Land and Water Boards of the Mackenzie Valley

Technical Reference Document for the Method for Determining Available Winter Water Volumes for Small-Scale Projects

April 7, 2021

Produced by Hutchinson Environmental Sciences Limited

Contents

1.0 Introduction

In the Northwest Territories, winter activities such as ice road construction and exploratory drilling require the use of water from ice-covered water bodies. Excessive water withdrawal threatens fish habitat through depletion of oxygen-rich waters, loss of open water habitat volume, loss of littoral habitat, and exposure of fish eggs to freezing conditions. The Land and Water Boards of the Mackenzie Valley (the Boards) reference the Department of Fisheries and Oceans 2010 "Protocol for Winter Water Withdrawal from Ice-covered Waterbodies in the Northwest Territories and Nunavut" (the DFO Protocol, DFO 2010)[1] to ensure sustainable winter water withdrawals from ice-covered water bodies. The DFO Protocol limits winter water withdrawal to 10% of the under-ice water volume and requires the use of detailed bathymetric methods (DFO 2010, Cott et al. 2005) in order to estimate water volumes in a water body such that the allowable 10% withdrawals can be determined.

Quantitative assessments of lake volumes are required for all stages of a development and applicants are required to assess the ability of each proposed water source to provide sufficient water needs at the time of application for a water licence. Financial constraints on proponents during early exploration, however, often means that the expertise and resources required to measure bathymetry and estimate volume in water bodies according to the DFO protocol are not available until later stages of the project. Proponents have stated that, for some applications, detailed bathymetric methods require disproportionate expertise and effort and have requested guidance on simpler means to estimate water volumes. For example, in relation to mineral exploration, Golder (2019) reiterates this challenge as follows:

> *Drills are moved frequently depending on the results as they come in during the drilling campaign. Conducting bathymetry on a lake prior to withdrawal is also not feasible for an exploration project as the collection of detailed bathymetry information requires separate, specialized equipment for both summer and winter seasons, skilled and trained staff, and several days to a week to process the data; the resulting delay makes it impractical or unfeasible to collect bathymetry data for an exploration program. It would also incur additional costs for the proponent that may not be proportional to the small water withdrawals and limited environmental impacts of drilling.*

In response, the Boards, and the Government of the Northwest Territories – Environment and Natural Resources (GNWT-ENR) initiated the "Water Source Guidance Project" in 2019 to develop a simple method that could be applied to estimate available under-ice water volumes in support of early-stage exploration or small-scale applications to use water. The intent was to determine a simple method that would provide a conservative volume estimate that can be used without the need for detailed bathymetry.

---

[1] The DFO protocol applies to "water bodies" - lakes and ponds. Water takings from rivers are assessed by other means although the DFO threshold is still a withdrawal of 10% that is applied to instantaneous flow. (DFO 2013)

This document describes the technical process used to develop a method that could estimate water withdrawal volumes that would meet the limits outlined in the DFO Protocol, but which could be completed without the need for formal bathymetric surveys of lakes. The process used the following steps:

1. Review of methods submitted in response to a request by the Boards and GNWT-ENR (Section 3).
2. Literature review for other methods (Section 4).
3. A feasibility assessment of the submitted methods by testing them against a set of lakes in which bathymetry was measured using the DFO Protocol (Section 5).
4. Presentation and discussion of initial results and the preferred approach at a workshop in Yellowknife.
5. Testing of the preferred method on three bathymetric data sets to account for the effect of ice cover on estimates of available water (Section 7).
6. Documentation of the preferred method in a Guidance document.

2.0 Existing Guidance

At the simplest level, the volume of a water body is estimated as:

Volume (m3) = Surface Area (m2) X Average Depth (m)

Surface area is easily determined from existing mapping, air photo interpretation or Google Earth imagery but average depth can only be determined as a) direct measurement for a simple water body with uniform depth or b) measurement of detailed bathymetry using standard bathymetric procedures. Cott et al (2005) outline the requirements for conducting bathymetric surveys using the DFO Protocol.

The Cott et al (2005) study[2] lakes ranged from a maximum depth of 1.9 m to 28 m and from a maximum length of approximately 0.5 km to approximately 6.5 km. Lake size was not related to lake depth, with a third of the lakes ~1 km long being ~3.5 m in maximum depth and almost half of lakes <1 km in length having maximum depths >3.5 m. The authors conclude "*Given the inherent variability of natural lakes, it is essential that bathymetry is gathered with rigor in order to adequately estimate volume.*"

Where it is not feasible to collect the necessary bathymetric data, however, estimates of water volume can only be made if:

a) There is a reliable way to estimate average depth from available data (i.e., a relationship between average depth and surface area - which was not present in the Cott et. al (2005) analysis); or
b) There is a reliable model of volume derived from bathymetry that is sufficiently accurate and conservative that it can be generally applied to all lakes to ensure that it does not exceed DFO's allowable 10% water withdrawal.

The intent of the Water Source Guidance Project, therefore, was to review simple methods that can be applied to conservatively estimate available water volumes without the need for detailed bathymetry.

[2] The text of the report states that 55 lakes were measured. Bathymetric profiles are presented for 55 lakes in the appendix, but morphometric summaries were only provided for 37 lakes.

3.0 Summary of Technical Submissions

On October 18, 2019, the Boards and GNWT-ENR requested technical submissions on proposed methods for estimating available water source volume, particularly from lakes. Three submissions were received: from the NWT-Nunavut Chamber of Mines, Golder Associates, and NorEx Engineering on behalf of the Northwest Territories Power Corporation (NTPC). TerraX (now Gold Terra Resources Corp.) also contacted Hutchinson Environmental Sciences Limited (HESL) about including information from its Yellowknife Gold Project (found on the MVLWB Public Registry). All submissions were reviewed for their ability to estimate lake volumes accurately and conservatively. The submissions are summarized below.

3.1 NWT-Nunavut Chamber of Mines: Determining Water Source Capacity – Development of Joint Guidance by the Land and Water Boards and the Government of the Northwest Territories. November 7, 2019.

The NWT-Nunavut Chamber of Mines submission did not provide a method for bathymetric estimation. It documented their concerns with the need for bathymetric estimates and stated support for the procedure developed by Golder Associates that informed the Nighthawk Gold Indin Lake submission that was provided for consideration in the development of joint guidance.

3.2 Golder Submission: Technical Memorandum "Proposed Approach to Determining Water Source Capacity for Mineral Exploration Projects." November 12, 2019.

Golder provided a detailed submission with a summary of available water estimates that were derived in support of two developments - an ice road development for the Back River Project (Golder 2018) which required 675 m3 of water per kilometer of ice road and the Nighthawk Gold Indin Lake Project.

The Golder submission concluded "*Based on a technical memorandum prepared by Golder for the Back River Project (Golder 2018), the withdrawal of a 10% under-ice volume during winter may result in mean water level change of 0.183 m (standard deviation [SD] ± 0.065 m) for waterbodies that range in area from 2 to 93 ha (n = 41). Therefore, Golder proposes a water level change of 12 cm or less (i.e., 0.183 minus 1 SD reported in Golder [2018]) as a conservative threshold for protecting aquatic habitat during water withdrawals.*" It therefore follows that:

"Allowable water taking = Lake Area (m2) X 0.12"

For the Back River Project (Golder 2018), water volumes of 41 water bodies, ranging in size from 2 ha to 93 ha, were calculated using detailed bathymetric profiles for each water body which were estimated by remote sensing. A GIS system was used to develop a Digital Elevation Model (DEM) for 118 waterbodies and watersheds using photogrammetric interpretation of stereo, 8 band, 50 cm satellite imagery collected in August 2017 by Digital Globe's Worldview-2 satellite. Areas would be easily calculated by this method.

Golder used the interpreted slope of the terrain surrounding each water body to derive the slopes entering the water bodies and extrapolated from there to estimate water depth from the blue and green satellite spectral bands which "*allow the identification of detailed lakebed topography to a depth of 30 m*". Comparison of this method with volumes derived using the DFO bathymetry protocol (Table 7 in Golder 2018) showed that the GIS model overestimated the volume by, on average, 9% (range 6.2% to 37%).

On average, a calculation of 10% of the under-ice volume was equivalent to a water level decrease of 0.183 +/- 0.065 m. A conservative estimate of an acceptable water withdrawal over one year was therefore recommended as 12 cm (mean minus one standard deviation (SD)).[3] Golder (2019) then translated this finding into the following guidance:

- *Calculate surface area for each possible water source (can be completed in Google Earth [i.e., using the Ruler tool] or within a Geographic Information System using spatial data that are publicly accessible through federal government websites).*
- *Estimate the annual available volume for each water source less than 100 ha*[4] *in size by multiplying the surface area by 12 cm*.

The DFO's allowable water withdrawal of 10% was intended for under-ice volume estimates. Although, the Golder Back River Model was also based on under ice water volume, the calculation is based on surface area which was derived from the lake surface (e.g., Google Earth), not on the smaller surface area that would be available beneath ice cover. Estimating under-ice volumes based on surface area therefore risks overestimating the available water beneath the ice. This is addressed in Section 6 of this technical memorandum.

The Golder submission also referenced the Nighthawk (2019) Gold Indin Lake Project, for which areas were derived using 1:50,000 CanVec hydrographic feature data (NRCAN 2017). If there was no bathymetry data, it was assumed that the water body had a maximum depth of 3 m - accounting for 1.5 m of ice and 1.5 m of water depth below ice. Water bodies that had a maximum depth <3 m would not be considered as water source candidates. If maximum depth exceeded 3 m then the average depth of water was assumed to be 1 m and volume was calculated as area X 1 m. The method required field confirmation – in that case a minimum of three measurements taken within 500 m of the water intake were required to exceed 3 m.[5]

[3] While this is a useful summary, the average comes from a large range of lake sizes and so a water level drawdown of 12 cm may represent >10% of the volume of a small lake, although the derivation as "mean – 1 SD" would incorporate a certain fraction of the smaller lakes.

