquatic life within Kennady Lake. The main body of Kennady Lake and Area 8 will be more productive as a result of increased nutrients, which will be reflected in increased biomass of lower trophic communities, and may also increase fish productivity, e.g., growth and production of large-bodied fish species, such as northern pike and burbot, compared to the present nutrient-limited system. However, if productivity increases are too high, overwintering habitat suitability or availability may be negatively affected from decreases in under-ice dissolved oxygen levels, especially for lake trout (a VC) and round whitefish, which are less tolerant of low dissolved oxygen levels. The moderate magnitude rating is based primarily on the dewatering and subsequent loss of the aquatic ecosystem in Kennady Lake during mining operations, the refilling of Kennady Lake during closure and the recovery of water quality through post-closure once the lake is filled and reconnected with Area 8. These projected impacts are local in geographic extent, long-term in duration, and reversible.

After the initial 100 year period, the projected impacts of the Project were rated as negative in direction, low in magnitude, local in geographic extent, long-term in duration, and not reversible. The low magnitude rating is based on the potential for changes to occur in the composition of the aquatic community and no predicted long-term effects to aquatic health that would impair the suitability of the water quality to support aquatic life. Under both time periods, the projected impacts are considered to be continuous and likely to occur. As indicated, the above classification of impacts to this assessment endpoint is subject to re-evaluation once further predictive modelling of nutrient concentrations and the associated effects assessment is complete.

8.14.3.2 Residual Impacts to the Abundance and Persistence of Desired Population(s) of Key Fish Species

In Section 8.10, the effects of the Project on fish and fish habitat in Kennady Lake and in small lakes and streams in the Kennady Lake watershed resulting from the pathways of physical changes, and changes to water quantity and quality were assessed for construction and operations, and for closure and post-closure. The expected recovery of Kennady Lake and the nature of the final ecosystem are described in Section 8.11. The residual effects for each assessed pathway were summarized in Section 8.13. As noted in Sections 8.10, 8.11 and 8.13, the potential effects of changes to nutrient levels in Kennady Lake have not been presented. They are the subject of continuing evaluation and are therefore not included at this time in the classification of potential effects for this assessment endpoint. Once the continued analysis is complete, the classification results outlined herein will be updated as appropriate and required.

Changes to fish habitat will occur in Kennady Lake and the Kennady Lake watershed due to the development of the Project. However, the conceptual compensation plan (CCP) (Section 3, Appendix 3.II) will provide compensation habitats to offset fish habitat permanently lost due to the Project. Areas 2 to 7 of Kennady Lake will be dewatered or partially dewatered to allow mining to proceed, resulting in the temporary loss of productive capacity of fish habitat; however, it is expected that a self-sustaining fish population will be present in Kennady Lake post-closure. Raising water levels in lakes A3, D2, D3, and E1 from the A, B, D, and E watershed diversions will result in increased lake habitat area, which may create a benefit to fish residing in these lakes through additional space and overwintering habitat. A slight increase in nutrient concentrations was predicted in Area 8 during isolation, which could result in a slight increase in productivity of plankton and benthic invertebrate communities. The fish community of Area 8 is also expected to be affected by the isolation, due to existing overwintering limitations in Area 8 and the elimination of alternative overwintering refugia in Areas 2 through 7.

Table 8.14-5 Residual Impact Classification of Projected Impacts to Water Quality and Fish in Kennady Lake

Assessment Endpoint	Direction	Magnitude	Geographic Extent	Duration	Frequency	Reversibility	Likelihood	Ecological Context
Suitability of water within the Kennady Lake watershed to support a viable and self-sustaining aquatic ecosystem								
Construction to 100 years from Project start	negative	moderate	local	long-term	continuous	reversible	likely	high
Beyond 100 years from Project start	negative	low	local	long-term	continuous	not reversible	likely	high
Abundance and persistence of Arctic grayling within the Kennady Lake watershed								
Construction to 100 years from Project start	negative	high	local	long-term	continuous	reversible/	likely	high
Beyond 100 years from Project start	negative	low	local	long-term	continuous	not reversible	likely	high
Abundance and persistence of lake trout within the Kennady Lake watershed								
Construction to 100 years from Project start	negative	high	local	long-term	continuous	reversible/not reversible	likely	high
Beyond 100 years from Project start	negative	moderate	local	long-term	continuous	not reversible	likely	high
Abundance and persistence of northern pike within the Kennady Lake watershed								
Construction to 100 years from Project start	negative	high	local	long-term	continuous	reversible	likely	high
Beyond 100 years from Project start	neutral	negligible	-	-	-	-	-	-

"-" = not applicable.

When mining is complete, the B, D, and E diversion systems will be decommissioned, the water levels in the raised lakes D2 and D3, and E1 will return to baseline levels, and Kennady Lake will be refilled.

An aquatic ecosystem is expected to become established in the refilled Kennady Lake. The expected time-frame for recovery of the phytoplankton community is projected to be approximately five years after refilling is complete. Zooplankton community development is projected to closely follow recovery of the phytoplankton community, with the recovery of the benthic invertebrate community expected to take up to ten years after refilling is complete. During this time, the forage fish community will also develop, followed by a slower recovery of the large-bodied fish community. Due to changes in habitat conditions, the fish community may differ from pre-Project conditions but overall biological productivity is expected to increase in comparison to the nutrient-limited pre-development conditions.

From the pathways assessed in Section 8.10, the classification of projected impacts of the Project on the abundance and persistence of the three highly valued fish species, namely Arctic grayling, lake trout, and northern pike, is outlined in more detail below. As described above, the projected impacts on the abundance and persistence of the three key fish species were classified over two time periods: from the start of the Project to 100 years later; and after the first 100 years.

8.14.3.2.1 Arctic Grayling

During the first 100 year time period, the projected impacts on the abundance and persistence of Arctic grayling are negative in direction, high in magnitude, local in geographic extent, long-term in duration, continuous in nature, reversible, likely to occur, and high ecological context (Table 8.14-3). The largest impact to Arctic grayling in Kennady Lake and its watershed during construction and operations will be the dewatering of Areas 2 through 7 of Kennady Lake and the associated temporary loss of habitat. However, it is expected that Arctic grayling will be able to persist in Area 8 during isolation, although the population may be affected by predicted flow changes in streams downstream of Kennady Lake (Section 9). Persistence of Arctic grayling in the diverted watersheds will be dependent on the suitability and use of spawning and rearing habitat constructed in the diversion channels, and by potential immigration of Arctic grayling from the neighboring lakes in the N watershed. The impacts are considered reversible, as it is expected that Arctic grayling will re-colonize the refilled Kennady Lake during post-closure.

During the second time frame, projected impacts are negative in direction, low in magnitude, local in geographic extent, long-term in duration, and not reversible (Table 8.14-3). The re-established Arctic grayling population may take time to recover, or may not recover to existing conditions (i.e., in terms of standing stock and annual production rates) because of predicted changes in habitat conditions in the refilled Kennady Lake and downstream watershed.

Arctic grayling will likely establish a self-sustaining population in the refilled Kennady Lake earlier than northern pike. Arctic grayling will be able to access Kennady Lake from the downstream M watershed, as well as the upper B, D, and E watersheds. The recovery of the planktonic community will provide a stable food source for Arctic grayling rearing in Kennady Lake. Spawning habitat will be available in streams in the reconnected B, D, and E watersheds and downstream of Area 8. It is expected that this species will be able to overwinter and form a self-sustaining population within the refilled Kennady Lake.

Arctic grayling begin to reach maturity in about four years and have a life expectancy of 6 to 10 years. A self-sustaining population of Arctic grayling reared in Kennady Lake should be present about 5 to 10 years after the exclusion measures are removed, or about 50 years after the start of construction. At that time, the abundance of Arctic grayling is expected to be substantially less than current abundance. However, given the relatively short time to maturity, the opportunities for immigration, and the reduction in predation by lake trout, the population is projected to increase in the next 50 years, which represents 5 to 10 generations. A precise prediction of fish abundance cannot be developed for an equilibrium state that will develop after 100 years; however, it is expected that a self-sustaining population of Arctic grayling will be present.

As indicated, the above classification of impacts to this assessment endpoint is subject to re-evaluation once further predictive modelling of nutrient concentrations and the associated effects assessment is complete.

8.14.3.2.2 Lake Trout

Projected impacts to the abundance and persistence of lake trout, from the start of Project activities to 100 years later, are rated as negative in direction, high in magnitude, local in geographic extent, long-term in duration, and reversible/not reversible (Table 8.14-3). The largest impact to lake trout in Kennady Lake and its watershed during construction and operations will be the dewatering of Areas 2 through 7 of Kennady Lake and the associated temporary loss of habitat. As a result of the existing overwintering limitations in Area 8 and the elimination of alternative thermal and overwintering refugia in Areas 2 through 7, lake trout may not continue to persist in Area 8 throughout the operational period, as they are less tolerant of low dissolved oxygen concentrations. Few lake trout have been captured in the lakes of the diversion watersheds, and only in lakes A3, B1, and D3. Lake trout that have been captured in lakes B1 and D3 are likely using the lakes seasonally for rearing and feeding; these lakes likely do not currently support self-sustaining lake trout populations due to their small size and shallow depths. As a result, is not expected that lake trout will persist in the lakes of the B, D, and E diverted watersheds during operations.

