Memo

To: Jackie Wells, EA Commitment/Environmental Effects Monitoring Programs Lead

From: James McCarthy, Senior Biologist/Aquatic Group Lead

cc: Robert Flett, Chief Scientist
Matthew Gosse, Environmental Biologist

Date: April 25, 2019

Re. Sediment Sampling Methodology, Goose Bay and Lake Melville

1. INTRODUCTION

Sediment samples collected to date from Goose Bay and Lake Melville have been ineffective to generate samples with appropriate sediment types to detect methylmercury. As part of their review process of the Environmental Effects Monitoring (EEM) Program, the Independent Expert Committee (IEC) appointed by the provincial government provided recommendations related to the sampling of sediment from Goose Bay and Lake Melville. The specific recommendation is below:

- 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.

While this recommendation provides general advice, no additional details or follow up has been provided to date. The following is a description of the proposed methodology for sediment collection to acquire the methylmercury and aging (Pb-210) data requested. The Churchill River itself is fast flowing and the estuary (Goose Bay and Lake Melville) is very large and deep and therefore both general and site-specific challenges have been identified and recommended solutions described.

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2. GENERAL OVERVIEW

Sediment samples can reveal chemical and metal contaminations in a time-integrated sample (Hakanson and Jansson 1983) provided they are collected in such as way as to preserve their structural integrity. They can also be used to determine sedimentation rates provided sample integrity is maintained (Robbins and Edgington 1975). Therefore, the collection of sediment samples for the purpose of gathering depth-stratified total mercury (THg) and sedimentation rates will require proper methods, handling, and analysis. THg will be analyzed from physically collected sections of properly collected, depth-stratified core samples. Sedimentation rates will be completed using radioactive isotopes such as Pb-210 and Cs-137 on the same core samples.

The spatial distributions of both Cs-137 and Pb-210 are principally via attachment to setting particles (Robbins and Edgington 1975, Ritchie and McHenry 1990) and are often used in combination to provide information on soil and sediment redistribution over the last 100-year time period. Since the 1970s, Pb-210 measurements have been used extensively for dating sediment deposits in a range of sedimentary environments, including, lakes, reservoirs, flood plains, wetlands, estuaries, and coastal marine environments, thereby permitting sedimentation rates of the last 10-150 years to be determined (Robbins and Edgington 1975, Kristensen et al. 2012, Mabit et al. 2014). When applying the Pb-210 technique, it is assumed that lake and ocean sediments are receiving a constant input of Pb-210 from the atmosphere. Cs-137 is radioactive fallout deposited across landscapes from atmospheric nuclear tests that is strongly absorbed on soil particles, limiting its movement by chemical and biological processes (Ritchie and McHenry 1990). As a result, most Cs-137 movement in the environment is by physical processes and hence is a unique tracer for studying erosion and sedimentation.

In order to ensure the most reliable design for collection of depth-stratified samples, the general and site-specific challenges related to this program have been reviewed and outlined below. Each is identified, and an approach developed.

3. SAMPLING CHALLENGES

Sediment samples are relatively simple to collect to document rates of sedimentation and methylmercury concentrations (Håkanson and Jansson 2002); however, the nature of the lower Churchill River and the Goose Bay/Lake Melville estuary presents challenges with respect to appropriate, representative samples (and sites) False conclusions are an obvious risk if such studies are based on biased field samples (Blomqvist 1991).

The instruments best suited for quantitative sampling of soft-bottom sediments appear to be those based on the coring principle with adequately designed and properly operated tube corers being the most versatile instruments at present (Blomqvist 1991, Ohio EPA 2001, U.S. EPA 2014). However, improper handling or faulty design of a coring device, can result in unrepresentative samples. Major factors in bias are (1) loss of surficial sediments, (2) redistribution, resuspension and loss of enclosed sediment, (3) core shortening, and (4) repenetration (Blomqvist 1991, Håkanson and Jansson 2002).