[4] Golder (2019) states "This threshold of 100 ha is proposed as a reasonable limit for the possibility of environmental effects resulting from withdrawal from a single waterbody source for mineral exploration drilling. For example, waterbodies larger than 100 ha in size can be exempt from additional calculations and monitoring because impacts to a lake this size would be negligible, and because a lake of this size of this size contains more water available for withdrawal than is allowable under Type B water licence ([100 ha x 0.12 m] / 365 days = 329 m3/day)."

[5] This confirmation was not verified or tested in the submission.

The two Golder approaches were carried forward for analysis:

- 12 cm as an assumed safe withdrawal from all water bodies ("Golder Back River").
- 10% of the volume calculated using area and an assumed average depth of 1 m ("Golder Nighthawk").

3.3 NorEx Engineering – for Northwest Territories Power Corporation (NTPC): Technical Input - Proposed Alternate Approach to Determine Water Source Capacity (IFR). November 6, 2019.

The NorEx/NTPC submission provided an alternative method for volume estimation. The submission respected the DFO protocol regarding:

- The extent of the water source is the ordinary high-water mark of the basin and excludes connecting watercourses
- The water body has >1.5 m of water depth when ice covered
- The allowable water withdrawal of 10% of under-ice volume
- Available Volume = Total Volume (Water Source) – Ice Volume (Max Thickness)

The submission proposed two approaches:

1. A "Maximum Depth" approach in which total water volume was estimated as:

   Total Volume (Water Source) = (Area X Depth) / 3, where

   Depth = **assumed maximum depth** of 3 m

This calculation assumes that water bodies are cone shaped as per the formula: Cone volume: *V= (πr2 h/3)*. Although area can be calculated from imagery such as Google Earth, the submission was not helpful on how to estimate depth, suggesting "onsite surveys (if available) or estimated based on available topographic information)."

2. An "Average Depth" approach in which an average depth of 1.5 m was assumed was also proposed as a standard conservative estimate:

   Total Volume (Water Source) = (Area X Depth), where

   Depth = **assumed average depth** of 1.5 m

The submission provided the following qualifiers to both approaches:

a) resolution/accuracy of public maps is 1:20,000 or 1:50,000 so there is some uncertainty in the calculation of surface area;
b) it may be hard to define the high-water mark from aerial imagery; and
c) the water body may not be conical i.e., the relationship of maximum depth to volume may not be a function of 3.

The two NorEx/NTPC approaches were carried forward for analysis:

The "Maximum Depth" model: Volume = (Area X Maximum Depth)/3

The "Average Depth" model: Volume = Area X 1.5

3.4 TerraX: Submission to the Mackenzie Valley Land and Water Board. January 25, 2019.

TerraX used bathymetric contours for three lakes which had been reported in a 1979 DFO report (Prosperous, Walsh and Banting) and for two lakes for which bathymetric contours were available from a previous drilling program (Daigle and Milner Lakes, TerraX, 2019). These were used to generate a 3-dimensional model of lake volumes and average depths (Table 1).

Table 1: Source bathymetry data for TerraX lakes

	Area (ha)	Volume (m3)	Average Depth (m)	Classification
Prosperous Lake	3349	1,025,100,000	30.6	Deep
Walsh Lake	877	77,367,000	8.8	Shallow
Banting Lake	369	45,002,000	12.2	Intermediate
Milner Lake	40.8	2,515,000	6.2	Shallow
Daigle Lake	13	1,518,000	11.7	Deep

Walsh and Milner Lakes were classified as "shallow" and Prosperous and Daigle as "deep". Banting was classified as intermediate and not carried forward for the modelling exercise.[6] Lake area was derived from CanTopo 1:50,000 mapping in a GIS platform. Power relationships were developed for "shallow" and "deep" lakes which related area to volume:

Shallow Lakes: Volume = 6843654 X Area1.16939

Deep Lakes: Volume = 16621633 X Area1.173949

[6] The text of the TerraX submission does not support the depth classifications presented in Table 3. Although Banting Lake was classified as "intermediate" its average depth exceeded that of Daigle Lake, which was classified as "deep". No explanation was provided.

This relationship was applied to estimate the volumes of 934 lakes in their exploration permit area from which the 10% volume was calculated to meet the DFO Protocol requirement. No knowledge of lake depth was assumed - instead, all lakes were modelled with both equations to provide a range of available volumes.

This approach has the advantage of being developed using bathymetric data collected using approved methods (though out of date) but proceeds with no knowledge of lake depth and with a very limited data set of measured lake volume – the power relationships were developed using two data points for each of the “shallow” and “deep” classifications. It could be applied using lake areas derived quickly using Google Earth or other available mapping to estimate area. It would best be applied assuming a lake was shallow as a conservative estimate or used as the basis for a routine in which lake depth was measured from several points.

The TerraX models were carried forward for analysis.

4.0 HESL Literature Review of Alternative Volumetric Estimation Methods

A literature search was completed by HESL and three alternative approaches to a traditional bathymetric survey were identified that might be used to approximate the volume of a water body. Most of the available literature and methods, however, were focussed on water withdrawal from rivers and were not applicable to lakes.

4.1 HAB-2 Modelling applied to optical true-colour imagery

Walther et al. (2011) evaluated the “Hydraulically Assisted Bathymetry” HAB-2 model to estimate depths from aerial, high resolution, film-based, true-colour imagery in the McKenzie River, Oregon. The model, however, is intended for estimation of stream flow and is not applicable to lakes.

The HAB-2 model was not carried forward for analysis.

4.2 AVIRIS Radiance Measurements

Hamilton et al. (1993) tested the accuracy of an Airborne Visible Infrared Imaging Spectrometer (AVIRIS) to measure lake depths in Lake Tahoe. The lake has a well-established dataset of depth measurements collected from traditional bathymetric surveys for comparison.

Measurements agreed well with the existing dataset within the study area to the maximum depth of 10.4 m. The authors noted that measurement accuracy was improved in low wind conditions and with greater lake transparency. It was specifically noted that oligotrophic lakes are better candidates for AVIRIS measurements given their greater clarity and resultant light penetration. The accuracy of AVIRIS depth estimates decreases with greater lake depths; while accurate measurements at depths >10.4 m are possible, they were not evaluated in this present study.

AVIRIS has been flown on four aircraft platforms: NASA's ER-2 jet, Twin Otter International's turboprop, Scaled Composites' Proteus, and NASA's WB-57 (NASA, 2019); the Twin Otter is a common aircraft in Canada’s north. The analytical approach to developing depth-based measurements from AVIRIS data used in this study is no longer applicable as more recent approaches have been developed since 1993 but AVIRIS is still an accepted approach and is currently used by NASA (2019).

Such remote sensing technology could be usefully applied over large areas to generate regional data sets of lake bathymetry, within certain limits of transparency and depth. It is a similar approach to that described in the Golder “Back River” technical submission (Section 3.2). Although it provides a means of estimating volumes of water bodies, it did not provide a simple means that could be easily applied by proponents.

The AVIRIS method was not carried forward for analysis.

4.3 Use of a Regional Dataset to Estimate Individual Lakes

Emmerton et al. (2007) used a dataset of 81 lakes in the Mackenzie River Delta, each with "only a few" measurements collected. Depth measurements were collected at least twice on each lake; once during ice cover and again during open water. Relative concentrations of major ions were compared between the two seasons to validate measurements of ice thickness by the ratio of solute exclusion (cryoconcentration). Water storage volumes were estimated for three categories of lakes based on their height above sea level (asl). Categories of lakes were as follows:

- Lakes that were <1.5 m asl were considered No-Closure Lakes. These lakes had an average depth of 4.271 m;
- Lakes that were >1.5 m asl were considered Low-Closure Lakes. These lakes had an average depth of 2.889 m; and
- Lakes that were >4.0 m asl were considered High-Closure Lakes. These lakes had an average depth of 0.818 m.

Lake volume for each was then estimated using surface area as determined by analysis of digital topographic maps. This method was based on measured lake depths and could be used to estimate lake volumes for the Water Source Guidance Project, assuming that lakes were >4.0 masl with an average depth of 0.818 m. The method may not be applicable outside of the Mackenzie River delta however, as delta lakes are founded in deposited sediments and their bathymetry likely differs from that of lakes in the rest of the Northwest Territories, which were formed on bedrock by glacial processes.

The Emmerton et al. (2007) method was not carried forward for analysis as the assumed average depth of 0.818m meant that all lakes would freeze to the bottom in winter with no available water.

4.4 Summary of Literature Search

Each of the three methods presented has advantages and drawbacks. The use of a regional dataset with lower resolution topographic maps is likely the easiest to apply once a large regional dataset has been established, but these datasets are unlikely to be available for much of the Canadian Arctic and would be costly to develop. Use of the HAB-2 model with true colour high resolution imagery is intended for use in rivers and not applicable to lakes. Finally, AVIRIS measurements are both effective over a large study area and to greater depths than the other two methods but require significant physical infrastructure (e.g., land airstrip) and are not likely to be cost effective for a small study area or individual proponent. AVIRIS measurements may be a promising option for regional governments interested in building a dataset of local water sources in a mineral rich area.