During the second time frame, the projected impacts on the abundance and persistence of lake trout are rated as negative in direction, moderate in magnitude, local in geographic extent, long-term in duration, and not reversible (Table 8.14-3).

Recovery of the population abundance is influenced by the ability of the lake trout to re-colonize Kennady Lake. Immigration of lake trout from downstream lakes is less likely to occur than for other species. Lake trout are fall spawners and typically spawn in lakes. They do not, as a result, have an inherent need to migrate into streams to complete their life cycle. However, this species may make movements into streams for feeding or rearing; for example, lake trout have been observed moving into the Kennady Lake outlet (Stream K5) in spring to feed on spawning Arctic grayling. In addition, there are numerous barriers present in the streams that connect Kennady Lake to the lakes in the M watershed. Upstream passage over these barriers is only possible during the spring freshet, not during the fall spawning period when lake trout may be traveling through the streams. It is for these reasons that a moderate magnitude was assigned.

However, the geographic extent of any projected impact was determined to be local, as the impact would not extend to lake trout populations in downstream lakes (e.g., Lake 410).

As indicated, the above classification of impacts to this assessment endpoint is subject to re-evaluation once further predictive modelling of nutrient concentrations and the associated effects assessment is complete.

8.14.3.2.3 Northern Pike

During the first 100 year time period, the projected impacts on the abundance and persistence of northern pike were rated as negative in direction, high in magnitude, local in geographic extent, long-term in duration, and reversible (Table 8.14-3). The largest impact to northern pike in Kennady Lake and its watershed during construction and operations will be the dewatering of Areas 2 through 7 of Kennady Lake and the associated temporary loss of habitat. However, it is expected that northern pike will be able to persist in Area 8 during isolation, although the population may be affected by predicted flow changes in streams downstream of Kennady Lake (Section 9). Although the dykes will isolate the northern pike populations within the A, D, and E watersheds for the duration of mine operations (and permanently in Lake A3), it is considered likely that the isolated populations will be self-sustaining. The impacts are considered reversible, as is expected that northern pike will re-colonize Kennady Lake during post-closure.

During the second time period, projected impacts on the abundance and persistence of northern pike were rated as neutral in direction and negligible (Table 8.14-3). Spawning and rearing habitat in the refilled Kennady Lake is expected to be similar to what currently exists for this species. Northern pike are dependent on aquatic vegetation for spawning and rearing. The presence of aquatic vegetation in Kennady Lake is currently limited by physical factors, such as rocky substrates and wave action. However, existing macrophyte beds in sheltered areas may benefit from the increased nutrient concentrations, which would be reflected in increased plant abundance and productivity. The recovery of the population may also be enhanced by the lack of lake trout as the top predator at least initially in the recovery. Northern pike populations are expected to recover to similar levels to what currently exists by the second time period.

It is expected that northern pike will establish a self-sustaining population in the refilled Kennady Lake. Although migrants will be located in nearby systems, including the B, D, and E watersheds, northern pike are dependent on aquatic vegetation for spawning and rearing. Currently, the abundance of aquatic vegetation in Kennady Lake is limited to small isolated pockets where fine substrates accumulate within the lake. The pockets commonly occur at the mouths of the small tributaries that flow into Kennady Lake. Although aquatic vegetation is expected to eventually become re-established in the lake, re-colonization of aquatic vegetation is expected to be slow. With the exception of the younger juveniles, northern pike feed almost exclusively on fish and will rely on the recovery of the forage fish base. Northern pike mature relatively quickly, with an average age to maturity of about three years. Their life span ranges from about 10 to 26 years, generally averaging around 25 years. Even though northern pike reach maturity relatively quickly, northern pike is expected to be one of the last fish species to re-establish self-sustaining populations in the refilled Kennady Lake, due to the need for re-colonization of aquatic vegetation in the lake for spawning and rearing, and the development of a forage fish food base. As a result, recruitment of northern pike in Kennady Lake will occur for some time primarily through migration from lakes in the D and E sub-watersheds, and to a lesser extent from downstream of Area 8.

The re-establishment of a stable, self-sustaining northern pike population Kennady Lake during post-closure is expected to take a long time (i.e., approximately 50 to 60 years following the complete refilling of Kennady Lake) and it may take additional time (i.e., greater than 100 years) for the abundance of northern pike to recover to current levels. A precise prediction of fish abundance cannot be developed for an equilibrium state that will develop after 100 years; however, it is expected that a self-sustaining population of northern pike will be present at levels similar to existing.

As indicated, the above classification of impacts to this assessment endpoint is subject to re-evaluation once further predictive modelling of nutrient concentrations and the associated effects assessment is complete.

8.14.4 Environmental Significance

Ultimately, significance will be determined by the Panel. In the Mackenzie Valley Environmental Impact Review Board (MVEIRB 2006) reference bulletin on interpretation of key terminology, the term “significant” means an impact that is, in the view of the MVEIRB, important to its decision. To determine significance, the MVEIRB (2006) “will use its own values and principles of good EIA. It will use its combined experience and knowledge”. Presumably the determination of significance will be made in a similar manner by the Gahcho Kué Panel. However, the Terms of Reference require that De Beers provide its views on the significance of impacts. To that end, projected impacts were evaluated to determine if they were environmentally significant.

The evaluation of significance for this key line of inquiry considers the entire set of primary pathways that influence a particular assessment endpoint, but does not assign significance to each pathway. The relative contribution of each pathway is used to determine the significance of the Project on assessment endpoints, which represents a weight of evidence approach. For example, a pathway with a high magnitude, large geographic extent, and long-term duration would be given more weight in determining significance than pathways with smaller scale effects. The relative impact from each pathway is discussed; however, pathways that are predicted to have the greatest influences on changes to assessment endpoints would be assumed to contribute to most to the determination of environmental significance.

Environmental significance is used here to identify projected impacts that have sufficient magnitude, duration, and/or geographic extent that they could lead to fundamental changes to the VCs. For example, significance is determined by the risk to the persistence of fish populations within the aquatic ecosystem. The following definitions are used for assessing the significance of effects on the protection of surface water quality for aquatic and terrestrial ecosystems, and human use are as follows.

Not significant – impacts are measureable at the local scale, and may be strong enough to be detectable at the regional scale.

Significant – impacts are measurable at the regional scale and are irreversible. A number of high magnitude and irreversible effects (i.e., pathways) at the regional scale would be significant.

The following definitions are used for assessing the significance of impacts on the persistence of VC fish populations, and the associated continued opportunity for traditional and non-traditional use of these VCs.

Not significant – impacts are measurable at the individual level, and strong enough to be detectable at the population level, but are not likely to decrease resilience and increase the risk to population persistence.

Significant – impacts are measurable at the population level and likely to decrease resilience and increase the risk to population persistence. A high magnitude and irreversible impact at the population level would be significant.

Suitability of water within the Kennady Lake watershed to support a viable and self-sustaining aquatic ecosystem

During the first 100 year time period, the projected impacts of the Project on the suitability of water within the Kennady Lake watershed to support a viable and self-sustaining aquatic ecosystem are considered to be not environmentally significant. During the second time frame, projected impacts are also considered to be not environmentally significant. Water quality is predicted to change but the level of changes in Kennady Lake (including Area 8) include a few metals that are expected to exceed water quality guidelines for the protection of aquatic life. Those that do (i.e., cadmium, chromium, copper and iron), are metals that have been measured above guidelines during existing conditions. Chronic effects benchmarks for these metals, and other parameters that were identified as SOPCs, in the aquatic health assessment were not exceeded.

The potential effects of changes to nutrient levels in Kennady Lake have not been presented. They are the subject of continuing evaluation and are therefore not included at this time in the determination of environmental significance for this assessment endpoint. Once the continued analysis is complete, the significance determination outlined herein will be updated as appropriate and required.

Abundance and persistence of Arctic grayling within the Kennady Lake watershed

The projected impacts on the abundance and persistence of Arctic grayling are considered to be not environmentally significant for both time periods. Arctic grayling will be affected by the loss of habitat in Kennady Lake during the life of the mine, but will continue to persist in Area 8 and the diverted watersheds. It is expected that a self-sustaining population will become established in the refilled lake.

The potential effects of changes to nutrient levels in Kennady Lake have not been presented. They are the subject of continuing evaluation and are therefore not included at this time in the determination of environmental significance for this assessment endpoint. Once the continued analysis is complete, the significance determination outlined herein will be updated as appropriate and required.

Abundance and persistence of lake trout within the Kennady Lake watershed

The environmental significance for this assessment endpoint is currently considered “not environmentally significant”. Lake trout will be affected by the loss of habitat in Kennady Lake during the life of the mine, and are not expected to persist in Area 8. Although migration into Kennady Lake may be impaired for this species, they will have access to immigrate over time. Competition with other predatory species and the rate at which they re-colonize may influence the size of the resulting population.