Loss of surficial sediments can occur due to bottom disturbance prior to sampling. This can be caused by hydraulic shock created in front of the sampling device opening which can wash away flocculent or easily resuspended surficial sediments before the corer reaches the sediment surface (Blomqvist 1991). This bias can be minimized by use of equipment with unimpeded water flow through the corer during descent to avoid hydraulic shock. Additionally, gentle, slow entry and penetration of the coring tube into the sediment bed are essential in order to prevent loss of surficial sediments and minimize core shortening or any associated core deformation. The lower end of the coring tube should be sharply tapered on the outside to provide an effective sampling area similar to the inside cross-sectional area of the tube and to also facilitate penetration (Blomqvist 1991).

Redistribution, resuspension and loss of enclosed sediment can occur if corers penetrate too deeply or at an angle. Corers that sink too deeply may not provide a representative sample (Blomqvist 1991) and gravity corers not equipped with a supporting stand, can readily tilt on the bottom which may result in redistribiton and resuspension of enclosed sediment and in loss of material. To prevent material from being lost during retrieval, samplers should be fitted with an efficient closing mechanism (Håkanson and Jansson 2002). However, samples can still be disturbed during the

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closing operation and withdrawal from the sediment as well as during retrieval and should be considered. While adequately designed box corers might be appropriate for sampling benthic macrofauna and infauna in particular, when dealing with unconsolidated surficial or flocculent samples, properly locking corer lids are preferred (Blomqvist 1991).

In cases in which the structure of the sediment must be preserved (e.g., annual laminations), freezing the sediment in place with a dry-ice solution is also a potential option (Wright 1991). However, while freezing in-situ can provide quantitative samples for studies such as micro layering in lakes, sampling the uppermost surficial layers using this technique, requires particular care (Blomqvist 1991).

Core shortening is an important consideration when using open tube corers. Sediment core shortening in open-barrel corers, i.e., the difference between depth of sediment penetration by the coring tube and interior length of the core, is a phenomenon which may severely bias sampling. Core shortening principally involves deficient entry of sediment into the sampler. Between-station variations in the physical character of sediment can also result in varying degrees of core shortening. Clayey silty sediments are shortened more than light, unconsolidated organic sediments. If soft sediment is overlaid by stiffer matter, however, the former is more thinned than the latter. The problem is further complicated by the fact that the initiation of the core shortening is related to sampling tube diameter, and the degree of shortening is influenced by the penetration velocity and diameter of the coring tube employed. Incomplete recovery on individual drives is not necessarily a result of sediment compaction but can be the build up of friction on the tube interior, by which the core forms a plug that prevents further recovery (Wright 1991). In essence, it is most important to be aware of core shortening when evaluating data from sediment coring. To properly record and correct for core shortening in samples is most difficult and seems in practice often impossible (Blomqvist 1991).

To minimize frictional resistance and the risks from sediment deformation and compaction during sediment penetration, coring tubes with smooth inside surfaces should be used, with a moderate outside clearance and with a sharp edge and a small edge angle. The tube must allow unrestricted flow during sediment penetration and the closing mechanism must not close until the sampler is pulled up. Håkanson and Jansson (2002) indicated that sediment compaction in coring tubes can be revealed by means of double-sided tape placed on the outside wall of the tube; sediment intrusion should be at the same level as the “dirt” verge of the tape, however Blomqvist (1991) has suggested this may be unreliable. A large coring-tube diameter reduces shortening and hence is preferable (Blomqvist 1991). Cross-section area of the edges should be less than 10% of the sample area (Hvorslev ratio). This requirement cannot be met for small tubes (Håkanson and Jansson 2002).

Re-penetration may easily lead to misinterpretations, such as apparent cyclicity of sedimentary records when using open-barrel gravity corers (Blomqvist 1991). The coring device should therefore allow the documentation of the core prior to extrusion (i.e., clear tubes so photos/inspections can occur) (Håkanson and Jansson 2002). In addition, mounting an underwater video camera as a standard on coring devices is recommended since it enables visual inspection and recording of each sampling event (Blomqvist 1991) and can corroborate asserted sampling qualities.