5.0 Analysis of the Alternative Methods

Appendix B of Cott et al. (2005) provides mapping of bathymetry for 55 lakes in the Mackenzie Delta Region (the DFO dataset). Bathymetry was measured during the summer season from a boat and so the volumes, areas and depths presented are for the "ice free" period. Summaries of lake volumes and areas were provided for 37 of these lakes and were transcribed to a spreadsheet for comparison with lake volume estimates derived using the methods submitted by Golder, NorEX/NTPC and TerraX (Section 3).

The lake data are presented in Appendix A1. Average depths of the 37 lakes ranged from 0.5 m to 5.3 m (average = 2.1 m), maximum depths from 1.9 m to 16 m (average = 5.5 m), surface areas from 12.5 ha to 3186 ha (average = 334 ha) and volumes from 0.13 to 44 million m3 (average = 4.4 million m3). These lakes provided an independent source of measured bathymetry for the analysis and, although they were limited to the Mackenzie Delta, they provided a greater range of depths and volumes than those in Emmerton et al. (2007).

5.1 Golder Back River Model

The Golder Back River model showed that, on average, withdrawal of 12 cm of water represented less than 10% of total lake volume and therefore met the DFO (2010) requirement for protection of fish habitat. However, when applied to the DFO dataset, the model was not sufficiently protective for seven of the 37 lakes (19%) in which a 12 cm withdrawal exceeded the 10% DFO threshold (Figure 1). Of note, the 10% DFO threshold exceedances all occurred for lakes <2 m in average depth (Figure 2).

Figure 1: Percent of total lake volume taken with 12 cm water withdrawal - Golder Back River, all lakes.

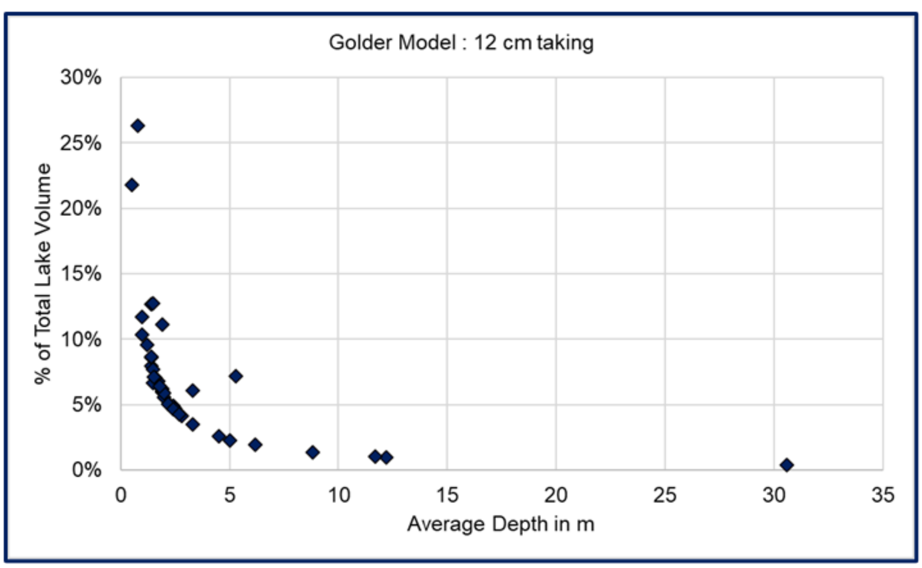
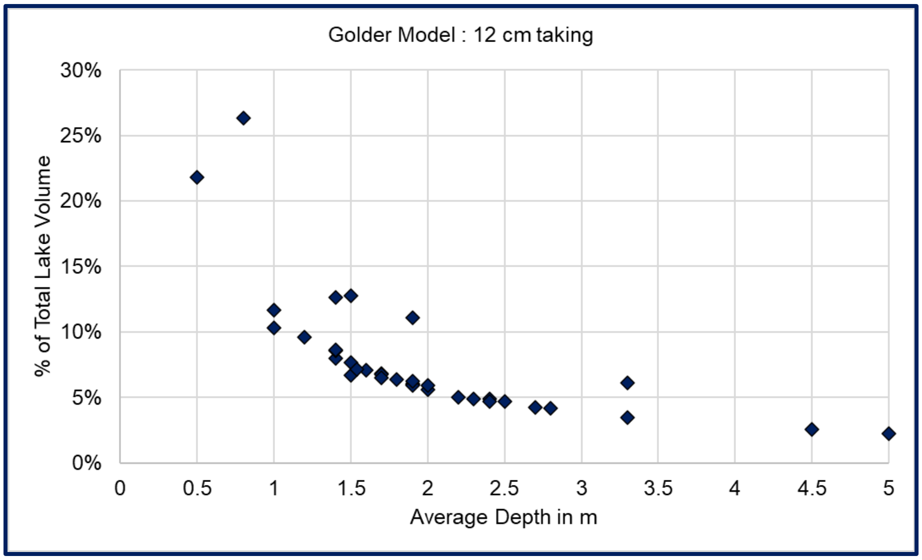
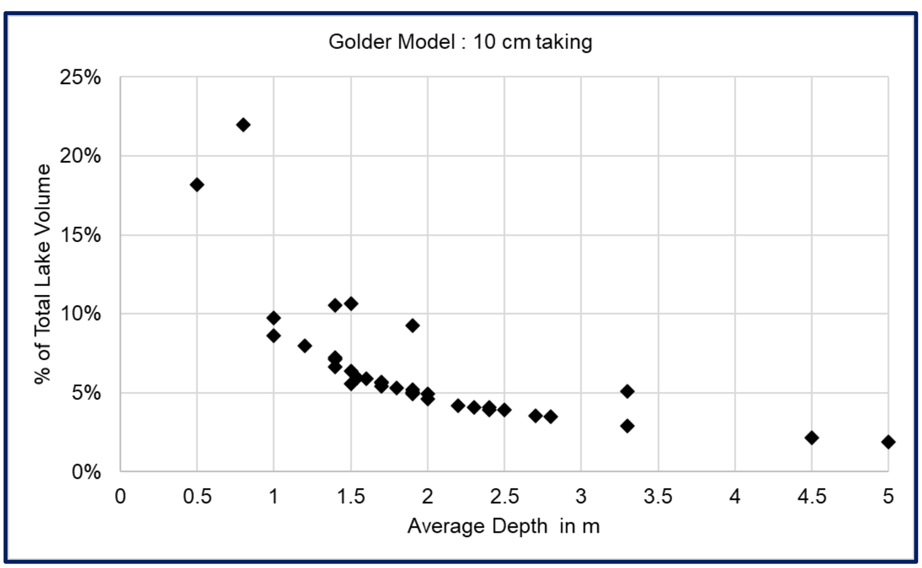


Figure 2: Percent of total lake volume taken with 12 cm water withdrawal – Golder Back River, Lakes <5 m.



Reducing the allowable withdrawal to 10 cm protected 89% of the 37 lakes - all lakes but those which were <1.5 m in depth (Figure 3). Although this analysis was done on open water (total) lake volume, it supports the DFO (2010) protocol: "*Only waterbodies with maximum depths that are >1.5 m than their corresponding maximum expected ice thickness should be considered for water withdrawal … Waterbodies with less than 1.5 m of free water beneath the maximum ice are considered to be particularly vulnerable to the effects of water withdrawal.*" Regardless of ice cover, a minimum depth of 1.5 m of water is required to support a withdrawal of 10 cm without exceeding 10% of the volume.

Figure 3: Percent of total lake volume taken with 10 cm water withdrawal – Golder Back River, Lakes <5 m.



5.2 Golder Nighthawk Model

The Golder Nighthawk model estimated volume as "Lake Area X assumed average depth of 1 m" for lakes where the maximum depth exceeded 3 m. 10% of the resultant estimate was then compared to the 10% figure derived from the DFO data set.

The Golder Nighthawk Model screened out eight of the 37 lakes in the test set that were <3 m deep, although it is recognized that, in practice, these lakes would not be screened out until such time as the required depth confirmation was made. Of the 29 remaining lakes, withdrawal of a volume corresponding to 10 cm of an assumed average depth of 1 m exceeded the DFO threshold of 10% in three lakes – habitat was thus protected in 90% of the test lakes (Figure 4). Average water depths in the lakes where withdrawal exceeded 10% were 0.8 m, 1.4 m, and 1.5 m.

In practice, volumes would be calculated from surface area for all lakes with no screening for maximum depth until field measurements were possible. If all 37 lakes were included without screening for a maximum depth of 3 m then water withdrawal exceeded 10% in four of the 37 lakes in which average depths were 0.5 m, 0.8 m, 1.4 m, and 1.5 m (Figure 5). Therefore 89% of lakes were protected. All lakes in which average depth exceeded 1.5 m were protected if maximum depth exceeded 3 m and allowable water withdrawal was calculated as "0.1 X Surface area in m." (Figure 4).

Field measurements confirming that average under-ice depth was >1.5 m was therefore more protective than field measurements confirming a maximum depth >3 m.

Figure 4: Percent of total lake volume taken with Golder Nighthawk Model, Lakes >3 m.