The potential effects of changes to nutrient levels in Kennady Lake have not been presented. They are the subject of continuing evaluation and are therefore not included at this time in the determination of environmental significance for this assessment endpoint. Once the continued analysis is complete, the significance determination outlined herein will be updated as appropriate and required.

Abundance and persistence of northern pike within the Kennady Lake watershed

The projected impacts on the abundance and persistence of northern pike are considered to be not environmentally significant for both time periods. Northern pike will be affected by the loss of habitat in Kennady Lake during the life of the mine, but will continue to persist in Area 8 and the diverted watersheds. It is expected that a self-sustaining population will become established in the refilled lake.

The potential effects of changes to nutrient levels in Kennady Lake have not been presented. They are the subject of continuing evaluation and are therefore not included at this time in the determination of environmental significance for this assessment endpoint. Once the continued analysis is complete, the significance determination outlined herein will be updated as appropriate and required.

8.14.5 On-going Refinement of the Classification

The Terms of Reference require that De Beers identify all proposed mitigation measures, along with evaluations of confidence levels in the effectiveness of those measures and describe residual effects. In addition, it states that the developer must provide its views on the significance of impacts. Accordingly, De Beers has both qualitatively and quantitatively assessed the potential effects of the Project on the Key Line of Inquiry: Water Quality and Fish in Kennady Lake. At this time, the analysis of potential nutrient related effects is on-going. De Beers is currently considering a variety of environmental design features and mitigation to reduce or eliminate the potential effects related to nutrients, such as:

- Promotion of permafrost development in the Fine PKC Facility.
- Use of low permeability cover material to limit infiltration into key areas, such as the Fine PKC Facility.

The effectiveness of these environmental design features and mitigation is uncertain and requires further analysis. Accordingly, the amount of phosphorus that may be released into the environment is uncertain at this time. As a result, potential effects related to phosphorus have not been presented and will not be available until such time as additional analysis is completed. This analysis will be provided to the Panel in 2011 following additional work that will be undertaken over the next few months. At that time De Beers will provide the Panel with its updated findings with regard to significance, the associated level of confidence, and confirmation of the mitigation measures that De Beers will incorporate into the Project design.

8.15 UNCERTAINTY

Key areas of uncertainty for the assessment of effects to water quality and fish in Kennady Lake include the following:

- the Gahcho Kué Project (the Project) site water balance;
- quality and quantity of groundwater inflow to the mined-out pits;
- water quality modelling and quality of assigned chemistry of source inputs;
- dust and metals deposition to lakes adjacent to the Project;
- time required to refill Kennady Lake; and
- time to aquatic ecosystem recovery in Kennady Lake.

Each area of uncertainty is discussed in more detail below. The following discussion also includes a description of the approaches used to account for uncertainty in the effects analysis, so that potential effects were not underestimated. Where relevant, the inherent advantages of the design of the Project are also discussed, in terms of how they influence uncertainty in the assessment of effects to water quality and fish in Kennady Lake.

8.15.1 Project Site Water Balance

The site water balance describes the movement of water through the Project site over the life of the Project. The water balance determines how much water will be discharged from the Project site to the receiving environment. The site water balance also identifies the sources of water entering and leaving the site.

The site water balance was developed through the use of a water balance model, and there is a high degree of confidence in the hydrological aspects of the project description that are considered in the water balance model. In most cases, the changes to the Kennady Lake watershed that will result from the Project are well-defined and subject to limits arising from environmental design features. For example, the volume of Kennady Lake is well-defined, and discharges during dewatering will be managed within specified limits. Similarly, the drainage areas of the diverted A, B, D, and E watersheds are well-defined, and discharges will be managed within specified limits.

There is a corresponding high degree of confidence in the meteorological inputs to the water balance model inputs (e.g., temperature, precipitation) for median conditions, due to the quality of the available regional dataset. The length of the available datasets, which span from 46 years for the regional dataset to 2 to 7 years for more site-specific information, results in a lower level of confidence in the prediction of events with longer return periods, such as 1-in-50 or 1-in-100 year events. However, lake dynamics are driven to a greater extent by average or median conditions than by extreme events. As such, confidence levels are highest around those elements of the water balance model of most importance.

8.15.2 Quality and Quantity of Groundwater Inflow

An important assumption underlying the prediction of water quality in Areas 3 through 7 during operations and closure throughout the life of the Project is the quantity and quality of groundwater inflows to the pits. Groundwater inflow to the pits will be pumped to the WMP, where it will mix with site contact water. While water in the WMP meets specific water quality criteria it will be discharged to Lake N11. At the end of operations, water in the WMP will be diverted to the Tuzo Pit. If these objectives are not met, it could result in a different water quality profile than presented herein for Areas 3 through 7 during operations and in Kennady Lake after refilling.

As with all other geologic and hydrogeologic studies, there is a level of uncertainty in all effects analysis results. These uncertainties are inherent in these studies due to uncertainties within the groundwater measurement database, and the requirement to extrapolate or interpolate properties to a continuum based on sparse measurements. The primary uncertainties with regard to groundwater component in the water quality analysis within this key line of inquiry are related to the analysis of:

- pit inflow volumes; and
- groundwater quality.

Pit Inflow Volumes

At existing diamond mines in the Northwest Territories (NWT), which are adjacent to large waterbodies, groundwater inflow tends to be the largest source of water entering the mine site. At the Snap Lake Mine, the underground mine is located beneath a lake, which creates a steep hydraulic gradient that induces water to flow from the bottom of the lake through the shallow bedrock and into the mine (De Beers 2002). At Lac de Gras, the Diavik Diamond Mine is constructed inside a ring dyke, and fractured rock associated with a vertical fault in the bedrock provides a more permeable pathway from the lake to the mine than initially anticipated (Diavik 2006). The degree to which groundwater flow rates can be accurately estimated, therefore, has a large influence on the overall mine site water balance at these facilities.

Other mine developments in the north have experienced significant under estimations of the volumes of water reporting to the pits or underground workings, particularly in the Snap Lake and Diavik diamond mines. This under estimation of groundwater inflow prior to mining has been due to the presence of enhanced permeability zones. Enhanced permeability zones are zones of greater fracturing or larger fracture apertures related to structures such as faults. These zones have been found at Diavik, Ekati and at Snap Lake; none of which were identified during extensive field investigations prior to mining. At Diavik, in addition to the 100 m wide enhanced permeability zone referred to as Dewey's Fault, similar but thinner zones have been found: one zone parallel to Dewey's Fault and the other two perpendicular to this fault.

The hydrogeological model developed for the Project assumes that enhanced permeability zones are present and associated with geologic faults identified in the geophysical surveys that intersect the proposed open pits. However, their presence has not yet been confirmed, and it is possible that the structures are less permeable, thinner and/or less lateral extensive than the ones represented in the base case hydrogeological model.

Based on past experiences at other mines in the north, increases in the overall mine inflow result in increased mass loading as more groundwater is moving upwards from the region where the deep-seated saline groundwater is present. At the Project site, this phenomenon is expected to be more pronounced, because of the presence of permafrost that nearly surrounds all three of the planned open pits (which will limit the dilution of the deep-seated saline groundwater by shallow fresher groundwater). The average model-predicted percentage of groundwater inflow that originates from the freshwater lakes at the Project site is about 40% to 50%. At the Diavik Diamond Mine, there is a continuous source of freshwater from Lac de Gras, and the percentage of groundwater inflow that originates from the lake is estimated to be greater than 70%.

Groundwater Quality

The results of groundwater quality monitoring were used to estimate the composition of groundwater that could upwell into the open pits during operations. The results of groundwater quality monitoring are discussed in Section 11.6 (Subject of Note: Permafrost, Groundwater, and Hydrogeology). Depth profiles were developed to evaluate the variability of groundwater composition with depth. TDS is known to vary with depth in groundwater in the Canadian Shield. The purpose of the depth profiles was to identify parameters that correlate with TDS relative to depth. Linear regression equations were developed based on the results in the groundwater quality dataset to estimate the concentrations of TDS (including calcium, chloride, potassium, magnesium, sodium and sulphate), arsenic, boron, copper, nickel and selenium with depth.

Concentrations of ammonia, phosphorus, aluminum, antimony, barium, beryllium, chromium, cobalt, iron, lead, manganese, mercury, molybdenum, silver, thallium, uranium, vanadium and zinc were estimated based on the range of results in the groundwater dataset. The groundwater quality dataset was used to develop input concentrations for groundwater inflows to the Hearne and 5034 pits. Input concentrations are equal to the maximum concentration measured in groundwater samples from each pit. This approach was developed based on a detailed review of the groundwater quality dataset. This approach is considered somewhat conservative because of the high variability in metal concentrations with depth and by location. Furthermore, the review of the results of groundwater quality monitoring identified concentrations of some parameters, such as chromium, that were anomalously elevated in select samples. These concentrations were not excluded from the statistical calculations used to define groundwater input water quality; however, the input concentrations will be re-visited after supplemental groundwater samples are collected from the groundwater monitoring wells at the Project.

