Review of Methyl Mercury Biomonitoring Programs for the Muskrat Falls Project

Prepared for:

Independent Expert Advisory Committee
Muskrat Falls Project

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OLLSON
Environmental Health Management

Table of Contents

1 Introduction 1
1.1 Primary Assumptions for the Undertaking 2
2 Biomonitoring Studies Completed for the Muskrat Falls Project 2
3 Understanding of Biomonitoring and Review Criteria used in this Review 2
4 Methylmercury Benchmarks and Guidelines 4
5 Biomonitoring Programs Undertaken for Muskrat Falls Project 7
5.1 Golder 2015 7
5.1.1 Ethics Approval 7
5.1.2 Recruitment and Representative Sampling 7
5.1.3 Dietary Survey Methodology 8
5.1.4 Hair Sampling and Analytical Methodology 8
5.1.5 Results of Dietary Survey 9
5.1.6 Hair Biomonitoring 10
5.1.7 Conclusions and Reporting 13
5.2 Calder et al. 2016 13
5.2.1 Ethics Approval 13
5.2.2 Recruitment and Representative Sampling 13
5.2.3 Dietary Survey (Food Frequency Questionnaire (FFQ)) Methodology 15
5.2.4 Hair Sampling and Analytical Methodology 16
5.2.5 Results of the Food Frequency Survey (Dietary Survey) 16
5.2.6 Results of Hair Biomonitoring 18
5.2.7 Conclusions and Reporting 19
6 OEHM Conclusions of Biomonitoring Surveys 20
6.1 Feasibility of combining/consolidating the results of the two programs into one dataset for analysis (assuming that an agreement could be reached by the parties involved to share data). Would there be any added value in doing this? 20
6.2 Is the existing data sufficient to form a reliable baseline? Are the data sufficient to draw conclusions about all population groups in the Lake Melville area? 20
6.3 How do the biomonitoring results from the study area compare to the general Canadian population, more highly exposed populations and other susceptible subgroups? 21
6.4 Do the results permit reliable comments on the 'safety' of the country foods that are being consumed? Can individuals find themselves within this data given their own dietary habits? 23

6.5 Identify any significant data gaps and propose how additional work could fill these gaps and provide a more comprehensive understanding of exposure/health at the present time. 24

7 Overall Conclusion 24

8 References 25

List of Tables

Table 1. Developmental timeline for blood and hair MeHg benchmarks for use in biomonitoring studies in Canada. 4

Table 2. Canadian mercury guidance values and recommended actions (EC, 2016). 5

Table 3. Study participant information (Golder, 2015). 7

Table 4. Reported dietary consumption 9

Table 5. Summary statistics of THg in hair for all study participants (Golder, 2015). 10

Table 6. Summary statistics of THg in hair by community (Dillon, 2016). 12

Table 7. Food frequency questionnaire (FFQ) data collected in the Calder study (Calder, 2016). 14

Table 8. Hair mercury sample recruitment from Inuit communities (Calder, 2016). 15

Table 9. Example of MeHg concentration data in country foods (Calder, 2016). 17

Table 10. Material Guidance Value exceedances for blood concentrations (EC, 2016). 22

Table 11. MeHg Blood results for Nunavik Inuit (Lemire, 2015). 23

List of Figures

Figure 1. Golder box and whisker plot of THg in Hair results by community. 11

Figure 2. Measured concentrations of THg in hair (Calder, 2016). 19

Appendices

Appendix A Response to IEAC Comments on Draft Report

1 Introduction

In 2017, an Independent Expert Advisory Committee (IEAC) for the Muskrat Falls Project (the Project; also known as the Lower Churchill Project) was established to:

> *"independently assess the adequacy of mitigation, monitoring and management of the Lower Churchill Project, and to provide recommendations to the Responsible Ministers with respect to the protection of the health of the Indigenous and local population impacted by the Lower Churchill Project, with particular focus on methylmercury in the Churchill River and downstream."*
>
> (http://ieaclabrador.ca)

In the fall of 2017, the IEAC contracted Ollson Environmental Health Management (OEHM) to evaluate the methylmercury (MeHg) biomonitoring and dietary surveys that have been conducted for the Muskrat Falls Project. Dr. Christopher Ollson, an Environmental Health Scientist of OEHM completed this work. The specific objectives of the undertaking were to attempt to address the following:

