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 post-closure. 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 post-closure) are presented in Table 8.8-13. Results for phosphorus, following the application of supplemental mitigation strategies (described below), are provided in Table 8.8-14. 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 Post-closure

Regulated Parameter	Units	Water Quality Guidelines [(a)]	Kennady Lake Baseline WQ	Projected Values / 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
Nitrogen - 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 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

Table 8.8-13 Predicted Water Quality in Kennady Lake for Post-closure (continued)

Regulated Parameter	Units	Water Quality Guidelines [(a)]	Kennady Lake Baseline WQ	Projected Values / Concentrations in Kennady Lake	
				Maximum Post-closure Concentration [(b)]	Expected Long-term Steady State Concentration [(b)]
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
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.

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

Table 8.8-14 Projected Phosphorus Concentrations in Kennady Lake for Post-closure with Supplemental Mitigation Strategies

Regulated Parameter	Units	Water Quality Guidelines	Kennady Lake Baseline WQ	Projected Values / Concentrations in Kennady Lake	
				Maximum Post-closure Concentration	Expected Long-term Steady State Concentration
Phosphorus - Nutrients					
Dissolved phosphorus	mg/L	-	0.0048	0.021	0.016
Total phosphorus	mg/L	-	0.0048	0.023	0.018

WQ = water quality; mg/L = milligrams per litre

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).

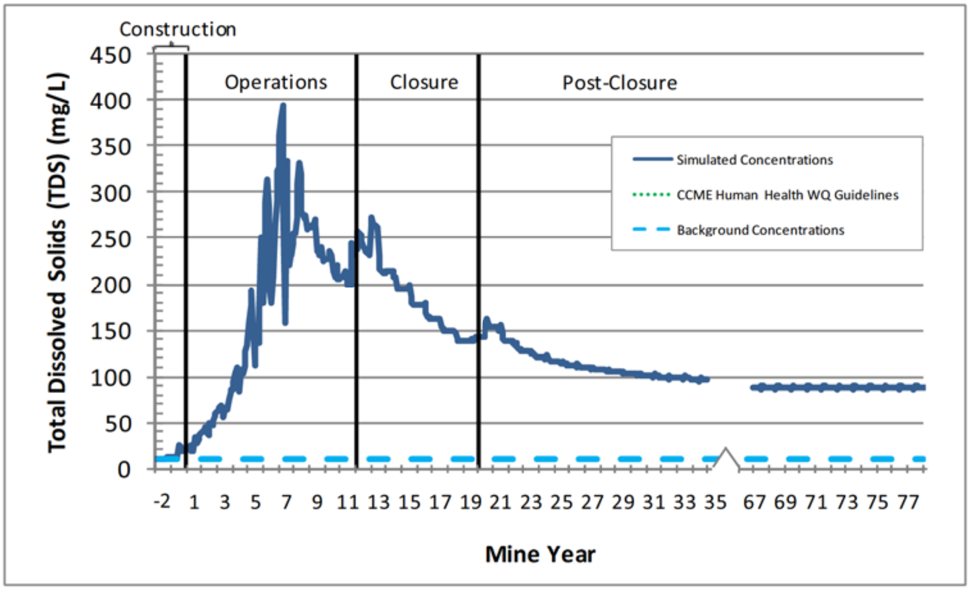
In post-closure, concentrations are predicted to continue to decline as Kennady Lake receives fresh water inflows (i.e., natural drainage) from the basin and Dyke A is breached. In one to two decades of post-closure, concentrations are predicted to approach steady state at slightly less than 100 mg/L 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 post-closure due to continued loading from geochemical sources.

The long-term results presented for post-closure 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 PKC Facility, mine rock piles and the Coarse PK Pile, 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.