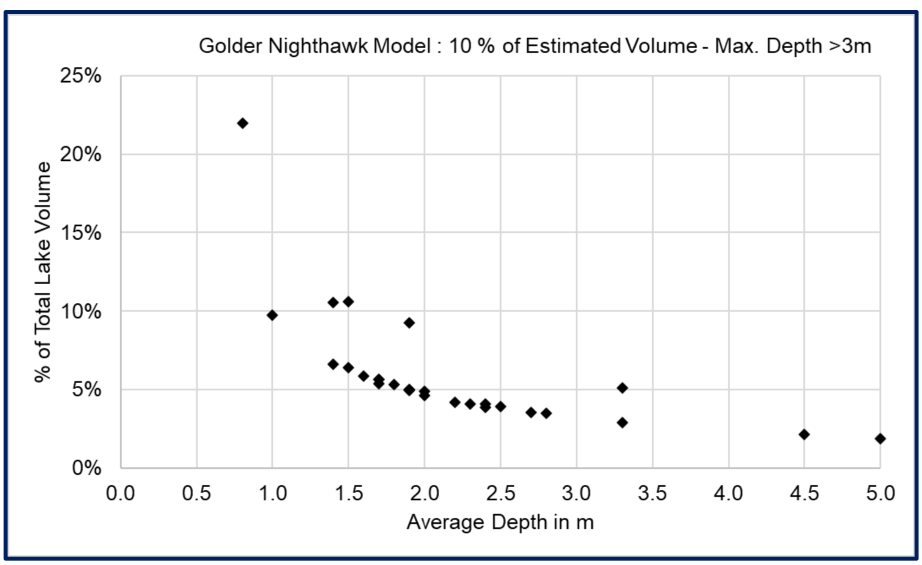
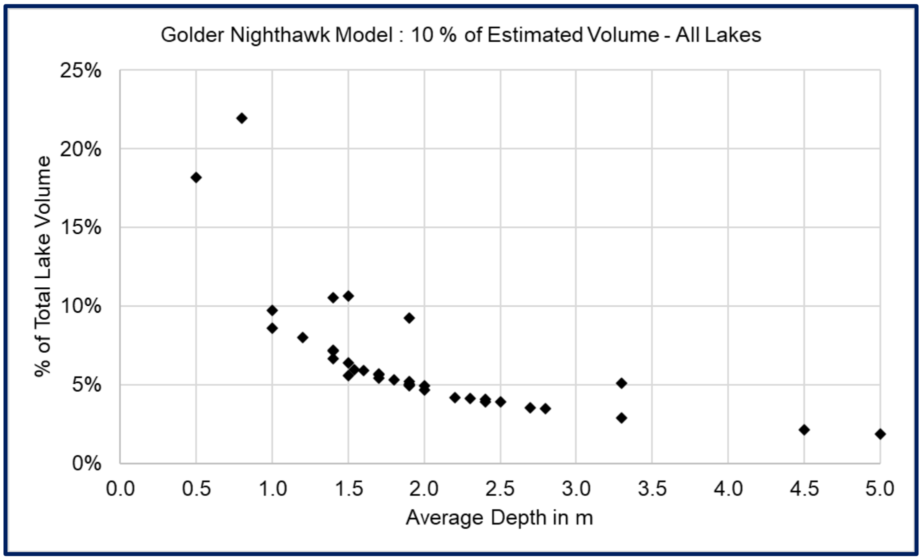


Figure 5: Percent of total lake volume taken with Golder Nighthawk Model, All Lakes.



5.3 NorEx/NTPC Model

The NorEx/NTPC Model assumed a 3 m maximum depth or a 1.5 m average depth in the absence of bathymetric information. Water volumes were calculated based on these assumptions, allowable water taking calculated as 10% of the estimated volume and then compared to 10% of the volume measured by DFO.

The “Maximum Depth Model” allowed greater water withdrawal but overestimated available water in 10 of the 37 lakes, thus only protecting habitat in 73% of the lakes in the DFO dataset (Figure 6). The magnitudes of the overestimates were larger than those in the Golder Back River and Nighthawk models. The “Average Depth Model” provided for lesser water withdrawals and overestimated available water in 4 of the 37 lakes, thus protecting habitat in 89% of the lakes in the DFO dataset (Figure 6). The magnitudes of the overestimates were larger than those in the Golder Back River and Nighthawk models.

5.4 TerraX Model

The TerraX Model used power functions to derive volumes based on area for lakes that were assumed to be deep or shallow:

Shallow Lakes:	Volume = 6843654 X Area1.16939
Deep Lakes:	Volume = 16621633 X Area1.173949

Both models produced very large overestimates of lake volume such that the estimated takings of 10% exceeded the DFO threshold for all lakes and ranged as high as 225% and 666% for the shallow and deep lake models, respectively (Figure 7). These magnitudes of error pose a substantial risk of damage to fish habitat if used as the basis for a 10% allowable volume calculation for water withdrawal.

Figure 6: Percent of total lake volume taken with NorEx/NTPC Maximum and Average Depth Models.

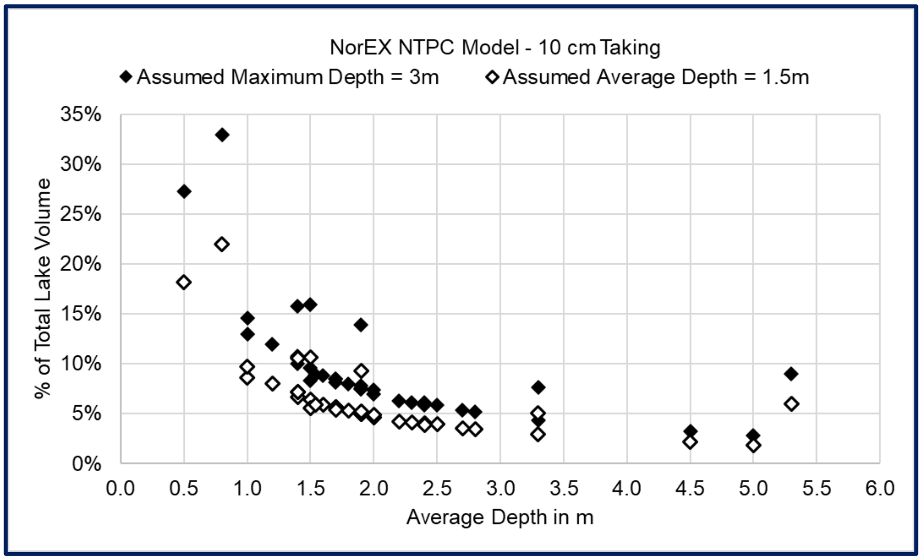
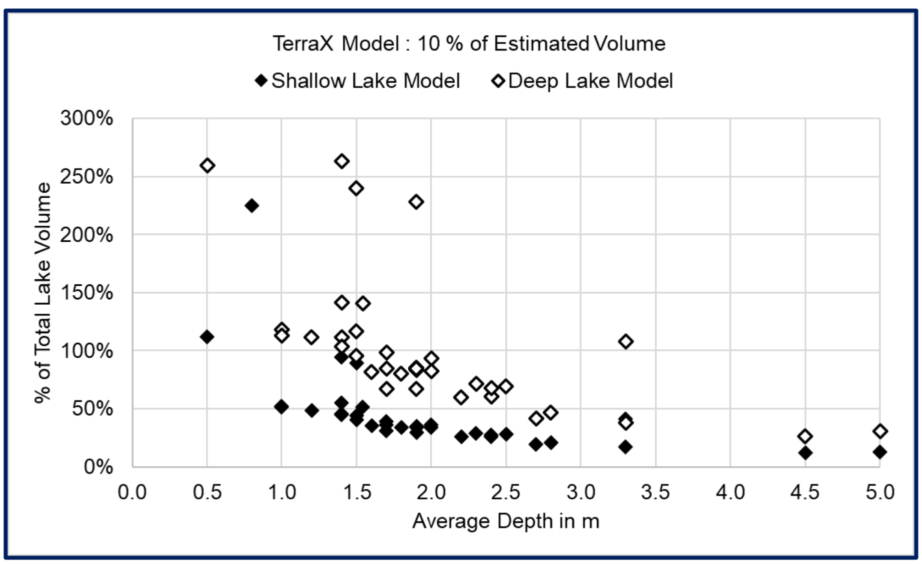


Figure 7. Percent of total lake volume taken with TerraX Shallow and Deep Lake Models.



5.5 Conclusions

The methods reviewed were, for the most part, variants of each other, using information on lake surface area derived from remote sensing techniques or existing mapping and assumptions on lake depth. These produced estimates of varying levels of accuracy when compared with volume estimates derived using the DFO approach (Cott et al. 2005).

The Golder Back River approach used the same sources to estimate lake area and a detailed GIS model of lake and terrain bathymetry to estimate depths. It recommended a conservative water withdrawal of 12 cm that could be applied to all lakes with no need for measurements. Reducing the allowable limit to 10 cm protected 92% of the 37 lakes - all lakes but three which were < 1.5 m in depth.

Although the Golder Back River method was derived using open water (total) lake volumes, it supports the DFO (2010) protocol: "*Only waterbodies with maximum depths that are >1.5 m than their corresponding maximum expected ice thickness should be considered for water withdrawal … Waterbodies with less than 1.5 m of free water beneath the maximum ice are considered to be particularly vulnerable to the effects of water withdrawal.*" Regardless of ice cover, a minimum depth of 1.5 m of water is required to support a withdrawal of 10 cm without exceeding 10% of the volume.

The Golder Back River method is therefore recommended as a viable alternative, requiring no knowledge of lake morphometry unless proponents wish to challenge findings by taking their own measurements.

6.0 Comparison of Lake Volumes Above and Below Ice Cover

Although the Golder Back River Model (the recommended guidance) was developed based on under-ice lake volumes, the application of the model reflects proponents' use of surface areas above the ice cover as derived by, for example, Google Earth or mapping. Therefore, application of the recommended 10 cm water withdrawal derived as "Surface Area X 0.1 m" will overestimate the available water under the ice, as lakes will have a smaller surface area beneath ice (and hence less volume) than they will at the surface.