1. *What biomonitoring (hair samples for THg and MeHg) has been done related to the Muskrat Falls project? We are aware of the sampling done by Nalcor for the HHRA and a separate study conducted on behalf of the Nunatsiavut Government. Has there been other sampling? What about dietary surveys?*
2. *Compare and contrast all biomonitoring data based on the criteria noted below and any other important criteria.*
    a. *Methodology*
    b. *Sample selection and sample size. Were all important subgroups in the affected communities included?*
    c. *Results*
    d. *Limitations*
3. *Conduct a similar comparison and contrast of available dietary surveys.*
4. *What is the feasibility of combining/consolidating the results of the two programs into one dataset for analysis (assuming that an agreement could be reached by the parties involved to share data). Would there be any added value in doing this?*
5. *Is the existing data sufficient to form a reliable baseline? Are the data sufficient to draw conclusions about all population groups in the Lake Melville area?*
6. *How do the biomonitoring results from the study area compare to the general Canadian population, more highly exposed populations and other susceptible subgroups?*
7. *Do the results permit reliable comments on the 'safety' of the country foods that are being consumed?*
8. *Could an individual 'find themselves' amongst the studied population given their own dietary habits and is there sufficient information to draw conclusions regarding their mercury exposure and health? Can tools be developed or adapted to provide such information?*
9. *Identify any significant data gaps and propose how additional work could fill these gaps and provide a more comprehensive understanding of exposure/health at the present time. If additional work needs to be conducted:*
    a. *Develop a scope of work that could be used for tendering purposes*
    b. *Provide a cost estimate for said work*

This report provides the review, findings and discussion for potential future work that could be considered by the IEAC. Appendix A contains responses to comments received from the IEAC on the draft report.

1.1 Primary Assumptions for the Undertaking

OEHM understands that there are a number of additional projects being considered by the IEAC as part of their mandate. The results of these additional projects were not considered herein. In addition, it is recognized that there is considerable controversy surrounding the Muskrat Falls Project. However, this review was guided solely by scientific principles and best practices for review of scientific publications and reports.

Any findings from this work should in no way be construed as OEHM being either for, or against, the Project proceeding. OEHM does not have any financial stake or interest in the Project, nor any potential conflict of interest with any of the parties that comprise either the IEAC or the Oversight Committee.

2 Biomonitoring Studies Completed for the Muskrat Falls Project

There are two primary mercury exposure biomonitoring studies and associated dietary surveys that have been completed in relation to the Project. They have been completed on behalf of Nalcor (Project proponent) and the Nunatsiavut Government (NG). Throughout this report they will be referred to as the:

> Golder and Associates (2015) Report on the Baseline Dietary Survey and Human Biomonitoring Program. Prepared for Nalcor Energy Lower Churchill Project. Technical Report.
>
> Calder et al. (2016) Future Impacts of Hydroelectric Development on Methylmercury Exposure of Canadian Indigenous Communities. Prepared for the Nunatsiavut Government. Published in Environmental Science and Technology. Environ. Sci. Technol. 2016, 50, 13115−13122.

In this report the order in which these documents is discussed typically starts with the Golder work and followed by the Calder work. This was done in order of publication of results and in no way reflects a preference of data or results from either work. A number of figures and tables were reproduced from these studies within this report.

A series of secondary data sources and reports were sourced and referenced in completion of this review. These consist of government reports and published journal articles that provide information on MeHg guidelines, exposures in other Canadian populations and biomonitoring programs being conducted for other indigenous populations around Canada. A detailed list of these reports is provided in the reference section.

3 Understanding of Biomonitoring and Review Criteria used in this Review

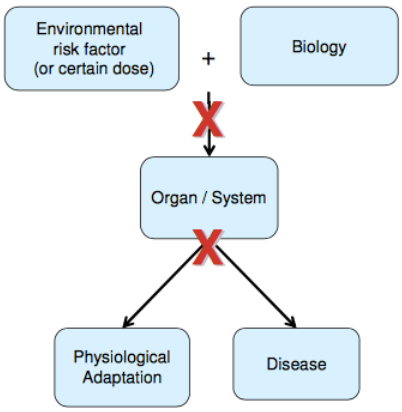
Biomonitoring for MeHg exposure has been conducted for 'at risk' populations around the world for decades. It is perhaps one of the most extensively studied environmental contaminants. Minamata disease was first reported in 1956 in a Japanese community that was exposed to very high concentrations of MeHg in fish that were impacted by industrial releases. Since that time medical and environmental agencies around the world have developed standardized protocols and approaches to ascertaining community exposure to MeHg and its potential to impact health.

A set of guiding principles for conducting biomonitoring programs from the World Health Organization (WHO) was used in the review of the Muskrat Falls Project studies. These principles are summarized in the WHO training session *Children's Health and the Environment – WHO Training Package for the Health Sector – Biomarkers & Human Biomonitoring – October 2011* (http://www.who.int/ceh/capacity/biomarkers.pdf). This readily available presentation and guiding principles are publically available and many of its figures have been reproduced in this report.