As indicated by the review of the groundwater quality dataset, groundwater quality varies with location and depth within the Kennady Lake area. The variability in groundwater quality may be a function of several factors:

- Difficulties encountered during groundwater sampling could have resulted in mixing of groundwater samples with drilling fluids, which, depending on the groundwater quality and chemical composition of these fluids, could result in over- or under-estimates of actual TDS levels in the deep groundwater.
- Groundwater quality, particularly TDS, could be influenced by local variations in the vertical and horizontal components of the convective flux due to hydraulic gradients, density gradients, hydraulic conductivity and/or local variations in diffusive flux from the deep-seated saline groundwater resulting from the relative interconnection of pore space in the rock mass.

Despite the variability in groundwater quality, the TDS values of groundwater samples are generally consistent with the TDS of groundwater observed at other sites in the Canadian Shield (see Section 11.6, Subject of Note: Permafrost, Groundwater, and Hydrogeology).

Because the inflow and TDS mass are interdependent, it is likely that if reasonably highly conservative values of bedrock hydraulic conductivity were simulated together with a reasonably highly conservative TDS/depth profile the result would be an overly conservative TDS mass load. Therefore, in a model sensitivity which employs a more conservative TDS/depth profile, less conservative values of bedrock hydraulic conductivity are considered to be appropriate.

As a consequence of the above, two model sensitivities were undertaken:

- Sensitivity Run #1: In this model simulation, the enhanced permeability zones were removed from the model. All other parameters, including the TDS/depth profile, remained the same as the Base Case model. This simulation resulted in a lower bound estimate of inflow and TDS mass.
- Sensitivity Run #2: In this model simulation, the enhanced permeability zones were removed, but a conservative TDS/depth profile was used. The TDS concentrations in this profile are twice that used in the Base Case model. All other hydrogeologic parameters remain the same as those in the Base Case model.

Results of Model Sensitivity #1 indicate that groundwater inflows to the mines, if the enhanced permeability zones were not present, would be on average approximately 40% lower than predicted in the Base Case. Generally, predicted groundwater inflows in this sensitivity simulation are very close to those predicted in the Base Case when the pits are shallow and groundwater inflow occurs primarily through the till and exfoliated rock units; however, for the ultimate pit configurations predicted groundwater inflows are between 50% and 70% lower than in the base case predictions. The predicted groundwater load in this simulation is generally lower than that predicted for the base case.

Predicted TDS concentrations for Sensitivity Run #2 are, on average, 1.5 to 2 times greater than those predicted for the Base Case. However, because predicted groundwater inflow rates in this scenario are lower than those under the Base Case, the overall mass loading to the pits is similar in each of the two scenarios (i.e., Sensitivity Run #2 and the Base Case).

While considerable effort has been expended assessing the dynamics of pit dewatering, backfilling, and flooding, the assessments have simplified a highly complex and dynamic system and represent bounding conservative calculations that result in a reasonable degree of confidence that effects on groundwater and the potential for changes in groundwater to affect surface waters have not been underestimated.

De Beers is committed to complete monitoring and testing using standard field and laboratory procedures during the Project operation to evaluate groundwater quantity and quality. Where necessary, the water quality and quantity input profiles assigned to the loadings for groundwater will be revised and Project effects will be re-assessed, as appropriate. Where required, adaptive management strategies will be adopted.

8.15.3 Water Quality Modelling

Water quality in Kennady Lake and in Area 8 as a whole (after refilling) will be dependent on the quality of the influent streams entering the basin / lake. The predictions of water quality in Area 8 during construction, operation, and closure, and that in Kennady Lake during and after refilling, was completed using a dynamic, mass-balance model built within GoldSim™, which is widely used in environmental assessment. The GoldSim™ model was specifically used to simulate water quality outcomes in a receiving environment over time with multiple input variables.

The GoldSim™ water quality model was based on the site water balance and included inputs of material from the following sources:

- natural runoff to Areas 1 through 7, and Area 8, which were assigned mean baseline water quality;
- metals and other elements associated with the suspended solids in the WMP (the quality of which was defined by laboratory analysis of bed sediment from Kennady Lake [Appendix 8.I]);
- groundwater that will be pumped from open pits into the WMP (quality of which was derived from observed groundwater chemistry [Appendix 8.I]);
- contact runoff from Project areas to the WMP, including the input of:
  - mine rock and coarse PK contact water and seepage from the Fine PKC Facility (quality of which was defined based on geochemistry studies and loading calculations provided in the Metal Leaching and Acid/Alkaline Rock Drainage Report [Appendix 8.II]); and
  - blasting residue (quality of which was defined based on the nitrogen release assessment provided [Appendix 8.I]).

Baseline water quality data from the Project area provided the basis for estimation of the quality of natural runoff and inflows from unaffected areas. The prediction of water quality in Area 8 was based on modelling Project releases to mean baseline water quality conditions. Some uncertainty around these predictions results from the use of a mean baseline value assigned to each water quality parameter, when the dataset contains a naturally large degree of variability. The modelling was also focused on median climatic conditions. Although these areas of uncertainty exist, the selected approach is appropriate for lake systems, which are more strongly influenced by average conditions, rather than short-term extremes. In addition, the modelled water quality parameters were all treated as conservative substances; no chemical transformations, biological uptake, degradation, or precipitation was assumed. When deriving means for baseline water quality, individual data that were below reporting limits were replaced with a value equal to half the detection limit. This approach will likely yield a conservative estimate of the actual mean concentrations.

Projections of modelled water quality were based on the assumption that Area 8 will be completely mixed during open water conditions. This approach was adopted, because Area 8 has a short residence time, in the order of one year.

As described in Appendix 8.II, the composition of water that comes into contact with mine rock and processed kimberlite was estimated based on the results of geochemical characterization:

- Mine rock contact water qualities were defined based on the results of humidity cell testing discussed in Appendix 8.II, Section 8.II.4.3.4. Water qualities were defined for each mine rock type based on the concentrations measured during the initial flushing of the humidity cell tests, and the longer term, “steady state” results of humidity cell testing, respectively.
- The results of humidity cell testing and submerged column testing of fine and coarse PK, respectively, were used to define the composition of PK runoff and seepage water quality. Fine PK and coarse PK exposed in the Fine PKC Facility and Coarse PK Pile, respectively, will undergo seasonal wet and dry cycles during the summer months as discussed in Appendix 8.II, Section 8.I.2.4.4. The maximum concentration reported in the first five weeks of testing in the fine PK test programs was selected to represent the drainage water quality from fine PK materials during freshet (see Appendix 8.II). At the time of modelling, only five weeks of humidity cell test results were available from the supplemental fine PK humidity cell sample. Based on the available results, it was difficult to ascertain if steady-state conditions had been realized. As such, to determine the expected long-term concentration in the humidity cell tests, the 2008 fine PK humidity cell tests were compared to the water collected from the bottom of the submerged fine PK column tests. The expected steady-state water quality for fine PK was calculated as the maximum concentration reported in the last five weeks of testing

from the AMEC (2008) humidity cell tests and the maximum concentration reported in the bottom water of the submerged column test.

- The results of PK process water analysis were used to estimate the composition of the discharge from the Fine PK Facility. Process water, which is typically recycled multiple times through the plant, will be discharged to the Fine PKC Facility as a component of the fine PK slurry. As such, it is considered reasonable that the pond in Area 2, collecting drainage from fine PK runoff and seepage will have a composition similar to the process water quality. During operations, when a pond will be maintained in Area 2, Fine PKC Facility discharge was calculated as the maximum of the simulated Area 2 pond water quality and the process water quality.
- Submerged column tests were initiated to evaluate the effect of submerged fine and coarse PK in Kennady Lake. The composition of water in contact with submerged PK was defined based on the maximum results measured during the first five weeks of submerged column testing, as this was the only information available at the time of preparation of the water quality predictions.

The approach and assumptions for contact water loading from mine rock and PK to runoff are consistent with the approaches used for other mine sites, such as at the Snap Lake Mine. However, the principal loading of a large number of dissolved metals for the modelling (including antimony, arsenic, cadmium, cobalt, chromium, copper, iron, lead, mercury, selenium, silver, and zinc) is based on contact water tests with a high number of results (>90%) below the detection limit (Appendix 8.II). Therefore, while some uncertainty exists around the predictions of these metals, there is a reasonable degree of confidence that the loading rate to the WMP will be lower than assumed.

Although the modelling results and potential effects of phosphorus are not presented in this document, phosphorus concentrations in contact water tests were measured using two methods: ICP-MS and colorimetry. Phosphorus loading from the contact water tests (Appendix 8.II), in particular, was derived from results measured by ICP-MS that were consistently below the analytical detection limit. The detection limit of 0.15 milligrams of phosphorus per litre (mg P/L) was considered too high to use in the water quality model to reliably predict phosphorus concentrations in oligotrophic waters, which have phosphorus levels below 0.010 mg P/L (CCME 2004). To reduce the uncertainty around the prediction of phosphorus from mine rock drainage, kinetic test phosphorus concentrations used to calculate mine rock contact water loadings were revised to incorporate average dissolved phosphorus concentrations measured by colorimetry (i.e., detection limit of 0.020 mg/L). The revised phosphorus concentrations are within the range of with phosphorus concentrations measured in runoff from PK that has been produced during mining at the Snap Lake Mine (i.e., 0.020 mg/L; De Beers 2010). This data will be used in the further evaluation of the potential effects of phosphorus in the environment.