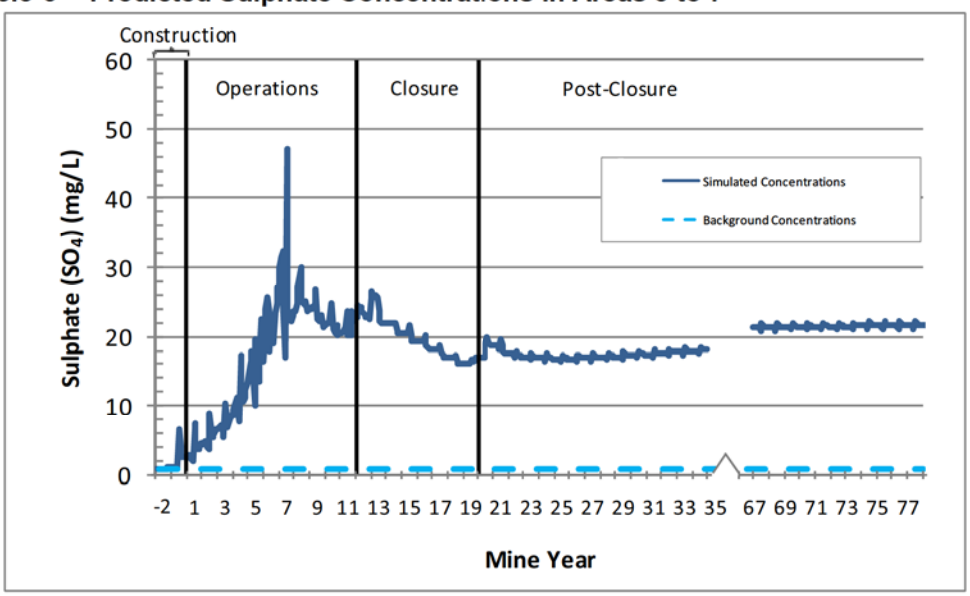
There are no CCME guidelines for TDS or any of the major ions. To put the predicted concentrations into context, TDS and all major ions are predicted to remain above background conditions but below levels that would affect aquatic health (see Section 8.9.3.1.1).

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:

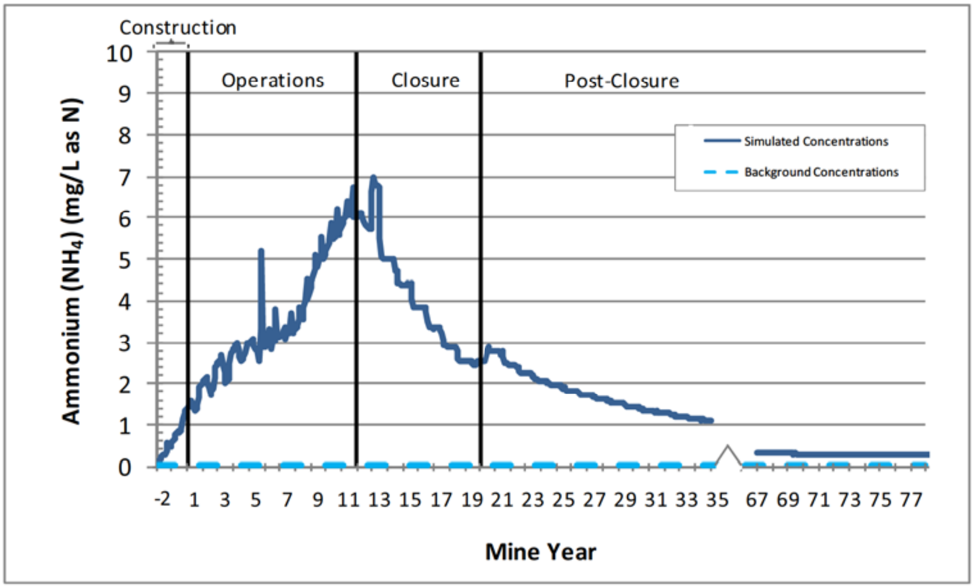
- the most bioavailable forms of nitrogen;
- potential contributors to aquatic toxicity; and
- the predominant forms released in explosives residue.

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 operations, 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).