The following are key definitions:

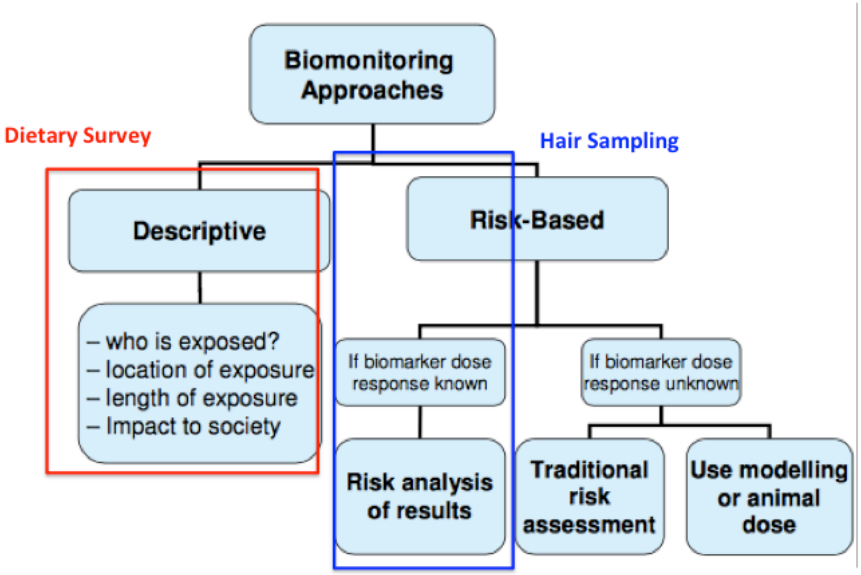
- ***Biomarker:*** *a chemical, its metabolite, or the product of an interaction between a chemical and some target molecule or cell that is measured in the human body.*
- ***Environmental monitoring:*** *the measurement of a contaminant's concentration in a medium (e.g., air, soil, water, or food).*
- ***Human biomonitoring****: the direct measurement of people's exposure to toxic substances in the environment by measuring the substances or their metabolites in people, such as blood, urine, or hair.*

The primary route of environmental exposure for people to MeHg is through the consumption of food, and in large part freshwater or marine species. In the case of the Muskrat Falls Project human biomonitoring has involved the direct measurement of people's exposure to MeHg and total mercury (THg) in hair. This monitoring allows public health officials to ascertain the level of MeHg that people in the area have been exposed to through consumption of both country food and store bought food. It is assumed in human biomonitoring that 100% of the THg in hair is actually present as MeHg.



The mere presence of MeHg in human hair does not necessarily mean that environmental illness will occur. For many environmental contaminants, including MeHg, the level of exposure must exceed a benchmark before there is concern that individual or community health could be affected. Health Canada, and other international medical and environmental agencies have set MeHg guidelines for biomonitoring and consumption (Section 4). Therefore, the results of the Muskrat Falls Project biomonitoring programs should be benchmarked against these levels to comment on the potential for health impairment or disease.

There are two complementary approaches to biomonitoring – descriptive and risk-based. In this case descriptive biomonitoring seeks to answer questions about the potential sources of exposure to MeHg. The dietary surveys completed for the Muskrat Falls Project were reviewed to ascertain the extent to which one could trace back the exposure to foods consumed. The risk-based biomonitoring approach was the sampling of hair and subsequent analysis for THg



and MeHg. Given that there is good biomarker dose/response, toxicological and health data for MeHg concentrations in hair then the results can be directly compared to established action level benchmarks.

In reviewing biomonitoring programs one must first review the approach and methodology used to undertake the assessments:

- Ethics review and approval;
- Recruitment and obtaining representative sample;
- Dietary survey methodology;
- Hair sample collection;
- Analytical methodology;
- Benchmarks and data interpretation; and,
- Conclusions and reporting.

These factors were all considered in review of the biomonitoring programs for the Muskrat Falls Project.

4 Methylmercury Benchmarks and Guidelines

OEHM undertook a review of biomarker response levels for MeHg in hair prior to initiating the review of the Project biomonitoring programs. This is an important first step as it sets the benchmark against which all results were interpreted. This is not a review of the current state of the science of MeHg toxicity or an attempt to develop new guidelines.

Health Canada has long been involved in the development of guidelines and exposure limits for MeHg for the Canadian population. A detailed review of the history, timelines, supporting data and limits is reported in Legrand et al. (2010). OEHM has reproduced a brief synopsis below but Legrand et al. (2010) should be consulted for additional details.

Table 1. Developmental timeline for blood and hair MeHg benchmarks for use in biomonitoring studies in Canada.