4. PROPOSED SAMPLE PROGRAM DESIGN

Obtaining good cores and making the right radioisotopic measurements are very important in generating the best possible estimates of sediment age within a core (Flett Research). The Pb-210 method is used to determine the accumulation rate of sediments in lakes, oceans and other water bodies. In a typical application, the accumulation rate over a period of 100 - 200 years is obtained. From the accumulation rate, the age of sediment from a particular depth in the sediment column can be estimated.

4.1 Equipment and Ice Cover

Core samplers are typically used to sample vertical columns of sediment and can maintain a more representative vertical profile of the sediment stratigraphy, create less disturbance by shock waves and can collect more highly consolidated deposits (Ohio EPA 2001, U.S. EPA 2014). They are particularly useful when a historical picture of sediment deposition is desired since they preserve the sequential layering of the deposit. They are also particularly useful when it is desirable to minimize the loss of material at the sediment-water interface. Many types of coring devices have been developed, depending on the depth of water from which the sample is to be obtained, the nature of the bottom material and the length of core to be collected. They vary from hand-driven push tubes to electronic vibrational core tube drivers (Region 4 US EPA Science and Ecosystem Support Division, Athens, Georgia. Sediment Sampling Operating Procedure 2014).

They are particularly useful in pollutant monitoring because turbulence created by descent through the water is minimal (Håkanson and Jansson 2002), thus the fines at the sediment-water interface are only minimally disturbed; the sample is withdrawn intact, permitting the removal of only those layers of interest; core liners of glass or Teflon reduce possible sample interferences; and the samples are easily delivered to the lab for analysis (Region 4 US EPA Science and Ecosystem Support Division, Athens, Georgia. Sediment Sampling Operating Procedure 2014). Freeze-sampling is a technique which can provide certain quantitative sediment samples for e.g. studies of micro layering, but it has practical restrictions which preclude its more general use. A sampling device with which truly quantitative soft-bottom samples may be taken must have a definite sampling area which encloses the corresponding underlying sediment column, retains the sample and minimizes disturbances of the sediment during sampling and recovery. Consequently, such sampling must involve either (1) open-barrel gravity corers, (2) box corers (which are open rectangular gravity corers) or (3) piston corers (Blomqvist 1991).

One disadvantage of coring devices is that a relatively small surface area and sample is obtained, often necessitating repetitive sampling in order to obtain the required amount of material for analysis. Because it is believed that this disadvantage is offset by the advantages, coring devices are recommended in sampling sediments for trace organic compounds or metals analysis by the US EPA and will be utilized for this program.

4.2 Sample Locations

Sample location is very important for obtaining representative samples with minimal disturbance, redistribution, and biological mixing.

The sedimentological record in dynamic estuarine environments is often distorted or obscured by sediment reworking as a result of biological activity of by depositional and erosional processes associated with phenomena such as wave action or storm surges (Smith and Walton 1980).

Sites in the deepest water may have faster rates of sediment accumulation because of resuspension of shallow-water sediment and its deposition in deep water (focusing) (Wright 1991).

Flett Labs propose that the best location to obtain a core for Pb-210 or Cs-137 dating is most likely the deepest part of the lake. The isotope activities will usually be highest and most easily measured at this site, and physical and biological mixing may be reduced, particularly if the deep waters are anoxic (see Figure 4-1). A general bathymetry map of Lake Melville is provided in Figure 4-2. As shown, there are several locations where deeper troughs and shelves are identifiable. The locations labelled 1-4 are proposed for sediment sampling.