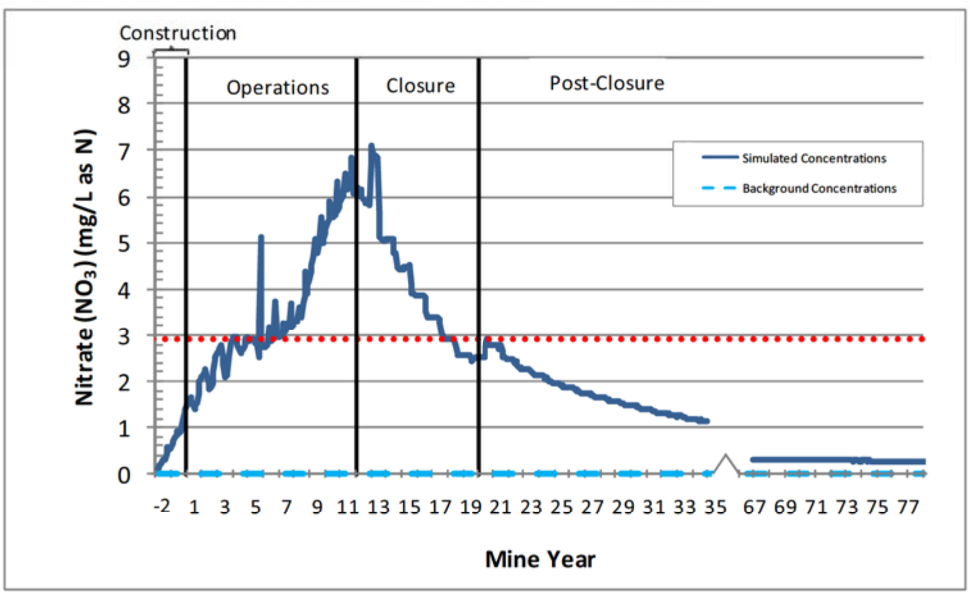
Total nitrogen, for which there is no CCME guideline, is predicted to follow a similar pattern, as it is predominantly comprised of nitrate and ammonia. Based on the total nitrogen concentrations predicted for post-closure, nitrogen is not anticipated to be a limiting nutrient.

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

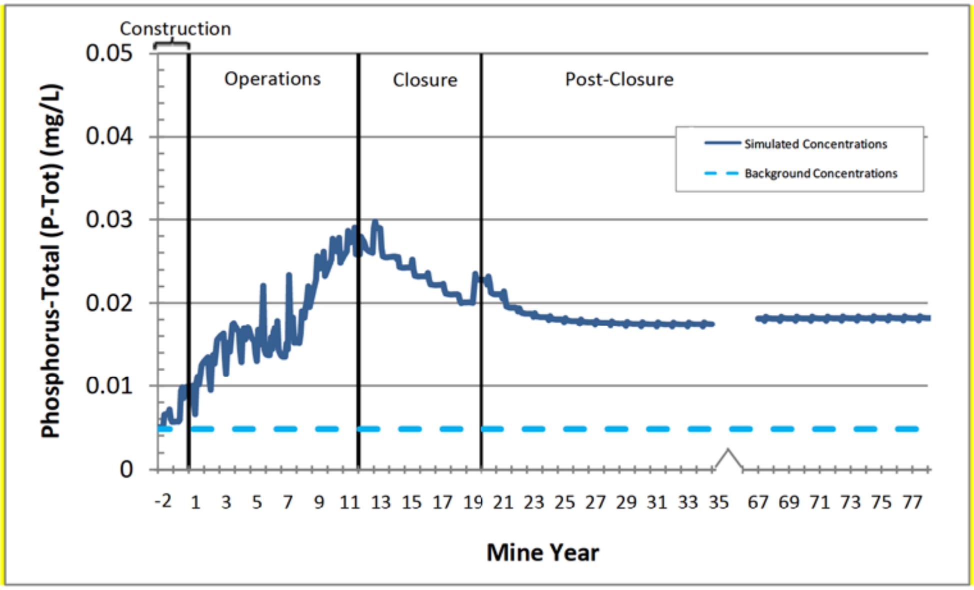
Phosphorus plays an important role in freshwater systems primarily because of its importance in biological metabolism. In contrast to the availability of other nutrients to biota (e.g., carbon and nitrogen), phosphorus is generally the least abundant nutrient. This lack of natural availability commonly leads to phosphorus limitation in lakes, which affects biological productivity (i.e., low autotrophic productivity). Most natural lakes are considered phosphorus-limited or co-limiting with nitrogen.

Concentrations of phosphorus are projected to increase in Areas 3 to 7 of Kennady Lake during the operations phase due to loading to the WMP from process water, runoff and seepage inputs from Project facilities, and groundwater inputs. Concentrations are then projected to decrease during the closure phase due to the refilling of Kennady Lake, and then gradually increase to steady state concentrations in post-closure. The long-term phosphorus increases result from seepage through the mine rock piles, Coarse PK Pile, and the Fine PKC Facility, which eventually flows to Kennady Lake. More specifically, phosphorus is mobilized into seepage flows that come into contact with mine rock, coarse PK, and fine PK material as flows travel through the external structures, with fine PK in saturated conditions being the largest contributing source of phosphorus.

