Recommendations on changes to the scope and quality of the Muskrat Falls Aquatic Monitoring Program

by Wolfgang Jansen, Jim McCarthy, Jane Kirk, and David Lean

Reviewed by Maureen Baikie and Trevor Bell

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1. Introduction

The scope and extent of the current regulator mandated Aquatic Environmental Effects Monitoring Program (AEEMP) for Muskrat Falls must be considered exceptional compared to other similar monitoring programs in Canada (e.g., KHLP 2014). Nevertheless there exist a number of issues mainly related to detection limits, sampling frequency, and the scope of sampled components that could be addressed to enhance the overall quality of the AEEMP. In addition, data analysis and reporting could be improved at least for some components to allow for unbiased comparisons and better interpretation of the results, particularly when being used in relation to methylmercury exposure of humans and potential health risks. Finally, other aquatic monitoring programs exist that collect relevant data for the Muskrat Falls Project. Sampling coordination and data integration or at least sharing of information between those programs could result in substantial synergies, avoiding sampling duplication while strengthening the data base. Some of these issues are addressed in the following.

2. Detection Limits (DL)

There have been a number of recent changes to the Method Detection Limits (MDL) of the various components of the Aquatic Environmental Effects Monitoring Programs (AEEMP; Table 1). All of these changes resulted in a lowering of the initial MDL for a component, and now generally provide limits that will likely result in measurable concentrations instead of non-detects (i.e., <MDL). High numbers of non-detects are still being recorded for methylmercury (MeHg) in water samples (43 and 22% for dissolved and total MeHg*, respectively), and 100%for MeHg and total mercury (THg) in sediment samples (which for THg should improve with the adoption of a MDL of 0.002 mg/k on September 8, 2017). However there exist other issues with sediment sampling that result in a compromised usefulness of this component (see section 5) and the respective MDLs are not further discussed here.

* Dissolved MeHg is the fraction of MeHg that is transported in the water as a dissolved molecule (such as sugar in a coffee cup after extensive stirring); Total MeHg includes, in addition to dissolved MeHg, MeHg that is bound to particles floating in the water (similar to sugar crystals, to follow the above analogy). These can be living algea, dead organic material (also called detritus) or inorganic particles such as clay.

Table 1. Summary of Method Detection Limits (MDL) for monitoring components of the AEEMP.

Parameter	Initial MDL	Modified RDL	Increase in sensitivity (modified MDL times initial MDL)	Date MDL was modified
Water				
Dissolved Methylmercury	0.01 ng/L	-	-	-
Total Methylmercury	0.01 ng/L	-	-	-
Total Mercury (THg)	1.9 ng/L	0.05 ng/L	38	June 28, 2017
Sulphate	2 mg/L	0.2 mg/L	10	September 11, 2017
Sulphide	0.05 mg/L			
Ammonia (as N)	0.03 mg/L			
Total Kjeldahl Nitrogen (as N)	0.4 mg/L			
Nitrate as N	0.05 mg/L			
Total Phosphorous	0.03 mg/L	2 µg/L	15	September 11, 2017
Total Organic Carbon (TOC)	0.5 mg/L			
Dissolved Organic Carbon	0.5 mg/L			
Total Suspended Sediments	5 mg/L	1 mg/L	5	August 16, 2017
Turbidity	0.1 NTU			
Dissolved Oxygen	0.1 mg/L			
Total Dissolved Solids	0.001 mg/L in situ			
Sediment				
Methylmercury (MeHg)	0.4 ng/g			
Total Mercury	0.05 mg/kg	0.002 mg/kg	25	September 8, 2017
Sulphide	0.01 (%)			
Total Sulfur	0.01 (%)			
Fish				
Total Mercury	0.05 mg/kg	0.02 mg/kg	2.5	January 2016

*****stored samples are available at the lab (May-Aug) that can be re-run at this MDL.

A lowering of the MDL was particularly important for THg in water, where a large majority of results prior to June 28, 2017 recorded non-detects. This was mainly a result of the fact that the original MDLs for total THg (1.9 ng/L) and dissolved THg (2.5 ng/L) were not comparable to other labs in Canada and globally that are accredited for this analysis. Therefore, there is very little reliable data above the detection limit for THg prior to the flooding of the headpond to ~22 m a.s.l.(above sea level) initiated in November 2016 and likely no true baseline concentration to compare future levels once full supply level is reached. The new detection limit of 0.05 ng/L (Table 1) is adequate and the almost 40 times greater sensitivity of the new /modified MDL is expected to result in measurable concentrations at all sampling sites/dates.