Available water volumes were therefore calculated above and below ice cover for three lake sets in which detailed bathymetry and ice depth were available. All were located on Precambrian Shield terrain in the Northwest Territories and Nunavut and were therefore more representative of lake morphometry than the Mackenzie Delta lakes in the Cott et al. (2005) data set. The three lake sets used were:

1. The Golder Back River data set which assumed a 2 m ice cover.
2. The data set for lakes along the Tibbitt to Contwoyto Winter Road. In 2013, EBA (2013) published bathymetric estimates of volume and surface area above and below 1.5 m ice cover to support water withdrawal for ice road development. Appendix A provided estimates using the DFO protocol for 28 lakes, of which 12 were frozen to the bottom. The 16 lakes from Appendix A which were not frozen to the bottom were used to test the preferred approach of allowing a 10 cm withdrawal and comparing the volumes taken with and without accounting for 1.5 m of ice cover.
3. The Kennady Lake data set provided by Golder (Hunt, 2020) for lakes adjacent to the Kennady Lake Diamond Project. Detailed bathymetry data was provided for 28 lakes ranging in maximum depth from 0.8 m to 14.5 m, average depth from 0.4 m to 4.7 m and surface area from 0.4 ha to 90.1 ha. Assumed ice depth was 2 m, and bathymetry was provided for 0.25 m intervals from surface to bottom.

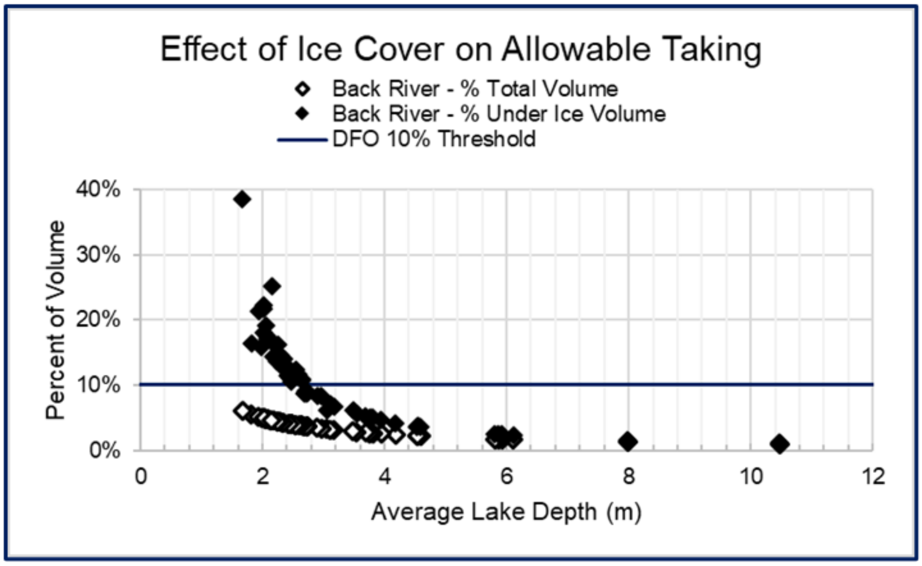
Data for each lake set is provided in Appendix A.

6.1 Golder Back River Lakes

The Golder Back River data set assumed a 2 m ice cover. On average, the under-ice volume was 44% +/- 18% of the total water volume. Average lake depth ranged from 1.7 m to 34 m.

- The allowable water withdrawal of 10 cm amounted to 0.3% – 6% (average = 3.5%) of the total lake volume, well within the DFO Protocol of 10% (Figure 8).
- The allowable water withdrawal of 10 cm amounted to 0.3% – 38% (average = 10.6%) of the under-ice volume and exceeded the DFO Protocol of 10% in 26 of the 54 lakes (Figure 8). These 26 lakes had an average depth of 2.8 m or less.

Figure 8: Effect of Changes in Under-Ice Surface Area on Allowable Water Taking for Back River lakes.

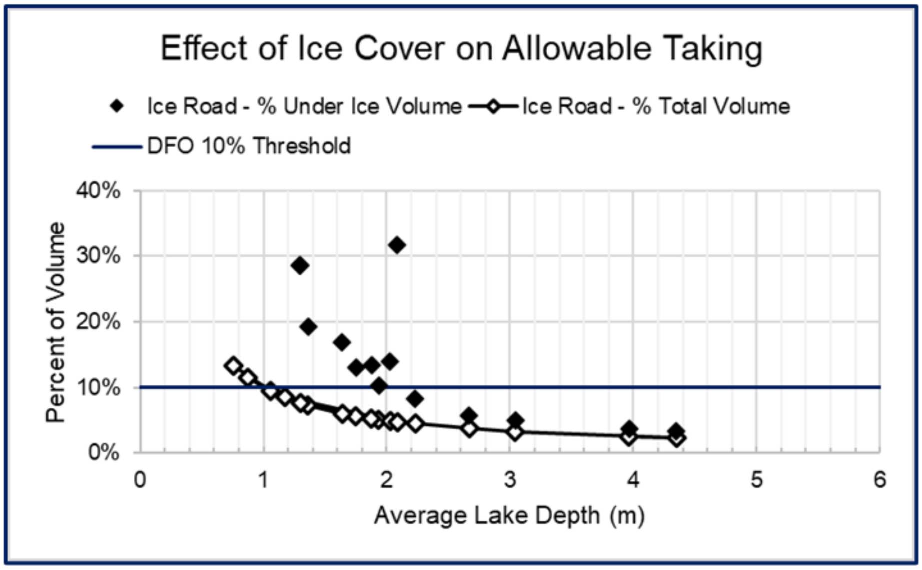


6.2 Tibbitt to Contwoyto Lakes

The Tibbitt to Contwoyto data set assumed a 1.5 m ice cover. On average, the under-ice volume was 52% +/- 26% of the total water volume. Average lake depth ranged from 0.8 m to 4.4 m.

- The allowable water withdrawal of 10 cm amounted to 2% – 13% (average = 6.2%) of the total lake volume but exceeded the DFO Protocol of 10% in 2 of the 17 lakes (Figure 9).
- The allowable water taking of 10 cm amounted to 4% – 138% (average = 30.2%) of the under-ice volume and exceeded the DFO Protocol of 10% in 11 of the 17 lakes (Figure 9). These 11 lakes had an average depth of 2.1 m or less.

Figure 9: Effect of Changes in Under-Ice Surface Area on Allowable Water Taking for Tibbitt-Contwoyto Ice Road Lakes.

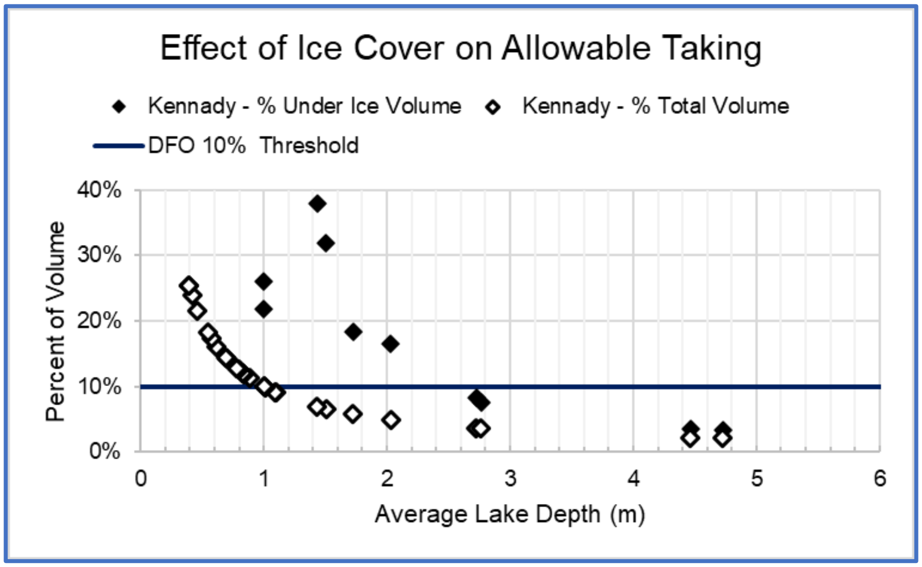


6.3 Kennady Project Lakes

The Kennady Project data set assumed a 2 m ice cover. Eight of the 28 lakes were <2 m of maximum depth and were assumed to freeze to the bottom. On average, the under-ice volume of the remaining 20 lakes was 28% +/- 21% of the total water volume. Average lake depth ranged from 0.4 m to 4.7 m.

- The allowable water withdrawal of 10 cm amounted to 2% – 24% (average = 9%) of the total lake volume for those lakes >2 m maximum depth but exceeded the DFO Protocol of 10% in seven of the 20 lakes (Figure 10).
- The allowable water withdrawal of 10 cm exceeded the entire under-ice volume in eight of the 20 lakes >2 m maximum depth, averaged 26% in the remaining lakes, and exceeded the DFO Protocol of 10% in all but four of the lakes. These four lakes had an average depth of 2.8 m or greater (Figure 10).