Organization	Date	Value	Basis
WHO Joint Expert Committee on Food Additives (JECFA)	1972	Tolerable Weekly Intake (TWI) for MeHg of 3.3 µg/kg bw (body weight)/week. TWI was adopted by Health Canada's Food Directorate, and expressed as the Provisional Tolerable Daily Intake (pTDI) of 0.47 µg MeHg/kg bw/day.	Lowest blood concentration associated with adverse clinical effects was approximately 200 µg/L. Safety factor 10x. Based on Japanese and Iraq epidemiological data.
FNIHB	1970s	Refers to blood levels below 20 µg/L (or 6 mg/kg in hair) as being "acceptable" and levels greater than 100 µg/L in blood (or 30 mg/kg in hair) as "at risk". 0.47 ug/kg-d of MeHg Still used for M>18 and F>50	The basis was the WHO JEFCA values. FNIHB employed a hair to blood ratio of 300, derived from Canadian data with First Nations Although the developing fetus was considered as a sensitive sub- group, no specific threshold values were proposed.
Health Canada	1990s	Health Canada proposed that the increased susceptibility of the developing fetus to MeHg toxicity	Following the release of preliminary results from both the Seychelles and Faroe Island infant cohort studies, and considering the

Organization	Date	Value	Basis
		should be recognized	findings from a smaller New Zealand fish-eating cohort.
Health Canada	1998	pTDI 0.2 µg/kg bw/day	In 1998, 10 mg/kg mercury in maternal hair was proposed as a toxicological reference on which to set a tolerable intake for sensitive sub-groups. 5-fold uncertainty factor to account for inter-individual variability, They used an international standard of hair to blood ratio of 300 to arrive at 0.2 ug/kg-d intake.
USEPA IRIS	2000	RfD - 0.1 ug/kg-d	Same basis as Health Canada value although the applied a 10-fold uncertainty factor instead of 5-fold.
JEFCA	2003	pTWI of 1.6 µg/kg bw (approximately 0.23 µg/kg bw/day)	Using a composite maternal hair mercury value of 14 mg/kg but a larger uncertainty factor, JECFA suggested that a pTWI of 1.6 µg/kg bw (approximately 0.23 µg/kg bw/day) was sufficient to protect the most vulnerable population subgroup.
Health Canada	2010	Blood value <8 µg/L Hair Value <2 mg/kg	A blood value of 8 µg/L was used as a provisional interim blood guidance value applicable to women of childbearing age and pregnant women for the protection of the fetus for neurological and developmental effects.

The Canadian Mercury Science Assessment Report (Environment Canada, 2016) includes Chapter 14 Mercury and Human Health. This chapter also includes a review of the Health Canada guidelines and references them in Table 14.1 of their report (note unit error in the table mg g^{-1} should read ug g^{-1} or mg kg^{-1}). For females 0-49 years and males <18 Health Canada's guidance value is <2 mg/kg of MeHg in hair – below which no follow-up is required (Table 2). This is to ensure the protection of the fetus and young children against neurological impairment. For males >18 and females >50 the guideline is <6mg/kg – below which no follow-up action is required.

Table 2. Canadian mercury guidance values and recommended actions (EC, 2016).

TABLE 14.1 Canadian Mercury Guidance Values and Recommended Actions

Group and age	Blood value, mg L^{-1}	Corresponding hair value, mg g^{-1}	Recommended action
Pregnant women Females birth–49 Males ≤18	<8	<2[a]	No follow-up required
Pregnant women Females birth–49 Males ≤18	8–40	2–10[a]	Repeat hair/blood test in 6 months; provide dietary advice
Pregnant women Females birth–49 Males ≤18	>40	>10[a]	Repeat hair/blood test immediately; schedule appointment with public health official
Females > 50, Males >18	<20	<6[b]	No follow-up required
Females > 50, Males >18	20–100	6–30[b]	Repeat hair/blood test in 6 months; provide dietary advice
Females and males at any age	>100	>30[b]	Repeat hair/blood test immediately; schedule appointment with public health official; refer to physician or medical toxicologist

[a] Harmonized provisional interim mercury blood guidance value proposed by Legrand *et al.* (2010); based on hair:blood ratio of 250:1

[b] Proposed by Health Canada (1999); based on hair:blood ratio of 300:1

During the preparation of this report a presentation was made to the IEAC on preliminary findings and results. During the presentation committee members asked a number of questions about the continued use of the Health Canada guidance values. To that end, OEHM recommended that the Chair of the IEAC contact FNIHB to confirm that these values were still valid for use and screening in Canadian MeHg human biomonitoring studies. On February 1, 2018 Dr. Harold Schwartz of FNIHB responded to the IEAC request via email stating:

> "I have provided the latest reference for the mercury blood/hair guidelines from the Canadian Mercury Science Assessment Report, 2016. Chapter 14, Mercury and Human Health. Note that the hair guidance value for men and women over 50 is 6 ppm and not 5 ppm as stated below."

In addition, OEHM reviewed two recent scientific publications by leading academic researchers in Canada investigating MeHg human biomonitoring in indigenous populations. Lemire et al. (2015) from the Université Laval, used these Health Canada blood guidance values of <8 ug/L and <20 ug/L in their "*Local country food sources of methylmercury, selenium and omega-3 fatty acids in Nunavik, Northern Quebec"*. Similarly, Juric et al. (2017) used the hair equivalent reference values of <6 mg/kg and <2 mg/kg as benchmarks in "*A total diet study and probabilistic assessment risk assessment of dietary mercury exposure among First Nations living on-reserve in Ontario, Canada"*.