The modelled phosphorus projections outlined in Table 8.8-14 and Figure 8.8-9 were developed assuming contact of seepage flows with materials located in the mine rock piles, the Coarse PK Pile, and the Fine PKC Facility, including the supplemental mitigation associated with the fine PK deposit in the Fine PKC Facility. Long-term steady state water quality projections of total phosphorus of 0.018 mg/L were developed by setting water quality parameter concentrations based on ranked statistical measurements in the geochemical testing of mine rock, coarse PK, and fine PK completed in support of the EIS (Appendix 8.I, Attachment 8.I.3). As described in Section 8.8.2.1.1, water quality modelling did not include the aggradation of permafrost through the mine rock piles, the Coarse PK Pile, and the Fine PKC Facility.

The majority of the total phosphorus predicted to be present in Kennady Lake in post-closure is expected to be dissolved phosphorus, because it is likely to largely originate from geochemical reactions that occur within the mine rock piles, the Coarse PK Pile, and Fine PKC Facility. As a result, trends of these two parameters are predicted to be similar. There is no current CCME guideline for total or dissolved phosphorus.

Figure 8.8-9 Predicted Total Phosphorus Concentrations in Areas 3 to 7 with Supplemental Mitigation Strategies



mg/L = milligrams per litre

Without supplemental mitigation (i.e., mitigation as described below), modelling has shown that the concentration of total phosphorus in Kennady Lake during post-closure would increase to approximately 0.030 mg/L. Baseline concentrations of total phosphorus are typically lower, with a range of <0.001 to 0.010 mg/L. This nutrient enrichment could increase the productivity of the lake by two trophic levels, from oligotrophic to meso-eutrophic. This is likely to have implications on habitat for cold-water fish species, such as lake trout. Nutrient enrichment effects would extend further downstream beyond Kennady Lake. For these reasons, supplemental mitigation will be added.

Three mitigation strategies are being considered for the Fine PKC Facility, since fine PK is the largest source of phosphorus to the lake. These strategies include:

- reducing the overall footprint area of fine PK in the facility;
- reducing the potential for overall infiltration of water into the facility; and
- reducing seepage contact with materials with the potential to release elevated concentrations of phosphorus.

De Beers is committed to incorporating additional mitigation to achieve a long-term maximum steady state total phosphorus concentration of 0.018 mg/L in Kennady Lake. Pre-screening of the strategies listed above is underway and, where available, key information from this analysis, including the required reduction in flows through the fine PK needed to achieve the target phosphorus concentration, has been incorporated into the water quality modelling for Kennady Lake.

Prior to construction of the facility, and throughout operations, additional geochemical testing will be completed to obtain additional information about the potential for fine PK and other site materials to be a source of total phosphorus to Kennady Lake.

The environmental relevance of the predicted total phosphorus levels is discussed below, with reference to dissolved oxygen levels in Kennady Lake, and in Section 8.10 with respect to primary productivity and fish and fish habitat.

Potential Effects of Nutrient Enrichment

Phosphorus is generally a limiting nutrient in freshwater systems, so its concentration can determine trophic status. Kennady Lake can be classified as an oligotrophic lake, based on the total phosphorus during ice-covered concentrations ranging from <0.001 to 0.010 mg/L, and <0.001 and 0.006 mg/L during open water conditions (Section 8.3.4). Based on the long-term steady state total phosphorus concentration projected in Kennady Lake during post-closure (0.018 mg/L), the trophic status in Kennady Lake is expected to shift from oligotrophic to mesotrophic (CCME 2004; Environment Canada 2004).

Increased growth of algae would result in a larger amount of total organic carbon remaining in the lake after senescence each fall. The decomposition of this organic carbon will exert an oxygen demand over winter, after the ice has formed and atmospheric re-aeration has been cut off. Under these isolated water column conditions, photosynthesis and water mixing potential are substantially reduced. The rate of dissolved oxygen consumption in under-ice conditions is dependent on a set of biochemical factors including vital functions of various organisms (especially benthic community), concentrations of organic matter, and dissolved oxygen concentrations in the near-bottom layers of lakes (Mathias and Barica 1980; Golosov et al. 2007).

Three empirical models for Canadian lakes were used to determine a range of WODRs to estimate end of winter dissolved oxygen concentrations in specific depth zones of Kennady Lake based on the projected long-term steady state phosphorus concentration of 0.018 mg/L (Appendix 8.V). WODRs in Kennady Lake were estimated to be 32 to 106% higher during post-closure compared to baseline conditions, with the increased oxygen demands expected to affect 22% of the water volume in Kennady Lake (i.e., primarily depths below 6 m).