Currently, the MDL for MeHg in water (both total and dissolved) is 0.01 ng/L, which is comparable to the best low-level MeHg labs across Canada and globally. However, due to the existing low baseline concentrations of MeHg in this system, a large percentage of the reported data for Goose Bay and Lake Melville (66% for dissolved MeHg and 39% for total MeHg considering sampling sites N8-N13 as being in

Goose Bay and Lake Melville) is below the MDL (Figures 1 and 2; Table 2). Schartup et al. (2015) identified the halocline as a zone of MeHg production within Lake Melville; however, 74% and 47% of the dissolved and total MeHg monitoring data, respectively, collected at the Lake Melville halocline is below the MDL, including a large portion of the July 2017 data (Table 2).

Table 2. Percentage of total and dissolved MeHg concentration data collected between October 14, 2016 and July 19, 2017 that is below the MDL of 0.01 ng/L.; n represents the total number of samples analyzed. Halocline represents the transition zone in surface to bottom salinity gradient of Lake Melville were salt concentrations increase rapidly.

	Dissolved MeHg	**n**	**Total MeHg**	**n**
All reported data	43	468	22	477
Freshwater sites (N1-N6)	14	183	2	188
Freshwater sites (N1-N7)	15	212	2	218
Lake Melville sites (N8-N13, all depth)	66	255	39	258
Halocline Lake Melville samples	74	96	47	96

More importantly, with current MDLs and analytical methods, we will unlikely be able to detect the magnitude of potential changes in MeHg concentrations within Lake Melville water as a result of reservoir creation. Detectable changes in MeHg water concentration would be beneficial, as these may provide early indications of a potential increase in source MeHg for further biomagnification through the food web. Because this option is currently limited by the necessity to use accredited laboratories, analysis of lower trophic organisms may be considered to provide a useful indicator of changes in MeHg levels within Lake Melville. Zooplankton MeHg concentrations are commonly in a range well above the MDL of commercial laboratories and analysis of zooplankton from Lake Melville would likely result in information about the early impacts of changing MeHg water concentrations (due to the Project) within the food chain. A recommendation regarding the potential use of lower trophic indicators is provided below.

Similar to the analysis of THg in water, the MDL for THg in fish muscle was relatively high until recently, particularly when considering some of the low concentrations reported for several fish species (e.g., both sucker species, AFW 2016, Tables 3-38 to 3-41). Results are not particularly useful for human health studies if the mean concentration equals the detection limit. Also, considering that all results below the MDL were censored at 0.05 mg/kg (i.e. if the result was <MDL, 0.05 mg/L was used for statistical analyses), the question arises why some of the value ranges in Tables 3-39 and 3-40 include results of 0.02, 0.03, or 0.04 mg/kg in species other than Atlantic Salmon. The modified MDL of 0.02 mg/kg should address most of these issues, although it may still result in non-detects for some species.

In summary, the IEC is largely satisfied with the current MDL applied to AEEMP components, but has some recommendations:

- Re-analyze any remaining (archived) water samples for THg with the new, adjusted MDL of 0.05 ng/L.
- Add analyses of plankton of different size fractions (i.e., 80-153, 153-500, and >500 µm) to the monitoring program at all Lake Melville sites (i.e. 7-13) twice/year during the open water season (i.e.

June and September). All plankton samples to be analyzed for THg, MeHg, and C and N isotopes. Because of the very low baseline MeHg concentrations in water of Lake Melville which often fall below the MDL that is the lowest available from a commercial laboratory (35-74%, Table 2), mercury concentrations in (zoo)plankton should be measured as an early indicator of changes in the supply of MeHg to the Lake Melville foodweb. Zooplankton are a lower trophic organism group that would be key to many food webs associated with higher organisms such as fish and birds. Because they are an organism that is feeding on phytoplankton and other organic particular matter within the water, they typically can have a more reliable detection limit for MeHg (for example Schartup et al. 2015). Therefore, collection and analysis of these organisms would provide detectable levels both at existing natural concentrations and after reservoir creation. An indication of Carbon (C) and Nitrogen (N) stable isotopes would allow further analysis of the actual incorporation of this food type within existing food webs (e.g., Nelsen et al. 2015).