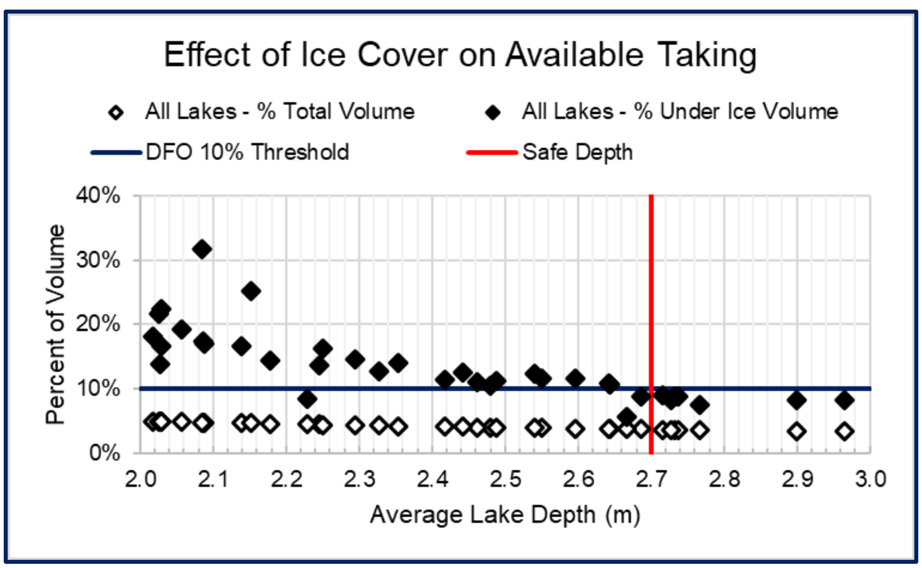
Figure 10: Effect of Changes in Under-Ice Surface Area on Allowable Water Taking for Kennady lakes.



6.4 Summary

Although accounting for ice cover reduced the available water and increased the possibility that taking 10 cm of water under the ice could exceed the DFO threshold of 10% of available water, this only occurred for lakes that were <2.7 m in average depth (Figure 11). The DFO threshold was protected in all lakes in which average depth exceeded 2.7 m.

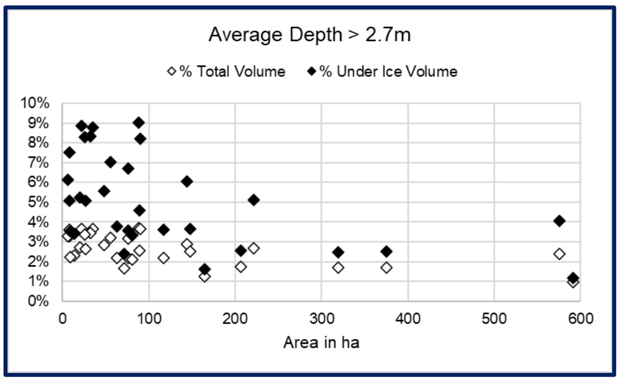
Figure 11: Average Lake Depth vs Percent Total or Under-Ice Volume Taken.

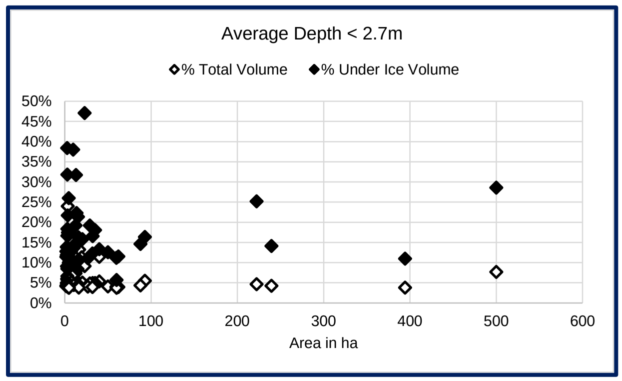


7.0 Lake Size vs Lake Depth

The data set used to test for under ice volume withdrawals (Sabina, Tibbitt-Contwoyto Winter Road, and Kennady Lakes, Section 6.0) was used to investigate whether or not there was a size threshold for a lake, above which there would be no need to measure bathymetry to support a water taking of 10 cm. Figure 11 (above) showed that all lakes in the data set with an average depth >2.7 m could sustain a 10 cm water taking. Figure 12 (left) confirms that finding by plotting the percentage of total and under-ice volumes taken with the 10 cm drawdown for all lakes in the data set exceeding 2.7 m in average depth. Surface area of these lakes ranged from 5.9 to 15,271 ha. Figure 12 (right) however, shows that lakes of average depth <2.7 m cannot sustain the 10 cm water taking, regardless of surface area. Surface area of these lakes ranged from 1.6 to 500 ha.

Figure 12: Effect of lake area on allowable water taking for lakes >2.7 m depth (left) and <2.7 m depth (right).





There is not, therefore, a threshold of lake surface area beyond which proponents can dismiss the implications of a 10 cm drawdown on the ability of maintain lake volume within the 10% threshold of DFO (2010). This conclusion, however, is based on the relative percentage of water taken from a water body and does not address the absolute volume of water needed.

The Golder (2019) submission concluded "*This threshold of 100 ha is proposed as a reasonable limit for the possibility of environmental effects resulting from withdrawal from a single waterbody source for mineral exploration drilling. For example, waterbodies larger than 100 ha in size can be exempt from additional calculations and monitoring because impacts to a lake this size would be negligible, and because a lake of this size contains more water available for withdrawal than is allowable under Type B water licence ([100 ha x 0.12 m] / 365 days = 329 m3/day).*" This statement can be supported, however, because it places the allowable withdrawal in the context of a finite volume of water that could be used in a Type B Water Licence under the Waters Act and Waters Regulations in the Northwest Territories.

8.0 Conclusions

Maximum lake depth cannot be easily established in the field without detailed bathymetry as proponents would need to know where the deepest portion of a lake was. A series of measurements made in the vicinity of a planned water withdrawal can, however, provide a coarse estimate of average depth without detailed bathymetry or extensive knowledge of lake basin morphometry. Golder (2019, see Section 3.0) recommended a minimum of three measurements but did not substantiate that conclusion. In addition, field measurements confirming that average under-ice depth was >1.5 m were more protective than field measurements confirming a maximum depth >3 m (see Section 5.2).

Analysis of the Cott et al. (2005) data set from Mackenzie Delta lakes (Section 5) concluded that calculating an allowable water withdrawal as 10 cm X Surface Area protected fish habitat in 91% of lakes that exceeded 3 m of average depth. Testing of the method on three sets of NWT/Precambrian Shield Lakes protected 100% of lakes with an average depth > 2.7 m (Section 6).

Analysis which considered ice cover in three data sets from Precambrian Shield terrain concluded that lakes which exceeded 2.7 m in average depth could sustain an allowable water withdrawal of 10 cm X Surface Area, regardless of their surface area but that lakes <2.7 m in average depth could not, regardless of their surface area.

An average depth of 3 m exceeds the minimum requirement of 2.7 m determined in this study, even for those lakes with 2 m of ice cover (Figure 11) as lakes at that depth can sustain a 10 cm withdrawal without exceeding the DFO Protocol of 10% loss of water volume below ice cover.

Applicants should include their proposed method of field verification within their application. Different approaches may be acceptable depending on the location and nature of the proposed activities and DFO and GNWT-ENR should be engaged on this as early in the licensing and permitting process as possible.

9.0 References

Cott, P.A., Monita, D.M.A., Majewski, A.R., Hanna, B.W., and Bourassa, K. 2005. Application of the NWT Winter Water Withdrawal Protocol with Bathymetric Profiles of Select Small Lakes in the Mackenzie Delta Region. Can. Manuscr. Rep. Fish. Aquat. Sci. 2731:vii + 73 pp.

DFO. 2010 Fisheries and Oceans Canada. 2010. "DFO Protocol for Winter Water Withdrawal from Ice-Covered Water Bodies in the Northwest Territories and Nunavut"

DFO. 2011. Fish Screen Design Criteria for Flood and Water Truck Pumps Fisheries and Oceans Canada. DFO Can. Available at https://glwb.com/sites/default/files/mvlwb/documents/DFO%20Water%20Trucks%20and%20Flood%20Pump%20Fish%20Screen%20Guideline%20Dec%2012%202011.pdf.

DFO. 2013. Framework for Assessing the Ecological Flow Requirements to Support Fisheries

in Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/017.

DFO. 2020. Interim code of practice: End-of-pipe fish protection screens for small water intakes in freshwater. DFO Can. Available at https://www.dfo-mpo.gc.ca/pnw-ppe/codes/screen-ecran-eng.html.

EBA 2013. 2007/2008/2009/2011/2012/2013 Bathymetry Program Tibbitt to Contwoyto Winter Road. Prepared for TCWR Joint Venture. September 2013, 243 pp.

Emmerton, C.A., Lesack, L.F. and Marsh, P., 2007. Lake abundance, potential water storage, and habitat distribution in the Mackenzie River Delta, western Canadian Arctic. Water Resources Research, 43(5).

Golder Associates Ltd. 2018. Winter Ice Road Water Withdrawal Evaluation – Back River Project. Prepared for Sabina Gold & Silver Corp., submitted to the Nunavut Water Board. 56 pages. ftp://ftp.nwb-oen.ca/registry/2 MINING MILLING/2A/2AM - Mining/2AM-BRP1831 Sabina/3 TECH/E WATER USE/181203 2AM-BRP1831 2019 Sabina WIR Technical Memorandum-IMLE.pdf.

Golder Associates Ltd. 2019. Technical Memorandum "Proposed Approach to Determining Water Source Capacity for Mineral Exploration Projects."

Hamilton, M.K., Davis, C.O., Rhea, W.J., Pilorz, S.H. and Carder, K.L., 1993. Estimating chlorophyll content and bathymetry of Lake Tahoe using AVIRIS data. Remote Sensing of Environment, 44(2-3), pp.217-230.

Hunt, Edward, pers. comm, April 21, 2020

NASA. Jet Propulsion Laboratory. 2019. Airborne Visible Infrared Imaging Spectrometer.

Nighthawk Gold Corp. 2019. Water Use Plan Version 2.1 for the Nighthawk Gold Corp Indin Lake Gold Property. Available at: http://registry.mvlwb.ca/Documents/W2018L2-0002/W2018L2-0002%20-%20Nighthawk%20-%20Water%20Use%20Plan%20-%20Version%202.1%20-%20June%2020_19.pdf.