During the course of this review OEHM also contacted the USEPA Integrated Risk Information System (IRIS) Hotline via email to ascertain whether the oral reference dose (RfD) was under review. As can be seen at https://www.epa.gov/iris/iris-agenda under the IRIS Program Multi-Year Agenda (December 2015) MeHg is listed under Table 2 as a Group 1 priority for review. However, information received from IRIS Hotline (email dated February 7, 2018) indicates that:

> *Before beginning assessment development, the IRIS Program releases an IRIS Assessment Plan (IAP), which presents summary of the IRIS Program's scoping and initial problem formulation conclusions, objectives, and specific aims of the assessment; criteria outlining the evidence considered most pertinent to the assessment; and identification of key areas of scientific complexity. An IAP has not been released for methylmercury at this time. The current RfD will remain applicable until an updated assessment for this chemical has been initiated (following release of an IAP) and that updated assessment has been completed.*

Therefore, although MeHg is on the priority list it has not entered even into the initial stage. In OEHM's experience these reviews, once initiated, often take five or more years to complete. There is no guarantee that just because a chemical maybe reviewed that the RfD will change. In addition, although Health Canada may review such updates from IRIS, they do not always adopt their findings. Such was the case in the 2000 release of the IRIS RfD, where Health Canada chose to keep the TDIs for MeHg.

Therefore, OEHM believes that the appropriate benchmark or guideline for reviewing the human biomonitoring results for the Muskrat Falls Project is <6 mg/kg MeHg in hair for M>18 / F>50 and <2 mg/kg MeHg in hair for M<18 and F<49. The IEAC is encouraged to monitor any changes in international benchmarks and consult with Health Canada in the future on their applicability to the Canadian population.

5 Biomonitoring Programs Undertaken for Muskrat Falls Project

5.1 Golder 2015

Golder and Associates (2015) conducted the first human biomonitoring program for Muskrat Falls Project. The approval of the Muskrat Falls Project was granted under Newfoundland Regulation 18/12 (2012) and included a number of conditions, in this case Nalcor committed to conduct baseline food consumption surveys and human hair sampling in the communities of Churchill Falls, Mud Lake, North West River, Happy Valley-Goose Bay, Rigolet, and Sheshatshiu.

5.1.1 Ethics Approval

A number of stakeholder engagements and ethics approvals were sought prior to undertaking the study. Consultation and approval was given by Health Canada, Innu Nation, the NL Health Research Ethics Board, and the NunatuKavut Community Council Research Advisory Committee. In addition, approval was not received from the Nunatsiavut Government Research Advisory Committee. Therefore, the community of Rigolet was not included in the survey. OEHM finds that the appropriate consultations and ethics approval were sought and obtained prior to start of work.

5.1.2 Recruitment and Representative Sampling

The Golder study envisioned a recruitment goal of 300 individuals from the communities of interest. This was meant to represent a number of subgroups for community, gender, and age that would enable appropriate statistical power for meaningful interpretation of the results. Details are provided in Section 4 of their report. They were able to recruit 293 participants from the five communities (Table 3).

Table 3. Study participant information (Golder, 2015).

Table 3: Study Participant Information

Category	Total Number of Survey Respondents	Number of Participants for Churchill Falls	Number of Participants for Happy-Valley Goose Bay	Number of Participants for Sheshatshiu	Number of Participants for North West River	Number of Participants for Mud Lake
Total Survey Respondents	293 (300)	28 (50)	121 (100)	71 (75)	53 (50)	20 (25)
Males	96	15	33	20	22	6
Females	197	13	88	51	31	14
Toddlers (1-4 years)	13 (60)	1 (10)	5 (20)	4 (15)	1 (10)	2 (5)
Children (5-12 years)	38 (60)	4 (10)	12 (20)	16 (15)	5 (10)	1 (5)
Adolescents (12-19 years)	38 (60)	7 (10)	19 (20)	7 (15)	5 (10)	0 (5)
Adults (>20)	204 (60)	16 (10)	85 (20)	44 (15)	42 (10)	17 (5)
Females between 15 and 44 years	104 (60)	8 (10)	52 (20)	27 (15)	13 (10)	4 (5)
Pregnant Females	3	0	2	1	0	0
Live in the community full-time	290	28	120	71	51	20
Belong to an Aboriginal Organization	196	6	67	71	40	12
Percentage of Total Survey Respondents that Belong to an Aboriginal Organization	66%	21%	55%	100%	75%	60%
Nunatsiavut Government[a]	82	0	38	5	30	9
Innu Nation[b]	70	0	6	63	1	0
NunatuKavut Community Council[c]	37	4	21	0	9	3
Other[d]	7	2	2	3	0	0

Although the community of Rigolet did not participate, an adequate sample size of 293 participants was achieved for the remaining communities. Representative sampling of males and females and potentially vulnerable age groups was also achieved. Dietary surveys and hair collection occurred between November 2014 and February 2015. This is a potential limitation of the Golder study, as the results may not have necessarily captured the highest MeHg exposure that could occur during the spring/summer

months, depending on consumption of particular country foods. Overall, the recruitment was adequate and provides a representative sample of the populations surveyed and their MeHg exposure at the time of sampling.