- Lower the MDL for THg in fish to ≤0.01 mg/kg (as is standard for most commercial laboratories).

- Reanalyse of stored sediment samples from the last collection at the very recently modified MDL of 0.002 mg/kg to obtain some information of THg concentration of mixed sediments for potential future comparisons. Discontinue the current collection of sediment samples and conduct sediment sampling using an alternate methodology (for details and rationale see section 5)

3. Frequency of THg and MeHg measurements in water

Total and dissolved MeHg is being analyzed frequently under the AEEMP (http://mae.gov.nl.ca/methylmercury_mrf.html). Fourteen samples were taken from seven different stations between October 14, 2016, when measurements started, and Dec 20, 2016. After a seven-week break, likely due to unfavourable ice and weather conditions, sampling continued at approximately weekly intervals from February 6 to August 21 of 2017. As indicated by the results for both MeHg fractions, concentrations of MeHg do not change much over the entire sampling period, except for a few substantial but transient increases in total MeHg at sites N1 (upriver of the headpond and reservoir area; Figure 2) and N4 (within the headpond and reservoir area) between late February and mid-April of 2017, shortly after water levels had increased by 7-8 m within the headpond. Recent MeHg flux studies on soil cores from the reservoir area by Balcom et al. (2017), who found relative little methylation potential under cold season conditions, also support low methylation potential during colder time periods.

In summary, the existing results on water mercury concentration and literature data indicate that weekly sampling of water MeHg, particularly during the winter months, does not provide information on temporal trends in MeHg that cannot be obtained from less frequent sampling and recommends:

- Reducing the sampling frequency for MeHg analysis to bi-monthly intervals during the cold temperature season (<6°C water temperature) while maintaining a weekly sampling schedule during the rest of the year. This recommendation applies to times when water levels are relatively stable, following discharge patterns of the river section upstream of the (future) reservoir footprint. In case of substantial and rapid changes in water levels similar to those observed in November 2016 and February 2017 that are triggered by the operation of Project infrastructure, weekly sampling is to be resumed also during the cold temperature season. The resources saved using the reduced sampling and laboratory analyses could be used to strengthen the AEMP in other areas (see sections 4 and 5).

4. Fish Monitoring

The current AEEMP collects fish on an annual basis which is more frequent compared to most other similar monitoring programs in Canada (e.g., KHLP 2014). However, in addition to reducing the relatively high method detection limit (MDL) for THg in fish muscle (see section 2), the fish mercury component of the AEEMP could be further improved and more closely aligned to address not only regulatory requirements under the *Fisheries Act* Authorization, but on key questions associated with the Muskrat Falls project (the Project) in terms of human exposures. Fish are the primary pathway of human exposure to mercury (Mergler et al. 2007) and to protect fish consumers from the detrimental effects of mercury and to provide advice on potential modifications in consumption patterns to lower exposure, sound information on current and future fish mercury concentrations is needed.

The IEC has identified the following shortcomings of the current fish mercury program, particularly when results are being used to address issues related to human health:

A relatively large number of species (n=6-8 depending on the sampling region) is analyzed for THg under the AEEMP. However, several species are consistently (i.e., years 2013 and 2014, yearly numbers for previous years are not provided) found in low abundance and sampled in numbers too small for rigorous annual statistical analysis and meaningful length standardization (AFW 2016; also see below). This applies to the Muskrat Falls area in general (Table 3-41), and for particular species and years from all other locations (Tables 3-38 to 3-40). While these samples can be used statistically as a combined dataset for overall baseline, annual resolution of changes during baseline will be lower and attempts should continue to collect a full complement of each target species per year for standardized length relationships.