Residual nitrogen loading in the water quality predictions are consistent with that used in other NWT diamond mines, and incorporates a mine production schedule as provided by the Project engineering team (Appendix 8.I). There is uncertainty in these loading predictions based on the possibility that blasting schedules, the amount of ammonium nitrate-fuel oil (ANFO) explosive required for blasting, and other factors (e.g., powder factors) may be altered during operation. In addition, other factors (e.g., powder factors) may be underestimated. De Beers is committed to updating modelled predictions of nitrogen loading to the WMP as blasting details are revised.

Detailed modelling of cover infiltration was not included in the current water quality assessment and it was conservatively assumed that precipitation on the covered Fine PKC Facility would infiltrate and seep through fine PK. This assumption assumes that the cover materials (e.g. coarse PK and mine rock) have negligible effects on the Fine PKC Facility drainage water quality. In reality, some of the precipitation will drain run through the cover materials and not come into contact with the underlying fine PK. To assess the Fine PKC Facility drainage water quality sensitivity with respect to isolation processes attributable to permafrost aggradation or cover efficiency, the following sensitivity cases were included in the Kennady Lake water quality model:

- Scenario 1: 5% Infiltration to fine PK; 95% Infiltration to coarse PK;
- Scenario 2: 0% Cover Infilitration; 100% mine rock runoff.

Scenario 1, provided by EBA (Horne and Zhang, pers. comm.; listed as EBA Case 3), assumes that only a small amount of the total precipitation reporting to the Fine PK footprint will infiltrate and come in contact with fine PK. In this scenario, this component of the water was assigned the average geochemical input water quality for fine PK (Table 3, Appendix 8.I). The remaining water was assigned average coarse PK water quality.

Scenario 2 is an analogue of permafrost forming throughout the entire cover and preventing any water from infiltrating into the fine and coarse PK units. Under this scenario, all runoff generating from the fine PK footprint was assigned average non-PAG granite mine rock water quality (Table 3, Appendix 8.I). It is important to note that this scenario also assumes that the active layer will not migrate below the one metre mine rock cover in the Fine PKC Facility.

De Beers is similarly committed to undertake regular monitoring and testing using standard field and laboratory procedures during the Project operation to evaluate water quality of components of the water management system (e.g., collection ponds), and the WMP. Where necessary, the water quality input profiles assigned to the loadings will be revised and Project effects will be confirmed. Where required, adaptive management strategies will be adopted.

8.15.4 Deposition of Dust and Metals to Lakes in the Kennady Lake Watershed

A simple mass balance calculation was used to predict changes in total suspended solids (TSS) and metal concentrations in lake water from deposition on the lake surface and within the watershed, for Area 8 and selected lakes in the Kennady Lake watershed. Changes in TSS and metal concentrations were calculated based on total suspended particulate (TSP) deposition rate and individual metal deposition rates, respectively, as predicted by air quality dispersion modelling (Section 11.4, Subject of Note: Air Quality).

A major source of uncertainty in the assessment of dust and metals deposition to lakes in and around the Project area relates to the air quality predictions (Section 11.4). The dispersion models used in the Air Quality assessment simplify the atmospheric processes associated with air mass movement and turbulence. This simplification limits the capability of a model to replicate discrete events and therefore introduces uncertainty. As a result of the uncertainty, dispersion models, coupled with their model inputs, are generally designed to conservatively model concentration and deposition values, so that practitioners can apply model results with the understanding that effects are likely to be over-estimated.

The following general comments are made with respect to air quality modelling results for this Project:

- Parameterization of emissions from diffuse area sources is difficult to simulate in dispersion models. Modelled results near mine pits and other sources of mechanically generated particulates are most uncertain. Most estimates of particulate emissions for mining activities are based on U.S. EPA emission factors. Many of these factors have limited applicability outside of the area in which they were developed (typically south-western United States coal mines). Based on experience, it is expected that emissions estimated using this approach would be conservative.
- The air quality and deposition rate predictions used the maximum emission rates from the Project during construction and operations associated with the development of the South and West Mine Rock Piles in Years 5 and 8. Predicted annual deposition rates were based on the maximum of the daily road dust emissions during summer and winter.

- Emissions of road dust from on-site haul roads, the primary sources of particulate matter and metal compounds, do not include potential mitigating effects of weather (such as precipitation or snow-covered ground) which will result in an overestimate of annual air quality predictions and deposition rates.
- Geochemistry data used to estimate metal concentrations in dust included a large proportion of concentrations below the analytical detection limit for cadmium, mercury, selenium, and silver. Concentrations of these metals were set at the detection limit for air quality and deposition modelling.
- Based on a review of the particulate material monitoring data at the Snap Lake and Ekati mines, the elevated particulate matter deposition rates identified in this assessment are due in part to the conservative emission estimates.

The approach used to estimate incremental changes in concentrations of TSS and metals in surface waters using the modelled deposition rates was also conservative, for the following reasons:

- No retention of particulates or metals was assumed in lake watersheds, i.e., all deposited material was assumed to enter the lakes.
- Settling of suspended sediments in lakes was not incorporated.

As a result of these factors, predicted changes in TSS and metal concentrations in lakes are considered to be conservative estimates of the maximum potential changes that could occur during construction and operations.

De Beers is committed to undertake regular air quality testing using standard field and laboratory procedures during the Project operation to evaluate dust emissions and metals concentrations associated with dust. Where necessary, the water quality input profiles assigned to the loadings will be revised and Project effects will be confirmed. Where required, adaptive management strategies will be adopted to reduce the fugitive particulate matter emissions.

8.15.5 Time Required to Refill Kennady Lake

The time required to refill Kennady Lake has been estimated at 8 to 9 years. This estimate was derived from average flow conditions. If climatic conditions are drier than assumed at the time of refill, then the refill period may take longer, up to 20 years (Section 8.7). Conversely, if wetter conditions prevail during the refill period, it may be notably shorter, in the order of seven years.

A change in the filling time of Kennady Lake may alter the proportion of the different influent waters in the lake. Under drier conditions, the refilled system may contain a higher proportion of water originating from the upper watershed than from Lake N11, because the total water withdrawal from Lake N11 will be capped to ensure the maintenance of 1-in-5 dry year flows downstream of Lake N11.

Similarly, under wetter conditions, the proportions of the different influent waters may also vary from those that would occur under the assessed case. However, in both scenarios, the variation that may occur in the relative contribution of the different influent sources is unlikely to result in a change to the conclusions of the effects assessment. The water quality from both watersheds is similar. The time to full recovery would be longer, relative to the start of Project operations, if more than 12 years is required to refill the lake.

8.15.6 Time to Aquatic Ecosystem Recovery

A perfect analogue for Kennady Lake is not available, and the time required for the aquatic ecosystem in Kennady Lake to recover has been estimated from information presented in the available scientific literature. There is, as a result, some uncertainty in the estimated time quoted for full recovery (e.g., 50 to 60 years following the complete refilling of Kennady Lake for northern pike). Similarly, if habitat conditions are suitable for lake trout in the refilled lake, it is expected that this species will also require a long time to re-establish a stable, self-sustaining population (i.e., approximately 60 to 75 years following the complete refilling of Kennady Lake). The quoted range was developed using the longest recovery times noted in the literature (Section 8.11) and extending them to account for the fact that Kennady Lake is located in the sub-arctic. Arctic systems usually recover slower than temperate or tropical systems, because of colder temperatures, shorter growing seasons, and low nutrient availability. A longer recovery of Kennady Lake compared to temperate zone lakes remains likely due to Arctic climate-related factors. Because uncertainty is high, conservative assumptions were used in the estimation of the length of time for recovery, as described above. Consequently, there is a moderate degree of confidence that the length of time required for the ecosystem to recover is not underestimated. A moderate degree of confidence is the highest level that can be achieved in the assessment. The greatest uncertainty lies in the extent to which the abundance of each highly valued fish species returns to baseline values.

8.16 MONITORING AND FOLLOW-UP

8.16.1 Scope of Potential Monitoring Programs

Pursuant to the assessment approach outlined in the environmental impact statement (EIS) Section 6, three types of monitoring are planned, and they include the following:

- compliance inspection;
- follow-up monitoring; and
- effects monitoring.

Compliance inspection will consist of programs designed to confirm the implementation of approved design standards and the environmental design features described in the EIS.

Follow-up monitoring will consist of programs designed to verify key inputs to the effects analysis, such as the quality of the influent waters to the Water Management Pond (WMP; Areas 3 and 5), as well as monitoring compensation habitat to confirm the no net loss objective has been achieved. Results of follow-up monitoring will be used to reduce the level of uncertainty related to impact predictions.