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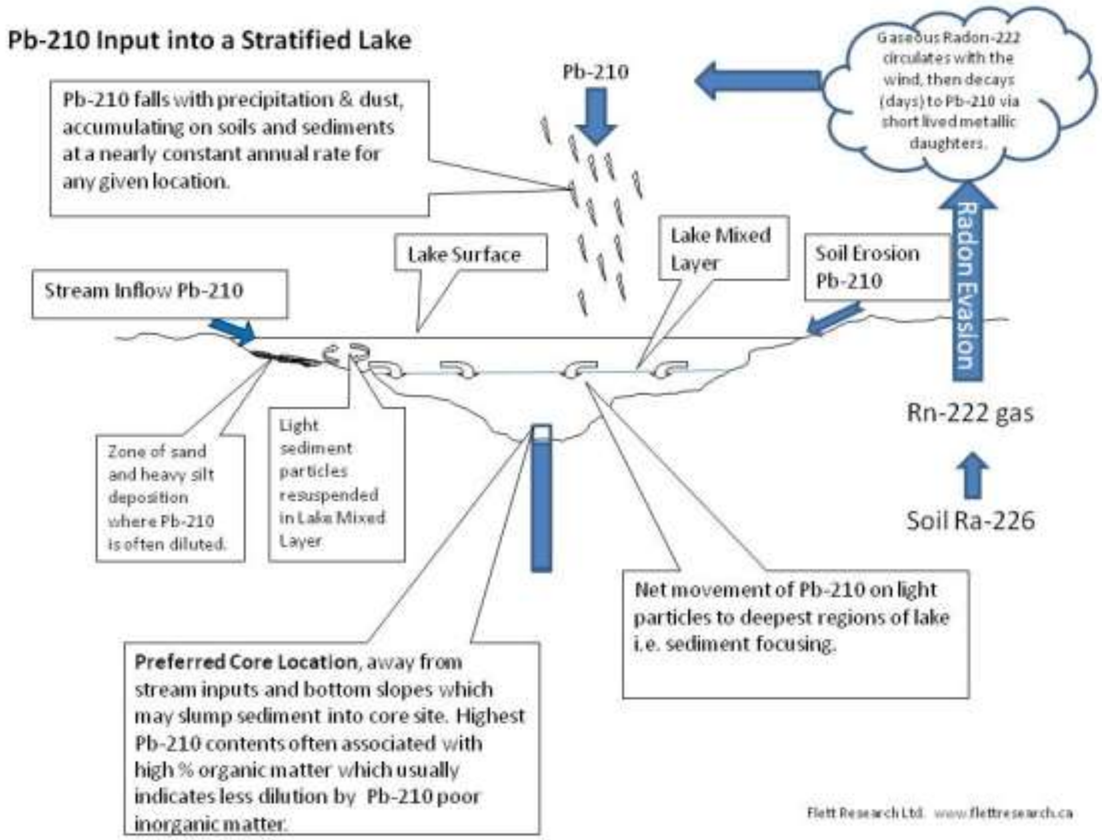

Figure 4-1: General rationale for sample location determination, Lake Melville.

4.3 Sample Collection, Storage, and Shipping

It is proposed to use the existing stable ice cover to assist in anchoring and maintaining vertical position during coring (Blomqvist 1991, Wright 1991). When using ice cover to maintain vertical position, it also allows very controlled descent and retrieval of the corer. A mobile sonar will also be deployed to determine distance to the bottom. The tether will be marked at 20 m intervals so that the last 20 m before the sediment interface, the unit will be slowly lowered into the substrate. An 8cm diameter HTH Corer will be used for the field program.

Each core will be retrieved and the core liners containing the sediment sample removed and processed (sectioned) at the sample location prior to demobilizing to avoid resuspension of material and/or core mixing. Each will be held in a vertical position and placed in a stand where they will be inspected for integrity. Carefully chosen cores will be sectioned, using a manual extruder, after the floc is allowed to resettle for up to an hour. The entire process will be completed during the spring at which time the air and water temperatures will be as similar as possible so as to prevent sediment expansion due to gas formation. Any suspended floc remaining will be removed by a syringe and kept for analysis, while, for the more consolidated sediments, intervals of well-defined thickness will be isolated by means of a centimeter-scribed collar, placed over the end of the core liner, into which an appropriate amount of material will be extruded.