In this context it is important to note that the generally larger and older fish analyzed for THg under the AEEMP may take several years to measurably respond to changes in environmental MeHg availability due to the Project. This is because of the relative large body burden of MeHg accumulated in years prior to the start of the Project, reflecting MeHg availability at that time. The existing mercury burden is only slowly eliminated (van Walleghem et al. 2007, 2013), and because fish obtain most of their MeHg via the diet (Hall et al. 1997; Harris and Bodaly 1998), mercury concentrations in individuals of piscivorous species do not reflect increases in environmental MeHg until these are manifested in forage fish. Conversely, young-of-the-year (YOY) fish from the Project area will accumulate their entire mercury burden during the few months after the start of exogenous feeding to the time they are potentially captured for mercury analysis, reflecting short-term changes in the supply of MeHg to the ecosystem. Furthermore, in contrast to most older (adult) individuals, YOY fish are not known to undertake extensive movements and more likely represent "local" conditions of MeHg production and bioaccumulation. The same reasoning applies, although to a lesser degree, if YOY fish are not easily available and 1-year old individuals may be more readily captured. For these reasons several North American monitoring programs have started to include YOY or 1-year old fish of at least one (forage) fish species to increase the probability of detecting short-term changes of ecosystem MeHg concentrations in biota closely linked to human exposure (Wiener et al. 2007; CAMP 2014; Rudd et al 2017).

The current program relies on destructive sampling to obtain fish mercury concentrations. Considering that abundances are low for some species at least in some sampling regions, the use of non-lethal sampling methods could limit potential impacts on the population status of target species and, thus, reduce uncertainty in obtaining fish at target sample size in the future. Non-lethal sampling by biopsy tools for Northern Pike and Lake Whitefish of >180 mm fork length has been shown to produce mercury measurements comparable in accuracy to traditional whole-fish methods without causing mortality (e.g., Baker et al. 2004). An added advantage of non-lethal sampling is the potential for obtaining mercury concentrations for the same individual over time, and thus a more direct measure of changes in mercury supply compared to sample averages.

As a lesser point, while the original Environmental Effects Monitoring Program Study Design Report outlines many of the methodological details (see AFW 2013), the current annual reporting of monitoring results does not include a full description of the methodology (see AFW 2016, p.19-20). For example, what part of the fish is actually analyzed and for what: is it skinless muscle or skin-on muscle, and is there a difference between fish smaller and larger than 50 grams. One assumes that the Hg species analyzed is THg, but is not explicitly stated in the report. Other issues include the lack of QAQC results: what certified reference materials are being used and what are the results of the respective analyses by AGAT Laboratories? While these are typically supplied by the lab, they do not appear to be provided within the report. In addition to inadequate detection limits for THg in some earlier datasets, two other issues prevent a rigorous statistical analysis of the fish Hg monitoring results and their interpretation in terms of human health: the often low sample size (see above) and the absence of fish length information in the reporting and the associated lack of length standardization of mean THg concentrations. Fish Hg concentrations are usually highly correlated with fish length, particularly in large predatory species, necessitating length standardization of mean Hg concentrations within species for meaningful comparisons among years and between sites. It is understood that a final baseline report with these analysis is pending upon final baseline sampling; however, it would be useful to include in the ongoing annual reports. The current level of analysis will not allow interpretation on how fish Hg concentrations may respond to the recent (November 2016 and ongoing) changes in water levels of the Churchill River due to construction and safety measures at the Muskrat Falls site.

Based on the above, the following changes to the fish mercury component of the AEEMP are recommended:

- A focus on fish that include at least one species from two or three different trophic levels that can be reliably captured at target numbers suitable for statistical analysis (see below); preferably these species should be the same for each sampling region. However, we recognize that the fish communities change along the Project area (Churchill River to Lake Melville) mainly due to a salinity gradient and different species may have to be used in a particular sampling region. Partially based on the sample sizes reported in Tables 3-38 to 3-41 of AFW (2016), we suggest to sample Northern Pike, Brook Trout, one of the sucker species (White Sucker?) in the Muskrat Falls reservoir area (Section Two) and the river mainstem with tributaries below (Section One), and Brook Trout, Rainbow Smelt, and White Sucker in

Goose Bay and Lake Melville; because of the importance of Atlantic Salmon as a country food, this species should also be sampled were possible (i.e., Lake Melville):
The application of a length standardization of fish mercury concentrations, and thus valid comparisons of fish THg concentrations over time and between regions, largely depends on a significant correlation between mercury concentration and fish length (Brouard et al. 1990). Because statistical significance of the correlation is related to fish sample size, target sample sizes for the AEEMP should be at least 15-25 fish per species (this number could be made more specific by analysis of past monitoring data to determine at what sample size the THg-length correlation tends to become significant).
The focus on key species outline here would likely result in an overall reduction in the number of samples, because a number of species that are not reliably captured in a particular region will be dropped from the Program.