Effects monitoring will involve programs focused on the receiving environment, with the objectives of verifying the conclusions of the EIS, evaluating the short-term and long-term effects on the physical, chemical and biological components of the aquatic ecosystem of Kennady Lake, estimating the spatial extent of effects, and providing the necessary input to adaptive management.

Follow-up monitoring and compliance inspection programs will be focused on the Gahcho Kué Project (Project) site, with little to no work occurring beyond the immediate Project area. Effects monitoring programs will encompass a larger area; however, they are unlikely to extend beyond Kirk Lake. Anticipated monitoring activities in the Kennady Lake watershed are described in this section.

There is no requirement for a cumulative effects monitoring program for aquatics, because the projected impacts of the Project on aquatics do not extend beyond the local study area. They do not, as a result, overlap with other regional projects (e.g., Snap Lake Mine).

8.16.2 Potential Monitoring Activities

8.16.2.1 Compliance Inspection

Compliance inspection by De Beers will verify that Project components are built to approved design standards and that environmental design features described in the EIS are incorporated. As each component of the Project is built, constructed features will be inspected to show that they comply with standard protocols, and that any variance from standard protocols has been completed with regulatory permission (as appropriate). A check list will also be developed to show that agreed-upon environmental design features are constructed as required. Compliance monitoring will extend throughout the life of the Project.

8.16.2.2 Follow-up Monitoring

Follow-up monitoring activities are expected to include water sampling in and around the South and West Mine Rock Piles, the Coarse PK Pile, the Fine Processed Kimberlite Containment (PKC) Facility, and other areas of the Project site to confirm the accuracy of the influent water quality profiles used to complete the effects assessment. Monitoring the progression of freezing within the external facilities will also be completed as part of this monitoring component.

8.16.2.3 Effects Monitoring

Effects monitoring programs will include a Surveillance Network Program (SNP) that focuses primarily on Project site operations as well as a more broadly focused Aquatic Effects Monitoring Program (AEMP). De Beers will develop the scope of the SNP and AEMP in consultation with regulators and interested parties. It is anticipated, however, that the AEMP will include water flow, water quality and sediment quality components, along with components focused on lower trophic communities (i.e., plankton and benthic invertebrates), fish and fish habitat. Sampling areas are likely to be located in the Kennady Lake watershed, potentially affected areas of the N watershed and the A, B, D, and E watersheds, Lake 410, and Kirk Lake, and a suitable reference lake. Components of the AEMP will be developed according to a common, statistically-based study design incorporating regulatory guidance and current scientific principles related to aquatic monitoring. Likely monitoring activities in the Kennady Lake watershed are described in this section.

Monitoring will also be conducted to evaluate the effectiveness of habitat compensation, and will include evaluation of both physical and biological characteristics. This monitoring will be critical to confirming that the no net loss objective has been achieved. The detailed monitoring plan will be included in the detailed No Net Loss Plan, and will be designed to meet all fish and fish habitat monitoring requirements included as conditions attached to regulatory authorizations, approvals or permits that may be issued for development of the Project.

The scope of the AEMP is expected to change over the life of the Project. In particular, monitoring in adjacent and downstream watersheds is expected to decline when operations cease. However, monitoring of Kennady Lake and the reference lake will be maintained during all phases of the Project.

Monitoring and sampling techniques, and analysis procedures, will be consistent with methods used during the baseline survey period to the extent possible. The field and laboratory processes will include the implementation of quality assurance/quality control measures for data acquisition, water and biota sampling, and analysis and reporting.

The assessment of data and information collected during the monitoring programs will be compiled into annual AEMP reports that will be submitted to the appropriate parties for review. Where necessary and appropriate, the results of other monitoring programs (e.g., groundwater monitoring) will be integrated into the AEMP reports.

8.16.2.4 Scope of the Aquatics Monitoring Programs

8.16.2.4.1 Construction and Operation

Potential monitoring in the Kennady Lake watershed during construction and operation is summarized below.

Hydrology

Monitoring of flows and water levels at key locations during construction and operation is considered necessary to determine actual runoff and discharge rates. Flow rates and water levels will be monitored during all phases of the Project at key lake outlets in the Kennady Lake watershed, specifically Area 8 and the A, B, D, and E watersheds. During construction and operation, continuous monitoring at the Area 8 outlet (Stream K5) will occur during dewatering over the open water period.

Hydrometric monitoring to provide measurements of lake levels and lake outlet discharges at key locations, including diversion channels at lake outlets, during open water conditions will be undertaken using hydrometric stations or gauging collection processes similar to those used as part of the baseline program (Section 8.3).

During the late season low flow period, in advance of the next season's spring thaw and freshet, observations will be undertaken to assess the integrity of the outlets and stream courses to monitor for the development of channel or bank erosion. Prior to the spring thaw (or snowmelt), snow surveys will be used to provide an early estimate of spring runoff. This is a reliable method to project annual watershed runoff volumes.

All piped and/or pumped discharges to lakes (e.g., to Area 8) will be monitored continuously.

Climate monitoring, including continuous measurements of rainfall and temperature, will be performed to allow validation of the hydrological model, assessment of seasonal conditions and to provide data for water management decision-making.

Water Quality

Water quality monitoring will focus on parameters monitored during baseline surveys and used as input variables through the modelling process, including pH, hardness, alkalinity, total organic carbon, total suspended solids, total dissolved solids, major ions, metals, nutrients (e.g., phosphorus), and selected organic parameters. Sampling points will include the WMP, the discharge zone in Area 8, the Area 8 outlet (Stream K5), the A, B, D, and E watersheds, and a suitable reference lake. Sediment sampling will be undertaken in the WMP and Area 8.

Sampling will occur on a seasonal basis (i.e., open water and under-ice conditions, at a minimum) to verify effect predictions related to changes in water quality and potential effects to aquatic health.

Fish and Fish Habitat

The fish and fish habitat monitoring program will be designed to obtain additional baseline information on watercourses and waterbodies that will be directly affected by the Project (i.e., permanent habitat losses), to determine if any effects to fish and fish habitat occur in watercourses and waterbodies directly (through changes in water quality) or indirectly (through changes in flow or water levels) affected by the Project, and to monitor the effectiveness of the development of compensation habitats. Fisheries data collected during fish salvages may also be used to complement data collected under the monitoring plan activities.

Monitoring will include phytoplankton, zooplankton, benthic invertebrates, and fish sampling of specific waterbodies in the Kennady Lake watershed and a reference lake. The frequency of sampling will be dependent on the trophic level.

8.16.2.4.2 Closure

The closure period is associated with the refilling of Kennady Lake, the re-connection of the B, D, and E watersheds and the removal of Dyke A. Throughout this period, the refilling of Kennady Lake will result in the continued reduction of downstream flows through Area 8. Natural refilling of Kennady Lake will be augmented by active pumping from Lake N11. Monitoring through this period is summarized below.

Hydrology

Flow rates and water levels will be monitored at lake outlets at key locations, specifically Area 8. Monitoring will occur on a seasonal basis at the Area 8 outlet (Stream K5).

During the drawdown of diverted lakes in the B, D, and E watersheds, lake water surface elevations and discharges from the lakes will be monitored until they are restored to pre-development levels. Re-established shorelines will be inspected on an annual basis until it is evident that shorelines are stable or until any required mitigation measures are implemented and shown to be effective.

Water Quality

Monitoring of Kennady Lake during refilling will test water quality predictions and once refilling is complete, provide a basis for measuring compliance with relevant applicable guidelines for the removal of Dyke A.

Water quality monitoring will focus on parameters monitored during the operation phase of the Project. Sampling points will include selected lakes in the upper watershed, the partially backfilled Hearne Pit and open Tuzo Pit, Areas 3 through 7, Area 8, and a reference lake. Additional physico-chemical water column profile monitoring in the Hearne and Tuzo pits will be conducted seasonally to monitor the extent of chemocline development.

Fish and Fish Habitat

Monitoring of phytoplankton, zooplankton, benthic invertebrates, and the fish community in the refilling Kennady Lake, in smaller lakes in the Kennady Lake watershed, and a reference lake will be required for the closure phase as summarized below:

- monitoring of spring spawning migrations and summer rearing densities of Arctic grayling in the Area 8 outlet (Stream K5);
- monitoring phytoplankton, zooplankton, benthic invertebrates, and forage fish in the refilling lake will be conducted to provide a basis to measure against the ecosystem recovery predictions for Kennady Lake. Monitoring will provide temporal trends and the information will also be useful to determine when Kennady Lake could support a piscivorous fish community to allow the removal of fish screens in the re-aligned B, D, and E watersheds, as well as Dyke A;
- monitoring fish migration in the channels of the restored B, D, and E watersheds will be conducted after the exclusion measures are removed to ensure fish movement between these watersheds and Kennady Lake. This program will include spring, summer, and fall sampling periods to document spring spawning migration, summer rearing success, and fall migration; and
- compensation habitats developed for the Project will be monitored for fish habitat and fish presence and abundance until the effectiveness of the compensation has been demonstrated.