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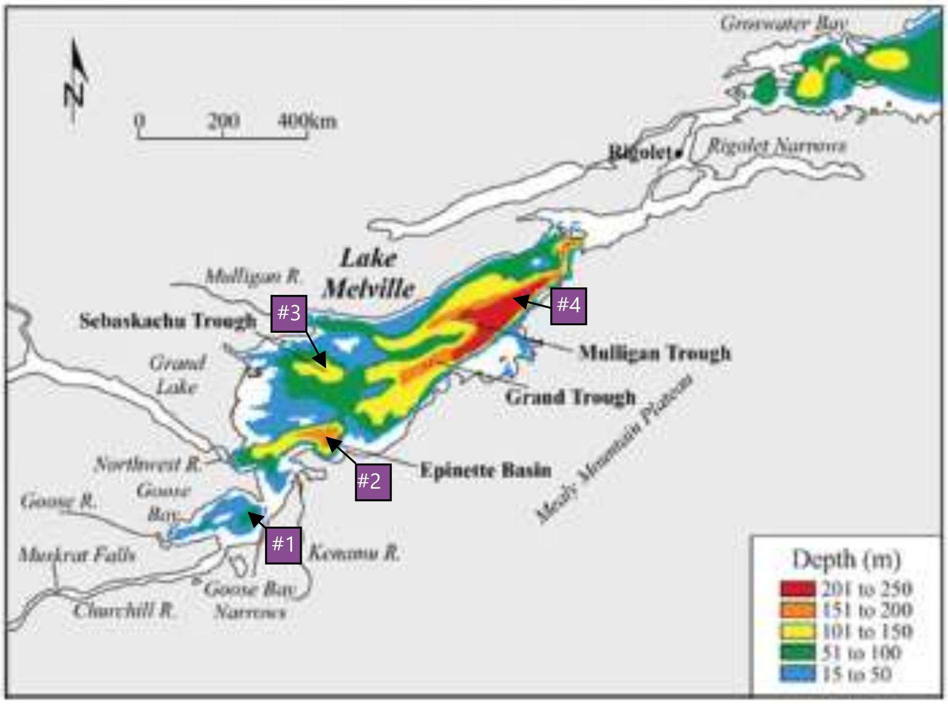

Figure 4-2: Bathymetric contours, Lake Melville (Kamula et al. 2017). Proposed sample locations are indicated with numbers 1-4.

During the sampling period, all core sections for lab analysis will be temporarily stored in coolers without ice (Wright 1991). Core sections will be shipped immediately after the field program to the lab for analysis. Photos of each core prior to extrusion will be completed to document layering, colour, and condition. It is also proposed to connect a video camera (e.g., GoPro with light) to the sampler to document, if possible, the coring.

Flett Labs indicate that the resolution of core sections depends upon the sediment accumulation rate at the sampling site. Typically, the cores are sectioned at 1-cm thickness in the upper 20 cm, 2-cm thickness between 20 and 40 cm and 5-cm thickness below 40 cm depth. If the sediment accumulation rate is very low (e.g. <0.05 cm/yr), then a higher resolution would typically be desired (i.e. 0.5 cm / section). If the sediment accumulation rate is very high (e.g. in a dam or river inlet), the core can be sectioned at 2-cm or 5-cm thickness or even thicker. If these samples are to be analyzed for other analytes (e.g. metals or contaminants), then the resolution may need to be defined by the study. Smith and Walton (1980) showed that cores can be homogenously mixed within upper 4 – 5 cm due to bioturbation caused by benthic invertebrates and fish disturbing the sediment during activities. The top 5 cm of sediment cores previously collected by other researchers in Lake Melville also show bioturbation (M. Kamula pers comm.). Therefore, the recommended sampling and sectioning of only the upper 5cm by the IEAC will not likely provide information on settling rates or methylmercury accumulation within the sediment material.