- Institute non-lethal sampling for larger-bodied fish where feasible. This may involve conducting a small study during which fish biopsies are collected in addition to regular muscle samples from sacrificed fish to show that results for muscle THg are largely identical for the species targeted for the AEEMP
- The inclusion of YOY or 1-year old individuals for at least one forage species from each of the four sampling regions; these juvenile fish should have their own target sample size and should be analyzed separately from their older conspecifics. If there is/are no obvious candidate species, a pilot study on the catchability of YOY from prospective species should be conducted.
- A complete reporting of the methodology, including QAQC results;
- The inclusion of fish length statistics in the results section and length standardization of mean THg concentrations;

We understand that the reporting of fish mercury results has recently changed and may incorporate our suggestions as of bullets 3 and 4. However, until the most recent report including data for the 2016 sampling year is available for review by the IEC, we include our assessment of AEEMP reporting based on the currently available document (AFW 2016, data up to 2015).

5. Other Modifications to the AEEMP

In addition to the suggested inclusion of the analysis of zooplankton in Lake Melville to circumvent problems with the MDL for MeHg in water (see section 2) we further recommend:

- Replacing existing sediment sampling using an Eckman sampler, with collection of intact dated sediment cores using a gravity corer.

  Mercury in sediment is primarily analyzed to provide information on depositional processes of mercury and the pool of mercury potentially available for transfer into the water column of the reservoir and export further downstream. However, the current method of sediment collection (Eckman sampler) disturbs sediment stratification and, thus, information on the timeline of mercury deposition. Thus, dated lake sediment cores are widely used to examine changes in deposition of mercury and other contaminants over time. We recommend sampling sediment cores from all sampling locations in the reservoir, Goose Bay and Lake Melville (sediment cores from rivers can be problematic due to the rapid movement of sediment) once in summer 2018. These cores would be sliced at 0.5 cm intervals and slices would then be dated using lead-210 methods and analyzed for concentrations of THg. We recommend that these sites be re-cored every ~5 years to examine changes in sedimentation rates and mercury deposition over time. We recommend that only the top 5 cm of each core be analyzed in samples collected every 5 years. We can make a more refined recommendation (sampling resolution, sample frequency) upon consultation with Zou Zou Kuzyk at the University of Winnipeg who cored similar sites and has determined sedimentation rates

- Sampling of country food other than fish that is known to substantially contribute to human exposure of MeHg (e.g.,bird eggs; also see Calder et al. 2016 and section 6). The implementation of this should consider input from local resource users as to the most appropriate representative species for inclusion.

6. Synergies with other Monitoring Programs

The Nunatsiavut Government conducts monitoring of MeHg in water at four sites in the study area outside of the purview of the AEEMP. In addition, plankton sampling and analysis by Environment Canada within Lake Melville in both 2016 and 2017 can provide valuable information on baseline zooplankton MeHg concentrations and whether any detectable changes were recorded as a result of headpond activities to date. Starting in 2017, there will also be duplicate samples collected at AEEMP sites which are to be analyzed at a second laboratory for additional quality control. Neil Burgess from ECCC analyzes mercury in colonial seabirds within the Project area. These are examples of other, independent programs that are collecting important data that could add to the overall understanding of the Churchill River/Lake Melville ecosystem and compliment the work being completed by Nalcor. However, there might be other studies collecting data that could inform on aspects of the IEAC mandate. It would be helpful if the IEC could be made aware of such studies. Ideally, to maximize the usefulness of these datasets there should be one unified database where all results relevant to the mercury issue are deposited. To promote timely responses to issues related to the mandate of IEAC, it may be expedient for the IEC to become the manager of such a data base, recognizing that such a decision will have resource implications.