8.16.2.4.3 Post-closure

After the removal of Dyke A, the upper Kennady Lake watershed and Areas 3 through 7 will be reconnected to Area 8 and downstream waterbodies. Anticipated post-closure monitoring is summarized below.

Hydrology

Hydrological monitoring of the reconnected watershed will occur at similar sites selected during the baseline surveys. Monitoring is expected to be less frequent than during operations or closure, and will only persist for several years after the removal of Dyke A. The primary purpose of this monitoring will be to determine that the post-closure watershed hydrology is consistent with pre-development conditions, taking into account the modified watershed and lake areas.

Water Quality

Water quality monitoring will focus on parameters monitored during the operation phase of the Project. Sampling points in Kennady Lake during post-closure will include the partially backfilled Hearne Pit and open Tuzo Pit basins, Areas 3 through 7, Area 8, and a reference lake. Additional physico-chemical water column profile monitoring will be conducted seasonally in the Hearne and Tuzo pits to monitor the seasonal regime of meromictic conditions and the extent of chemocline development.

Sampling may occur on a less frequent basis than during operations and closure, but will maintain a seasonal basis (i.e., open water and under-ice conditions). Monitoring would be expected to continue, until water quality conditions are consistent with the surrounding environment or are on a predictable trajectory to that endpoint. Sampling will also be conducted in a reference lake to provide a comparison with background temporal trends.

Fish and Fish Habitat

Monitoring will include phytoplankton, zooplankton, benthic invertebrates, and fisheries sampling in the refilled Kennady Lake, the Kennady Lake watershed, and a reference lake. Monitoring in the refilled Kennady Lake will focus on changes to fish and fish habitat resulting from changes in nutrient levels and trophic change.

These monitoring programs will persist until it is determined that fish and lower trophic communities of the Kennady Lake watershed have reached applicable recovery thresholds as determined by Fisheries and Oceans Canada (DFO) and other interested parties, and that the compensation habitats are considered to be effective and habitat compensation and confirming the predicted recovery processes and timing.

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8.18 ACRONYMS AND GLOSSARY

8.18.1 Acronyms and Abbreviations

ANC	acid-neutralizing capacity
ANFO	ammonium nitrate-fuel oil
API	American Petroleum Institute
ARD	acid rock drainage
BCF	bioconcentration factors
BOD	biological oxygen demand
$CaCO_3$	calcium carbonate
CCME	Canadian Council of Ministers of the Environment
CDWQ	Health Canada Guidelines for Canadian Drinking Water Quality
CEB	chronic effects benchmarks
CFU	coliform forming units
CO_2	carbon dioxide
COD	chemical oxygen demand
CP	collection pond
CWQG	Canadian Water Quality Guidelines
De Beers	De Beers Canada Inc.
DFO	Fisheries and Oceans Canada
DO	dissolved oxygen
DOC	dissolved organic carbon
DOM	dissolved organic matter
d/w	dry weight
e.g.	for example
EIS	environmental impact statement
EMS	environmental management system
ET	evapotranspiration
et al.	group of authors
Evap	evaporation
GIS	geographic information system
h	Hour
HEP	Habitat Evaluation Procedure
HSI	Habitat Suitability Index
HU	Habitat Unit
Hwy	Highway
i.e.	that is
ICP/MS	inductively coupled plasma/mass spectrometry

ISQG	Interim Sediment Quality Guidelines
L_N	Lake Number
LSA	Local Study Area
MDL	method detection limit
N	nitrogen
NAD	north American dataum
NAG	non acid-generating
NO_3^-	nitrate
NOEC	no observed effect concentrations
NO_X	oxides of nitrogen
NTU	nephelometric turbidity unit
NWT	Northwest Territories
P	phosphorous
PAG	potentially acid-generating
PAI	potential acid input
PK	processed kimberlite
PKC	processed kimberlite containment
PM	particulate matter
PMR	probable maximum rainfall
Project	Gahcho Kué Project
SE	standard error
SNP	surveillance net work program
SO_2	sulphur dioxide
SO_4^{2-}	sulphate
SOPC	substances of potential concern
SSD	species sensitivity distributions
SSWC	Steady-State Water Chemistry
STP	sewage treatment plant
SW	southwest
SWE	snow water equivalent
TCU	true colour unit
TDS	total dissolved solids
Terms of Reference	Terms of Reference for the Gahcho Kué Environmental Impact Statement
TKN	Total Kjeldahl nitrogen
TOC	total organic carbon
TP	total phosphorous
TPH	total petroleum hydrocarbon
TSP	total suspended particulates
TSS	total suspended solids

U.S. EPA	United States Environmental Protection Agency
U.S. FWS	United States Fish and Wildlife Service
ULC	Underwriters Laboratories Canada
UTM	Universal Transverse Mercator
V	volume
VC	valued components
WCB	Workers Compensation Board
WHU	weighted habitat units
WMP	Water Management Pond
WRD	mine rock drainage
WTP	water treatment plant
w/w	wet weight

8.18.2 Units of Measure

%	percent
~	approximately
<	less than
>	greater than
°	degree
°C	degree Celsius
µE/m^{-2}/min^{-1}	micro-Einsteins per square metre per minute
µg/g	microgram per gram
µg/L	microgram per litre
µg/L/y	microgram per litre per year
µg/m^{2}/s	microgram per square metre per second
µm	micrometre
µS/cm	microSiemens per centimetre
CFU/100 mL	coliform forming units per one hundred millilitres
cm	centimetre
cm/s	centimetre per second
cm^{2}	square centimetre
dB	decibel
g/m^{2}/y	grams per square metre per year
ha	hectares
Hz	Hertz
ind/m^{3}	individuals per cubic metre
keq/ha/y	kiloequivalents per hectare per year

keqH$^+$/ha/y	kiloequivalent hydrogen ions per hectare per year
kg	kilogram
kg N/ha/y	kilograms of nitrogen per hectare per year
km	kilometre
km^2	square kilometre
kPa	kiloPascals
L	litre
L/d	litre per day
L/ha/y	litre per hectare per year
m	metre
m/m	metre per metre
m^3	cubic metre
m^3/d	cubic metre per day
m^3/s	cubic metre per second
m^3/y	cubic metre per year
masl	metres above sea level
mbgl	metres below ground level
mg N/L	milligrams nitrogen per litre
mg P/L	milligrams phosphorus per litre
mg/kg	milligram per kilogram
mg/kg wet wt	milligrams per kilogram wet weight
mg/L	milligrams per litre
mg/L/m	milligram per litre per metre
mg/L/y	milligram per litre per year
MJ/m^2/day	mega joule per square metre per day
mL	millilitre
mm	millimetre
mm/h	millimetre per hour
mm/mo	millimetre per month
Mm^3	million cubic metres
Mm^3/y	million cubic metres per year
mpn/100 mL	most probable number per one hundred millilitres
m/s	metres per second
Mt	million tonnes
PM_{10}	particulate matter with particle diameter nominally smaller than 10 micrometres (µm)
$PM_{2.5}$	particulate matter with particle diameter nominally smaller than 2.5 µm
ppm	parts per million
W/D	width to depth (ratio)

8.18.3 Glossary

Acid Neutralizing Capacity (ANC)	The equivalent capacity of a solution to neutralize strong acids. Acid Neutralizing Capacity can be calculated as the difference between non-marine base cations and strong anions. This is the principal variable used to quantify the acid-base status of surface waters. Acidification is often quantified by decreases in ANC, and susceptibility of surface waters to acidic deposition impacts is often evaluated on the basis of ANC.
Acidification	The decrease of acid neutralizing capacity in water, or base saturation in soil, caused by natural or anthropogenic processes. Acidification is exhibited as the lowering of pH.
Acute	A stimulus severe enough to rapidly induce an effect; in aquatic toxicity tests, an effect observed in 96 hours or less is typically considered acute. When referring to aquatic toxicology or human health, an acute effect is not always measured in terms of lethality.
Alberta Environment (ANEV)	Provincial ministry that looks after the following: establishes policies, legislation, plans, guidelines and standards for environmental management and protection; allocates resources through approvals, dispositions and licenses, and enforces those decisions; ensure water infrastructure and equipment are maintained and operated effectively; and prevents, reduces and mitigates floods, droughts, emergency spills and other pollution-related incidents.
Alevin	A newly-hatched fish in the larval stage, dependent upon a yolk sac for nutrients while their digestive system develops.
Alkalinity	A measure of water's capacity to neutralize an acid. It indicates the presence of carbonates, bicarbonates and hydroxides, and less significantly, borates, silicates, phosphates and organic substances. Alkalinity is expressed as an equivalent of calcium carbonate. Its composition is affected by pH, mineral composition, temperature and ionic strength. However, alkalinity is normally interpreted as a function of carbonates, bicarbonates and hydroxides. The sum of these three components is called total alkalinity.
Anions	A negatively charged ion.
Anoxia	Little to no dissolved oxygen in the water sample. Waters with less than 2 mg/L of dissolved oxygen experience anoxia.
Anthropogenic	Pertaining to the influence of human activities.
Background	An area not influenced by chemicals released from the site under evaluation.
Base Case	The EIA assessment case that includes existing environmental conditions as well as existing and approved projects or activities.
Base Cation	An alkali or alkaline earth metal cation (Ca^{2+}, Mg^{2+}, K^+, Na^+).
Bathymetry	Measurement of the depth of an ocean or large waterbody.
Benthic Invertebrates	Invertebrate organisms living at, in or in association with the bottom (benthic) substrate of lakes, ponds and streams. Examples of benthic invertebrates include some aquatic insect species (such as caddisfly larvae) that spend at least part of their lifestages dwelling on bottom sediments in the waterbody. These organisms play several important roles in the aquatic community. They are involved in the mineralization and recycling of organic matter produced in the water above, or brought in from external sources, and they are important second and third links in the trophic sequence of aquatic communities. Many benthic invertebrates are major food sources for fish.
Biochemical Oxygen Demand (BOD)	An empirical test in which standardized laboratory procedures are used to determine the relative oxygen requirements of wastewaters, effluents and polluted waters.
Bioconcentration	A process where there is a net accumulation of a chemical directly from an