5.1.3 Dietary Survey Methodology

The completed Dietary Survey is found in Appendix B of the Golder report. Trained Golder team members administered the survey at the session the day after the community information session, or on the same day in Churchill Falls. The seasonal annual recall survey was administered through a direct personal interview and took approximately 45 minutes to complete. The study reports:

> *"The DS is based on a previous survey program delivered to the community of Sheshatshiu in 2002, and prepared by researchers at the Université du Quebéc à Montréal. The country and store-bought foods considered in the DS are based on multiple sources including the previous COMERN study, the Interim HHRA (Nalcor, 2009b) as well as community-specific knowledge of the Project Team and review comments received from Health Canada. As part of the Interim HHRA (Nalcor, 2009b), all available reports and studies were reviewed to extract relevant data related to dietary patterns and characteristics of Innu and/or non-Innu communities. Information on dietary patterns and country food consumption was extracted from the Lower Churchill River Fish Consumption and Angling Survey (Nalcor 2009c), the Current Land and Resource Use in the Lower Churchill River Area Study (Nalcor 2009d) as well as from published data collected by researchers at the Université du Quebéc à Montréal as part of the COMERN Project (these studies are cited in the following relevant subsections).*
>
> *The DS included a general questionnaire on respondent demographics, and food frequency questionnaires that asked questions related to consumption of both country foods and store-bought foods. Participants were prompted to also identify any other food sources that were not specifically listed in the survey. The DS is provided in Appendix B of this report."*

Overall, the Golder Dietary Survey appears to be adequate to provide details on seasonal dietary consumption of both country and store-bought foods. There are some drawbacks to asking individuals about annual dietary consumption patterns in such a manner. However, annual recall surveys are often conducted for similar indigenous population studies. Unlike the Calder study no harvest and subsequent MeHg analysis was conducted specifically in this study for country foods identified.

5.1.4 Hair Sampling and Analytical Methodology

Hair sampling and analytical protocols were reported in the Golder report:

> *The hair sampling protocol used in the HBP is a standard protocol (i.e., Gill et al. 2002) that is consistent with the Canuel et al. (2006) study that was carried out previously in Sheshatshiu as part of a COMERN project. As per the DS, personal information of participants in the HBP was kept private and confidential. Each hair sample was given a unique identification number that matches the hair sample to be sent for analysis to the individual it was collected from, but the identification of the individual will not be revealed publicly at any time. Once collected as per the standard protocol, hair samples were placed in labelled sampling bags and submitted to the analytical laboratory following all required and applicable data chain of custody procedures.*
>
> *The analysis of hair samples was carried out by Maxxam Analytics. (Maxxam) is accredited for hair Hg and MeHg analysis by the Standards Council of Canada (SCC) under ISO guide 17025.*

Details of Maxxam's accreditation can be viewed through the following link: http://palcan.scc.ca/Specs/PDF/51_e.pdf.

All hair samples were analyzed by Maxxam for total Hg, and 10% of the hair samples analysed for total Hg analysis were also analyzed for MeHg by Brooks Rand Laboratories (located in Seattle, Washington), subcontracted by Maxxam. The analytical method utilized a nitric acid/hydrogen peroxide microwave digestion followed by cold vapour atomic fluorescence spectroscopy. This is the same analytical method that was followed in Canuel et al. (2006), and in a Health Canada Interlab Study that Maxxam participated in where they demonstrated strong precision and accuracy with the noted analytical procedure (Gill et al. 2002). This particular analytical method is also the most commonly used in other studies of hair Hg concentrations conducted around the world.

All remaining hair samples were destroyed following analysis.

All 293 hair samples were of the full length of hair collected from each participant, and were analyzed for total Hg.

- *Thirty (30) samples of the full length of hair (approximately one out of every 10 samples) were also analyzed for MeHg.*
- *Nineteen (19) samples with the highest reported total Hg concentrations (ranging in concentration from approximately 1 to 4 mg/kg) were reanalysed for total Hg using a 3 centimetre length of hair closest to the scalp were analyzed to represent the previous three months of exposure.*
- *There were minor differences between the maximum Hg concentrations measured for the full length samples and the 3 centimetre samples. The difference is the full length sample represents a longer term average than the 3 centimetre sample.*

Overall, the sampling strategy for hair collection followed standard protocols. However, it is noted that full length of hair was collected and details of the individual hair length were not reported. Standard analytical protocols and accredited laboratories were used in analysis of THg and MeHg in hair. Therefore, OEHM places a high degree of confidence in the analytical results.