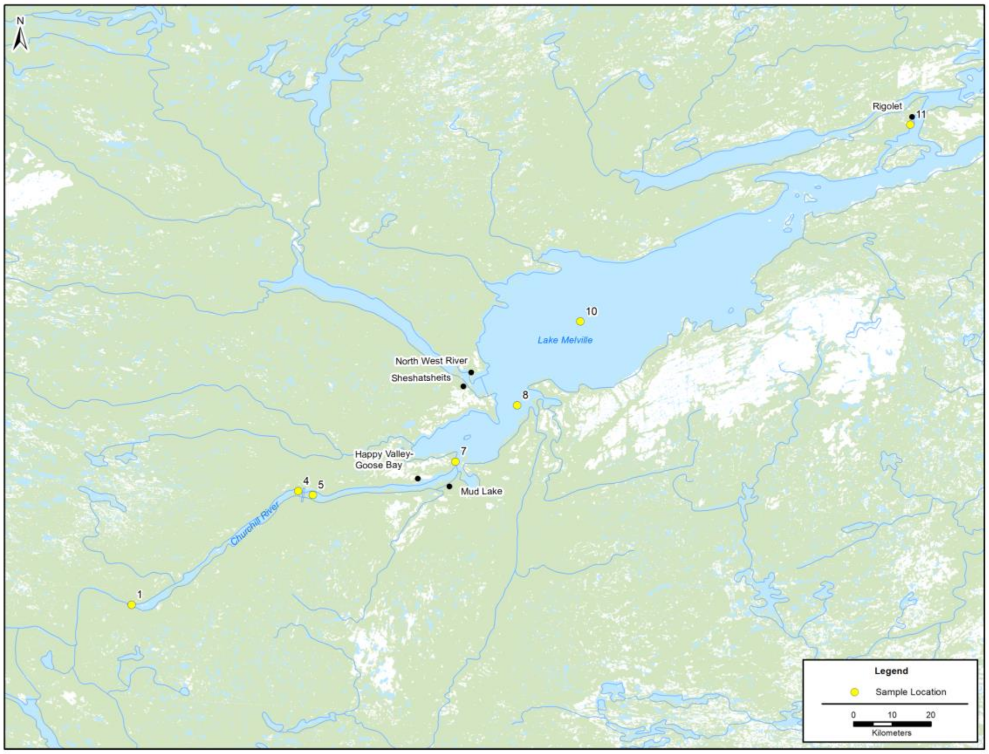

Figure 1: Map of sample locations, Lower Churchill River to Rigolet prior to mid-December 2016

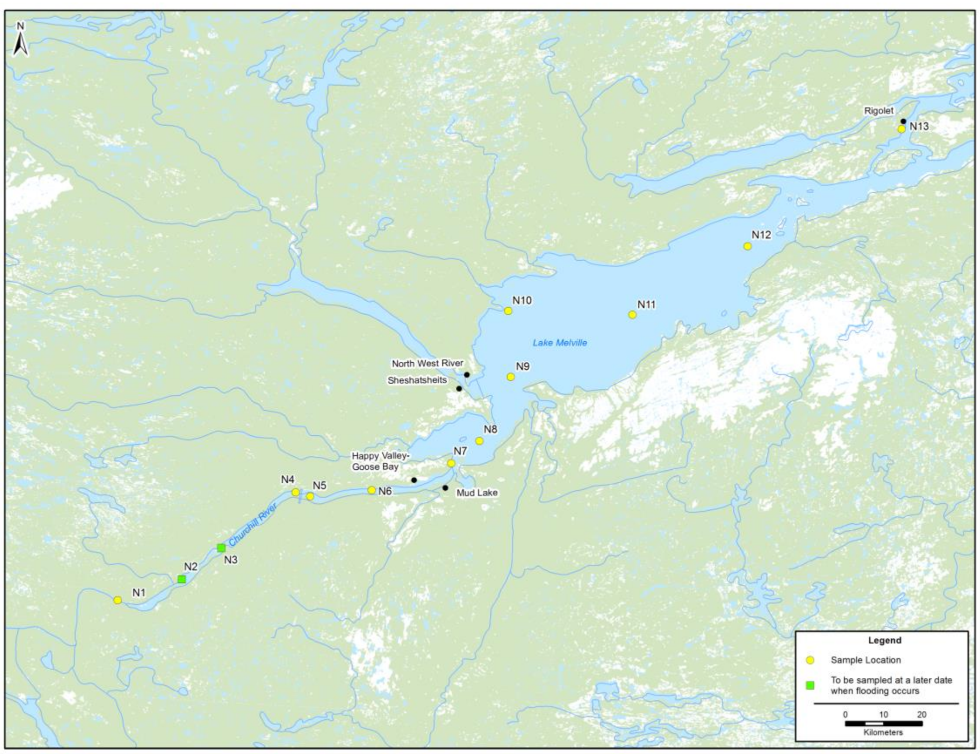

Figure 2: Map of sample locations, Lower Churchill River to Rigolet after mid-December 2016

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