	exposure medium into an organism.
Bog	Sphagnum or forest peat materials formed in an ombrotrophic environment due to the slightly elevated nature of the bog, which tends to disassociate it from the nutrient-rich groundwater or surrounding mineral soils. Characterized by a level, raised or sloping peat surface with hollows and hummocks. Mineral-poor, acidic and peat-forming wetlands that receives water only from precipitation.
Buffering	The capability of a system to accept acids without the pH changing appreciably. The greater amounts of the conjugate acid-base pair, the more resistant they are to a change in pH.
Cations	A positively charged ion.
Chlorophyll *a*	One of the green pigments in plants. It is a photo-sensitive pigment that is essential for the conversion of inorganic carbon (e.g., carbon dioxide) and water into organic carbon (e.g., sugar). The concentration of chlorophyll a in water is an indicator of algal concentration.
Chronic	The development of adverse effects after extended exposure to a given substance. In chronic toxicity tests, the measurement of a chronic effect can be reduced growth, reduced reproduction or other non-lethal effects, in addition to lethality. Chronic should be considered a relative term depending on the life span of the organism.
Conductivity	A measure of the capacity of water to conduct an electrical current. It is the reciprocal of resistance. This measurement provides an estimate of the total concentration of dissolved ions in the water.
Dissolved Organic Carbon (DOC)	The dissolved portion of organic carbon water; made up of humic substances and partly degraded plant and animal materials.
Dissolved Oxygen (DO)	Measurement of the concentration of dissolved (gaseous) oxygen in the water, usually expressed in milligrams per litre (mg/L).
Electrofishing	A ‘live’ fish capture technique in which negative (anode) and positive (cathode) electrodes are placed in the water and an electrical current is passed between the electrodes. Fish are attracted (galvano-taxis) to the anode and become stunned (galvano-narcosis) by the current, allowing fish to be collected, measured and released.
Epilimnion	A freshwater zone of relatively warm water in which mixing occurs as a result of wind action and convection currents.
Esker	Long, narrow bodies of sand and gravel deposited by a subglacial stream running between ice walls or in an ice tunnel, left behind after melting of the ice of a retreating glacier.
Eutrophic	The nutrient-rich status (amount of nitrogen, phosphorus and potassium) of an ecosystem.
Eutrophication	Excessive growth of algae or other primary producers in a stream, lake or wetlands as a result of large amounts of nutrient ions, especially phosphate or nitrate.
Evaprotranspiration	A measure of the capability of the atmosphere to remove water from a location through the processes of evaporation and water loss from plants (transpiration).
Forage Fish	Small fish that provide food for larger fish (e.g., longnose sucker, fathead minnow).
Glaciofluvial	Sediments or landforms produced by melt waters originating from glaciers or ice sheets. Glaciofluvial deposits commonly contain rounded cobbles arranged in bedded layers.
Glaciolacustrine	Sediments that were deposited in lakes that formed at the edge of glaciers when the glaciers receded. Glaciolacustrine sediments are commonly laminar deposits of fine sand, silt and clay.

Groundwater	That part of the subsurface water that occurs beneath the water table, in soils and geologic formations that are fully saturated.
Hydraulic Gradient	A measure of the force of moving groundwater through soil or rock. It is measured as the rate of change in total head per unit distance of flow in a given direction. Hydraulic gradient is commonly shown as being dimensionless, since its units are metres/metre.
Hydrogeology	The study of the factors that deal with subsurface water (groundwater) and the related geologic aspects of surface water. Groundwater as used here includes all water in the zone of saturation beneath the earth's surface, except water chemically combined in minerals.
Hydrology	The science of waters of the earth, their occurrence, distribution, and circulation; their physical and chemical properties; and their reaction with the environment, including living beings.
Morphology	Morphology or fluvial geomorphology is the term used in the description of closure drainage designs that replicate natural analogues. It describes the process and the structure of natural systems that are to be replicated in constructed drainage channels, including regime relationships for various channel parameters such as width, depth, width/depth ratio, meander wavelength, sinuosity, bed material, gradient and bank slope.
Nitrogen Oxides (NO_X)	A measure of the oxides of nitrogen comprised of nitric oxide (NO) and nitrogen dioxide (NO_2).
Oligotrophic	Trophic state classification for lakes characterized by low productivity and low nutrient inputs (particularly total phosphorus).
Outliers	A data point that falls outside of the statistical distribution defined by the mean and standard deviation.
Peatlands	Areas where there is an accumulation of peat material at least 40 cm thick. These are represented by bog and fen wetlands types.
Pelagic	Inhabiting open water, typically well off the bottom. Sometimes used synonymously with limnetic to describe the open water zone (e.g., large lake environments).
Permafrost	Permanently frozen ground (subsoil). Permafrost areas are divided into more northern areas in which permafrost is continuous, and those more southern areas in which patches of permafrost alternate with unfrozen ground.
pH	The degree of acidity (or alkalinity) of soil or solution. The pH scale is generally presented from 1 (most acidic) to 14 (most alkaline). A difference of one pH unit represents a ten-fold change in hydrogen ion concentration.
Piezometre	A pipe in the ground in which the elevation of water levels can be measured, or a small diameter observation well.
Polygon	The spatial area delineated on a map to define one feature unit (e.g., one type of ecosite phase).
Potential Acid Input	A composite measure of acidification determined from the relative quantities of deposition from background and industrial emissions of sulphur, nitrogen and base cations.
Riparian	Refers to terrain, vegetation or simply a position next to or associated with a stream, floodplain or standing waterbody.
Runoff	The portion of water from rain and snow that flows over land to streams, ponds or other surface waterbodies. It is the portion of water from precipitation that does not infiltrate into the ground, or evaporate.
Sedge	Any plant of the genus Carex, perennial herbs, often growing in dense tufts in marshy places. They have triangular jointless stems, a spiked inflorescence and long grass-like leaves which are usually rough on the margins and midrib. There are several hundred species.

Sediment	Solid material that is transported by, suspended in, or deposited from water. It originates mostly from disintegrated rocks; it also includes chemical and biochemical precipitates and decomposed organic material, such as humus. The quantity, characteristics and cause of the occurrence of sediment in streams are influenced by environmental factors. Some major factors are degree of slope, length of slope soil characteristics, land usage and quantity and intensity of precipitation.
Solar Radiation	The principal portion of the solar spectrum that spans from approximately 300 nanometres (nm) to 4,000 nm in the electromagnetic spectrum. It is measured in W/m^2, which is radiation energy per second per unit area.
Thermokarst	Pock-marked topography in northern regions caused by the collapse of permafrost features.
Total Dissolved Solids	The total concentration of all dissolved compounds solids found in a water sample. See filterable residue.
Total Organic Carbon	Total organic carbon is composed of both dissolved and particulate forms. Total organic carbon is often calculated as the difference between Total Carbon (TC) and Total Inorganic Carbon (TIC). Total organic carbon has a direct relationship with both biochemical and chemical oxygen demands, and varies with the composition of organic matter present in the water. Organic matter in soils, aquatic vegetation and aquatic organisms are major sources of organic carbon.
Total Suspended Particulate (TSP)	A measure of the total particulate matter suspended in the air. This represents all airborne particles with a mean diameter less than 30 µm (microns) in diameter.
Total Suspended Solids (TSS)	The amount of suspended substances in a water sample. Solids, found in wastewater or in a stream, which can be removed by filtration. The origin of suspended matter may be artificial or anthropogenic wastes or natural sources such as silt.
Toxic	A substance, dose or concentration that is harmful to a living organism.
Trophic	Pertaining to part of a food chain, for example, the primary producers are a trophic level just as tertiary consumers are another trophic level.
Wetlands	Wetlands are land where the water table is at, near or above the surface or which is saturated for a long enough period to promote such features as wet-altered soils and water tolerant vegetation. Wetlands include organic wetlands or “peatlands,” and mineral wetlands or mineral soil areas that are influenced by excess water but produce little or no peat.
Young-of-the-year (fish)	Fish at age 0, within the first year after hatching.