5.1.5 Results of Dietary Survey

The reporting of the results of the dietary survey was detailed and included a number of tables and figures indicating seasonal consumption patterns. Golder reports that all of the data was entered into a master database created in EXCEL to allow for data extraction and analysis. Appendix B of the report provides the "Frequency of Harvested Food Consumption" sheets. If more than 10% of respondents (n>29) reported consuming a particular species in any season, then further frequency analysis and serving size was completed. Table 4 provides the classification groupings reported for the dietary survey.

Table 4. Reported dietary consumption

Harvested Country Food Consumption	Store-Bought (Market) Food Consumption
Fish and Fish Organs Seafood and Shellfish Sea Mammals Birds and Bird Organs Mammal and Mammal Organs	Meat and Meat Organs Fish, Fish Organs and Canned Fish Seafood and Shellfish

The reporting of dietary survey results is well done, comprehensive and can be reviewed for particular data abstraction. It is recommended that the IEAC request an electronic version of the EXCEL database that could be mined for information in the future.

5.1.6 Hair Biomonitoring

Golder presents the results of the mercury biomonitoring program in several different ways within the report. They selected a THg in hair standard of 10 mg/kg based on their interpretation of the Health Canada's TDI. However, Golder did not apply the 5-fold uncertainty factor that Health Canada used to develop the TDI or their THg in hair guideline value of <2 mg/kg. Therefore, OEHM has reinterpreted their findings with the use of the <6 mg/kg (M>18 and F>50) and <2 mg/kg (F<50 and M<18) Health Canada guidelines.

Another challenge to interpreting the Golder data, as presented in the report, is that it only reports F>20. Therefore, without additional interpretation it is challenging to benchmark F>50 against the <6 mg/kg guideline.

Overall, Golder reports:

> *Total Hg concentrations measured in hair of the 293 participants from communities of interest ranged from less than laboratory detection limits (<0.004 mg/kg) to approximately 4 mg/kg. The concentrations of total Hg in hair from all participants were below the selected threshold of 10 mg/kg, which is the basis of Health Canada's TDI for total Hg that is protective of sensitive life stages.*

The summary statistics of THg in hair results were provided in the report (Table 5). Golder reported that all levels were below their selected guideline. However, the maximum concentration for F>20 was reported as 4.12 mg/kg, which could be greater than the Health Canada guideline of <2 mg/kg for females of childbearing age.

Table 5. Summary statistics of THg in hair for all study participants (Golder, 2015).

Table 5: Summary Statistics of Total Mercury Concentrations in Hair for All Study Participants

Community	Summary Statistics of Total Mercury Concentrations in Hair (mg/kg)					
	Arithmetic Mean	Geometric Mean	Median	Standard Deviation	Minimum	Maximum
All Participants (n=293)	0.3117	0.0931	0.089	0.5993	0.004	4.34
Females						
1-4 years (n=7)	0.0673	0.0484	0.0743	0.0495	0.012	0.134
5-11 years (n=27)	0.0506	0.0274	0.0274	0.0698	0.0061	0.288
12-19 years (n=24)	0.0536	0.0251	0.0195	0.0686	0.004	0.257
20+ years (n=139)	0.2802	0.1155	0.106	0.4767	0.0041	4.12
Males						
1-4 years (n=6)	0.0674	0.0391	0.04715	0.0638	0.0098	0.146
5-11 years (n=11)	0.0374	0.0226	0.017	0.0477	0.0095	0.158
12-19 years (n=14)	0.0763	0.0409	0.0695	0.0729	0.0041	0.244
20+ years (n=65)	0.7288	0.2781	0.329	0.9346	0.008	4.34

However, the Dillon (2016) baseline human health risk assessment prepared for Nalcor also used the same Health Canada guidelines as recommended by OEHM. They state:

> *There was one apparent exception (bolded in Table 7; value of 4.12 mg/kg ww for a female adult); however, closer examination of the data revealed that this exceedance was for a single female individual >50 years of age. Thus, the most applicable hair guidance value for this individual is 5 mg/kg ww, rather than 2 mg/kg ww. As such, there were no exceedances of HBP participant hair THg concentrations over the applicable "no action" Health Canada hair guidance values for THg in any of the LCHGP study area communities.*

Therefore, all Golder study participants had THg levels that were below the Health Canada guidelines that are protective of the most sensitive age groups, including the fetus.

The Golder report also presents a box and whisker plot that illustrates the THg concentrations in hair of all participants by community (Figure 1). OEHM has added the red lines to the figure that indicate the Health Canada guideline. However, the figure does not separate males and females and so the red lines need to be interpreted with caution.