Kamula et al. (2017) completed coring within Goose Bay and Lake Melville in areas similar to those proposed for this program. The typical core depths obtained were 10-23 cm in these areas with estimated sedimentation velocities of 0.14-0.25 cm/yr.

It is proposed that cores will be sectioned every centimeter throughout the entire core length. This will capture the available existing sediment dates and provide a description of the existing sediment mercury distribution. It is suggested that during the first post-reservoir sediment sampling program (i.e. five years after reservoir formation) that the upper 6cm be sectioned at 0.5cm to document any changes in sediment profiles dues to reservoir formation.

Each section will be well homogenized and collected in clean jars; heavy walled polypropylene is preferred because of resistance to breakage. The jars will also be waterproof to avoid water loss from the samples. Jar rims will be kept clean when closing to avoid particles on the sealing surfaces. Water loss from each section will be avoided as this will affect the bulk density which in turn will affect the Pb-210 dating calculations. Samples do not require special storage conditions for radioisotope analyses; holding times are unlimited. However, Total Mercury analysis will require shipment as soon as possible for analysis.

Samples will be provided to the lab as wet samples so that dry bulk density of the sediment (dry wt./wet volume) can be calculated before drying and analyzed for Pb-210.

It is anticipated that the following quantities will be obtained from each core section for analysis:

- Pb-210: 0.5 – 1.0 g (equivalent dry wt.) per sample
- Ra-226: 1.0 – 2.0 g (equivalent dry wt.) per sample
- Cs-137: > 5 g (equivalent dry wt.) per sample
- Total Mercury: 0.5 g dry weight equivalent per sample

4.4 Sample Analysis

Rather than strict analysis of each core section for all isotopes, an iterative approach will be used; typical of effective analysis by Flett Labs. For each core, it is typical to analyze 15 - 20 samples for Pb-210, covering an accumulation period of about 160 years. Analysis will start with about seven analyses of Pb-210, spread along the core length, to determine the basic profile shape, and then fill in where the profile dictates. This is the most cost-efficient way, i.e. the number of analyses will be optimized to obtain reliable dating results.

Several (2 – 3) Ra-226 measurements are often required for each core, in order to positively determine the Pb-210 background level(s). After all Pb-210 and Ra-226 analyses are completed, 8–15 Cs-137 analyses will be completed for each core, in order to validate the Pb-210 model(s).

Dry bulk density is required on each sample in order to apply the CRS model to the data. Typically, a known volume of wet sediment is dried at about 50°C and then the dry weight of remaining sediment is determined. This is important because the Pb-210 is measured on dry samples and therefore calculations of how much Pb-210 is contained within in each ml of the original wet core material is needed. After the Pb-210 background is subtracted from each ml of sediment, the total amount of excess (atmospheric sourced) Pb-210 in the core as DPM/cm^2 is calculated. This total excess Pb-210 inventory, together with the subtotals upon which it is based, are used by the CRS model to calculate accumulation rates and ages for each core section.

Data and interpretation/modelling will be included on a single XL97-2003 workbook for each core, in a standardized format. Where possible, ages will be assigned to the bottom of each section. Graphs of Pb-210 vs accumulated dry weight/cm2, dry bulk density vs accumulated dry weight/cm2, best fit regression of Pb-210 vs accumulated dry weight/cm2, CRS and linear model age vs depth comparison, CRS sediment accumulation rates vs depth, CRS sediment accumulation rates vs age, and Cs-137 vs depth are included where possible. All raw data, calibrations and calculations will be included in data tables.

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5. CLOSURE

If you have any questions, or require any further information, please feel free to contact me at your convenience.

Yours sincerely,

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