Natural Resources Canada. 2017. CanVec Geospatial Extraction Tool. [modified 28 June 2017; accessed 18 February 2019]. http://maps.canada.ca/czs/index-en.html?service=canvec.

TerraX Minerals Inc. 2019. Information Request (IR) from the Department of Fisheries and Oceans, Canada (DFO) related to the Type B Water License Application, Yellowknife City Gold Project (YCGP). Available at http://registry.mvlwb.ca/Documents/MV2018L2-0006/MV2018L2-0006%20-%20TerraX%20Minerals%20-%20Response%20to%20MVLWB%20Information%20Request%20-%20Jan25-19.pdf.

Walther, S.C., Marcus, W.A. and Fonstad, M.A., 2011. Evaluation of high-resolution, true-colour, aerial imagery for mapping bathymetry in a clear-water river without ground-based depth measurements. International Journal of Remote Sensing, 32(15), pp.4343-4363.

Appendix A. Bathymetry Data for Four Lake Sets

A1. DFO Lakes

Lake Name	Average Depth m	Maximum Depth m	Volume m3	Surface Area m2	10 cm Water Taking m3	% of Total Volume
1	1.4	3.9	1,571,297	1,044,082	104,408	7%
3	1.7	3.1	938,582	531,576	53,158	6%
5	1.9	3.6	2,383,667	1,192,044	119,204	5%
6	1.5	3.2	845,098	540,855	54,086	6%
7	1.7	3.7	263,238	148,653	14,865	6%
8	1.9	3.4	567,508	284,661	28,466	5%
9	1.6	3.2	612,159	360,387	36,039	6%
10	2.3	6.6	3,289,435	1,348,009	134,801	4%
11	2.4	4.4	1,289,354	525,228	52,523	4%
12	1.9	3.1	2,246,198	1,112,654	111,265	5%
13	1.7	3.5	3,100,134	1,676,252	167,625	5%
14	2	3.5	6,360,440	2,949,923	294,992	5%
15	1.9	3	1,763,876	913,892	91,389	5%
16	2	3.2	2,188,830	1,076,391	107,639	5%
17	1.5	2.5	6,765,805	3,765,805	376,581	6%
18	2.5	3.3	3,770,461	1,475,925	147,593	4%
19	5.3	16	43,868,500	26,326,225	2,632,623	6%
20	1.9	5.9	10,589,209	9,793,064	979,306	9%
21	0.8	7	14,520,335	31,864,335	3,186,434	22%
22	1.4	7.2	9,856,299	10,383,256	1,038,326	11%
23	1.5	3.5	5,426,767	5,769,203	576,920	11%
24	3.3	10	8,061,505	4,101,841	410,184	5%
25	1.54	2.9	13,008,359	7,724,101	772,410	6%
26	1.4	2.2	3,854,968	2,753,584	275,358	7%
27	1.8	3.1	1,112,403	591,192	59,119	5%
28	1	1.9	376,606	324,674	32,467	9%
29	1.2	2.1	469,133	374,200	37,420	8%
31	1	3.1	128,732	125,341	12,534	10%
36	2.2	9.4	993,729	417,487	41,749	4%
38	0.5	2.5	230,302	418,355	41,836	18%
44	1.4	2.6	613,239	441,881	44,188	7%
46	4.5	11.9	805,121	172,543	17,254	2%
47	2.4	12.9	3,452,380	1,343,999	134,400	4%
48	5	13.9	5,380,515	1,005,366	100,537	2%
49	2.8	9.6	814,227	283,121	28,312	3%
52	3.3	9.5	910,830	264,305	26,431	3%
54	2.7	9	402,504	142,544	14,254	4%

A2. Back River Lakes

Waterbody ID	North. UTM	East. UTM	Surface Area (SA) (m^2)	Volume (V) (m^3)	V:SA ratio (average depth) (m)	Under Ice Volume Below 2 m Depth (m^3)	DFO Threshold = 10% of Under Ice Volume	Ratio - total / Under Ice	Average below ice depth	10 cm Water Taking m3	% of Total Volume	% of Under Ice Volume	10 cm Meets DFO Threshold?
Lake 1-0	7272263	428691	348,021	951,009	2.7	396,025	39,603	42%	1.14	34,802	4%	9%	Yes
Lake 2-0	7273318	427649	598,077	1,487,839	2.5	535,068	53,507	36%	0.89	59,808	4%	11%	No
Lake 3-0	7273459	425284	557,865	1,738,708	3.1	793,748	79,375	46%	1.42	55,787	3%	7%	Yes
Lake 4-0	7275521	422778	349,596	705,486	2	193,786	19,379	27%	0.55	34,960	5%	18%	No
Lake 8-0	7276631	418218	765,711	2,427,790	3.2	1,137,977	113,798	47%	1.49	76,571	3%	7%	Yes
Lake 7-0	7277136	419314	2,211,876	8,325,456	3.8	4,336,453	433,645	52%	1.96	221,188	3%	5%	Yes
Lake 6-0	7277346	421197	224,514	614,579	2.7	253,622	25,362	41%	1.13	22,451	4%	9%	Yes
Lake 9-0	7277741	416761	620,172	1,581,371	2.5	537,030	53,703	34%	0.87	62,017	4%	12%	No
Lake 11-0	7280643	411983	885,771	2,406,329	2.7	981,876	98,188	41%	1.11	88,577	4%	9%	Yes
Lake 13-0a	7284074	407857	290,376	597,123	2.1	151,117	15,112	25%	0.52	29,038	5%	19%	No
Lake 14-0a	7287885	404204	3,942,630	10,415,812	2.6	3,597,800	359,780	35%	0.91	394,263	4%	11%	Yes
Lake 14-1	7293431	401036	2,221,497	4,779,159	2.2	881,912	88,191	18%	0.40	222,150	5%	25%	No
Lake 15-0	7298909	399919	1,441,269	5,027,754	3.5	2,373,270	237,327	47%	1.65	144,127	3%	6%	Yes
Lake 16-0	7303281	399696	2,068,272	12,016,309	5.8	8,139,725	813,973	68%	3.94	206,827	2%	3%	Yes
Lake 17-0	7305916	402441	5,913,261	61,932,318	10.5	50,372,624	5,037,262	81%	8.52	591,326	1%	1%	Yes
Lake 16-1	7306279	398021	319,815	812,512	2.5	260,311	26,031	32%	0.81	31,982	4%	12%	No
Lake LA17-0	7308172	395986	3,193,056	18,907,975	5.9	12,865,851	1,286,585	68%	4.03	319,306	2%	2%	Yes
Lake 18-0	7308843	401524	635,085	2,886,128	4.5	1,690,494	169,049	59%	2.66	63,509	2%	4%	Yes
Lake 984	7309759	402495	153,108	296,424	1.9	71,739	7,174	24%	0.47	15,311	5%	21%	No
Lake 18-1	7310007	401912	161,253	426,414	2.6	150,589	15,059	35%	0.93	16,125	4%	11%	Yes
Lake LA18-0a	7311590	396960	714,708	4,368,027	6.1	3,006,955	300,696	69%	4.21	71,471	2%	2%	Yes
Lake 19-0	7311911	401691	160,065	360,221	2.3	98,274	9,827	27%	0.61	16,007	4%	16%	No
Lake 985	7312109	395983	40,914	106,234	2.6	35,130	3,513	33%	0.86	4,091	4%	12%	No
Lake 986	7312574	392342	16,299	37,926	2.3	12,753	1,275	34%	0.78	1,630	4%	13%	No
Lake 989	7313114	391719	29,322	62,690	2.1	17,580	1,758	28%	0.60	2,932	5%	17%	No
Lake 987	7313141	398133	206,199	760,584	3.7	393,753	39,375	52%	1.91	20,620	3%	5%	Yes
Lake 991	7313599	391191	36,702	76,595	2.1	21,030	2,103	27%	0.57	3,670	5%	17%	No
Lake LA20-0	7313887	399363	324,144	940,089	2.9	389,431	38,943	41%	1.20	32,414	3%	8%	Yes
Lake 990	7314076	388751	761,706	3,456,788	4.5	2,130,011	213,001	62%	2.80	76,171	2%	4%	Yes
Lake 20-0	7314226	404075	5,757,903	24,053,493	4.2	14,139,389	1,413,939	59%	2.46	575,790	2%	4%	Yes
Lake 992	7314853	389975	893,646	3,525,249	3.9	1,938,558	193,856	55%	2.17	89,365	3%	5%	Yes
Lake LA21-0	7315592	399777	256,878	761,896	3	309,761	30,976	41%	1.21	25,688	3%	8%	Yes
Lake LA23-0	7315882	401330	265,968	1,013,844	3.8	524,720	52,472	52%	1.97	26,597	3%	5%	Yes
Lake LA21-1	7316914	399454	204,606	406,055	2	129,313	12,931	32%	0.63	20,461	5%	16%	No
Lake LA22-0	7317386	399995	2,393,802	5,635,137	2.4	1,697,105	169,711	30%	0.71	239,380	4%	14%	No
Lake 23-0	7318800	403392	498,888	1,218,007	2.4	396,365	39,637	33%	0.79	49,889	4%	13%	No
Lake 24-0	7321054	402094	876,762	2,011,377	2.3	599,951	59,995	30%	0.68	87,676	4%	15%	No
Lake 994	7323246	400275	136,197	276,346	2	61,034	6,103	22%	0.45	13,620	5%	22%	No
Lake 995	7325353	400617	103,959	233,491	2.2	75,975	7,598	33%	0.73	10,396	4%	14%	No
Lake 25-0	7326281	400452	483,390	1,713,886	3.5	868,241	86,824	51%	1.80	48,339	3%	6%	Yes
Lake 996	7327338	401382	26,253	43,840	1.7	6,832	683	16%	0.26	2,625	6%	38%	No
Lake 26-0	7328257	401915	59,454	181,351	3.1	97,110	9,711	54%	1.63	5,945	3%	6%	Yes
Lake 997	7329276	401911	17,280	41,763	2.4	15,122	1,512	36%	0.88	1,728	4%	11%	No
Lake 28-0	7332392	403397	265,680	653,963	2.5	239,515	23,952	37%	0.90	26,568	4%	11%	No
Lake 29-0	7334245	403433	1,174,887	5,393,491	4.6	3,246,825	324,683	60%	2.76	117,489	2%	4%	Yes
Lake 998	7336793	403071	46,809	125,763	2.7	53,343	5,334	42%	1.14	4,681	4%	9%	Yes
Lake 30-0	7340003	404631	927,360	1,683,771	1.8	566,741	56,674	34%	0.61	92,736	6%	16%	No
Lake 30-4	7343073	403851	48,825	101,926	2.1	28,590	2,859	28%	0.59	4,883	5%	17%	No
Lake 31-0	7351852	400718	82,758,231	,779,474,304	33.6	2,616,978,541	261,697,854	94%	31.62	8,275,823	0%	0%	Yes
Lake 999	7364930	391663	1,645,029	13,130,162	8	10,124,845	1,012,485	77%	6.15	164,503	1%	2%	Yes
Lake 31-1	7367584	391134	34,803	70,470	2	16,035	1,604	23%	0.46	3,480	5%	22%	No
Lake 31-2	7367973	390840	55,377	137,368	2.5	52,909	5,291	39%	0.96	5,538	4%	10%	Yes
Lake 32-0	7373635	387860	3,747,375	21,976,529	5.9	14,966,675	1,496,668	68%	3.99	374,738	2%	3%	Yes
Lake 33-0	7378706	385690	124,371	270,935	2.2	86,426	8,643	32%	0.69	12,437	5%	14%	No
Lake 34-0	7380542	390639	157,216,248	,320,662,011	21.1	3,010,754,419	301,075,442	91%	19.15	15,721,625	0%	1%	Yes

A3. Tibbitt-Contwoyto Lakes

Lake Name	Page of PDF	Latitude	Longitude	Surface Area (m2)	Volume (m3)		DFO Threshold = 10% of Under Ice Volume	Comment	Average Depth (Volume/Surface Area)		10 cm Water Taking m3	% of Total Volume	% of Under Ice Volume	10 cm Meets DFO Threshold?
					Total	Under Ice			Total	Under Ice				
HG-2	30	65.55	113.35	1,476,560	5,857,166	4,054,919	405,492		3.97	2.75	147,656	3%	4%	Yes
P2-1	33	62.59	113.31	600,000	1,600,000	1,050,000	105,000		2.67	1.75	60,000	4%	6%	Yes
3-1	34	62.61	113.31	57,216			-	frozen to bottom			5,722			
P-11	39	62.78	113.30	80,326	244,482	158,631	15,863		3.04	1.97	8,033	3%	5%	Yes
11-1	41	62.78	113.30	2,700			-	frozen to bottom			270			
12-2	44	62.79	113.30	75,000	145,000	73,000	7,300		1.93	0.97	7,500	5%	10%	Yes
P13	47	62.79	113.30	22,500	45,600	16,200	1,620		2.03	0.72	2,250	5%	14%	No
14-1	49	62.82	113.32	38,000			-	frozen to bottom			3,800			
P14-2	53	62.84	113.33	5,000,000	6,500,000	1,750,000	175,000		1.30	0.35	500,000	8%	29%	No
P16	56	62.87	113.34	148,000	330,000	177,000	17,700		2.23	1.20	14,800	4%	8%	Yes
20-1/Old	59	63.28	113.08	2,400			-	(assumed) frozen to bottom			240			
20-1	62	63.28	113.07	130,000	271,000	41,000	4,100		2.08	0.32	13,000	5%	32%	No
20-2	65	63.29	113.07	138,000	600,000	407,000	40,700		4.35	2.95	13,800	2%	3%	Yes
12-1	68	63.29	113.06	22,645			-	(assumed) frozen to bottom			2,265			
22-1	71	63.32	113.05	6,545			-	frozen to bottom			655			
22-2	74	63.32	113.05	43,734			-	(assumed) frozen to bottom			4,373			
23-2	76	63.34	113.04	12,500			-	(assumed) frozen to bottom			1,250			
23-3	79	63.34	113.03	52,500	92,000	40,000	4,000		1.75	0.76	5,250	6%	13%	No
23-4	82	63.35	113.02	28,200	33,200	5,600	560		1.18	0.20	2,820	8%	50%	No
25-1	85	63.36	112.99	44,200	72,500	26,200	2,620		1.64	0.59	4,420	6%	17%	No
P31	88	63.43	112.66	3,766			-	frozen to bottom			377			
P33-1	92	63.46	112.54	400,000	750,000	300,000	30,000		1.88	0.75	40,000	5%	13%	No
36-1	95	63.49	112.49	97,175			-	(assumed) frozen to bottom			9,718			
37-1	98	63.57	112.32	180,494			-	(assumed) frozen to bottom			18,049			
37-8	101	63.58	112.32	125,000	170,000	65,000	6,500		1.36	0.52	12,500	7%	19%	No
39-1	104	63.58	112.31	400,000	350,000	55,000	5,500		0.88	0.14	40,000	11%	73%	No
40-1	107	63.59	112.29	264,245			-	(assumed) frozen to bottom			26,425			
41-1	110	63.60	112.30	75,500	80,000	95,000	9,500		1.06	1.26	7,550	9%	8%	Yes
42-1	113	63.61	112.25	165,500	125,000	12,000	1,200		0.76	0.07	16,550	13%	138%	No

A4. Kennady Project Lakes

			Ave. Depth = Volume / Area		Area		Volume		DFO Threshold	10 cm Water Taking	% of Total	% of Under Ice	10 cm Meets DFO
	Name	Max. Depth	Surface	2m	Surface	2m	Surface	2m	= 10% of Under Ice Volume	m3	Volume	Volume	Threshold?
Lake 1	Faraday	8.8	2.7	2.0	900,575	536,250	2,456,415	1,094,906	109,491	90,058	4%	8%	Yes
Lake 2	Kelvin	14.5	4.7	4.0	804,400	614,250	3,804,075	2,432,104	243,210	80,440	2%	3%	Yes
Lake 3	M17	4.0	1.1	0.6	25,400	4,500	27,953	2,785	278	2,540	9%	91%	No
Lake 4	M2B	0.8	0.2	Frozen to Bottom	10,300		1,780		-	1,030	58%		
Lake 5	M50	1.0	0.4	Frozen to Bottom	24,300		9,556		-	2,430	25%		
Lake 6	M12	10.8	2.8	2.4	82,000	45,600	226,841	108,800	10,880	8,200	4%	8%	Yes
Lake 7	M46	12.0	4.5	4.0	90,900	64,200	405,693	258,313	25,831	9,090	2%	4%	Yes
Lake 8	L16	2.3	0.6	0.1	52,000	1,300	29,912	116	12	5,200	17%	4501%	No
Lake 9	L1a	1.3	0.4	Frozen to Bottom	35,600		13,994		-	3,560	25%		
Lake 10	M54	1.8	0.5	Frozen to Bottom	32,800		15,152		-	3,280	22%		
Lake 11	M31	3.0	0.8	0.2	39,500	4,200	32,798	973	97	3,950	12%	406%	No
Lake 12	M3b	2.5	0.4	0.1	34,900	900	14,542	133	13	3,490	24%	2624%	No
Lake 13	M10	4.5	1.4	1.1	96,800	23,500	138,829	25,466	2,547	9,680	7%	38%	No
Lake 14	M2B	5.8	2.0	1.3	322,400	154,600	654,220	194,670	19,467	32,240	5%	17%	No
Lake 15	M1	2.0	0.8	Frozen to Bottom	105,600		83,972		-	10,560	13%		
Lake 16	L10	3.3	0.9	0.4	195,100	15,300	172,573	5,423	542	19,510	11%	360%	No
Lake 17	M11	3.8	1.5	0.8	28,800	10,900	43,440	9,048	905	2,880	7%	32%	No
Lake 18	M30	3.0	1.0	0.4	54,100	7,600	54,700	2,828	283	5,410	10%	191%	No
Lake 19	M2a	2.3	0.8	0.0	22,800	200	19,191	4	0	2,280	12%	55757%	No
Lake 20	M24	4.5	1.0	0.9	44,800	19,800	44,800	17,251	1,725	4,480	10%	26%	No
Lake 21	M32	6.0	1.0	1.3	164,000	56,000	164,000	75,162	7,516	16,400	10%	22%	No
Lake 22	M33	2.3	0.8	1.0	72,300	69	56,365	69	7	7,230	13%	10415%	No
Lake 23	M28	8.0	1.1	2.0	228,400	24,800	250,133	48,525	4,853	22,840	9%	47%	No
Lake 24	M35	1.8	0.5	Frozen to Bottom	3,725		2,041		-	373	18%		
Lake 25	M36	2.3	0.7	0.0	113,425	125	78,513	3	0	11,343	14%	429338%	No
Lake 26	M43	1.8	0.6	Frozen to Bottom	14,775		9,161		-	1,478	16%		
Lake 27	M44	1.5	0.7	Frozen to Bottom	22,400		15,710		-	2,240	14%		
Lake 28	M34	5.3	1.7	1.5	30,038	11,081	51,796	16,374	1,637	3,004	6%	18%	No