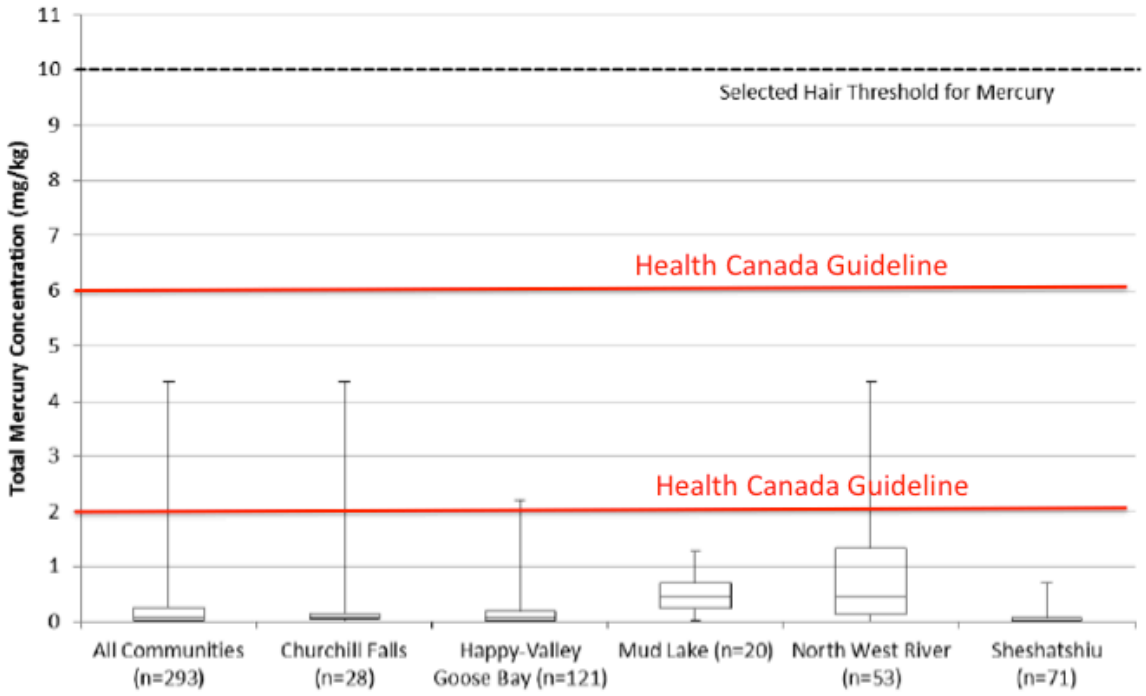


Figure 67: Box and whisker plot illustrating distribution of total mercury concentrations for all communities combined (n=293) and for each community. Lower and upper whiskers illustrate minimum and maximum, respectively, lower and upper limits of box illustrate first quartile (i.e., 25th percentile) and third quartile (i.e., 75th percentile), respectively, and middle line in box represents median (i.e., 50th percentile). The selected hair threshold for mercury is 10 mg/kg.

Figure 1. Golder box and whisker plot of THg in Hair results by community.

The Dillon (2016) report re-examined and presented the THg in hair by community. As can be seen in Table 6 all values are less than the applicable Health Canada guideline, including consideration of the female that was >50 years in age.

Perhaps of greatest interest in this dataset is that not only are individuals below the Health Canada guidelines, in most cases they are over an order of magnitude below the guideline. This suggests that

there is a considerable buffer between current MeHg in consumption of country food and store bought food and protective guideline values. However, there are a few exceptions where the maximum concentration of THg in an individual F>20 and M>20 are approaching the guidelines.

Table 6. Summary statistics of THg in hair by community (Dillon, 2016)

TABLE 7: SUMMARY OF HAIR THg DATA FROM THE BASELINE HBP AND COMPARISON TO HEALTH CANADA HAIR GUIDANCE VALUES FOR THg

Community	N	Arithmetic Mean; mg/kg ww	Geometric Mean; mg/kg ww	Median; mg/kg ww	Maximum; mg/kg ww	Applicable Health Canada Hair Guidance Level Associated with No Recommended Medical Follow-up; mg/kg ww
Churchill Falls						
F Toddler	1	0.0743	0.0743	0.0743	0.0743	<2
F Child	2	0.0511	0.0510	0.0511	0.0518	<2
F Teen	1	0.0087	0.0087	0.0087	0.0087	<2
F Adult	9	0.1137	0.0753	0.0966	0.278	<2
M Toddler	0	0.0000	0.0000	0.0000	0.0000	<2
M Child	2	0.0839	0.0393	0.0839	0.158	<2
M Teen	6	0.0974	0.0518	0.0823	0.244	<2
M Adult	7	0.7632	0.2192	0.1330	4.34	<5
Happy Valley-Goose Bay						
F Toddler	1	0.0172	0.0172	0.0172	0.0172	<2
F Child	8	0.0306	0.0225	0.0192	0.0859	<2
F Teen	16	0.0512	0.0218	0.0195	0.257	<2
F Adult	63	0.2118	0.1124	0.1150	1.55	<2
M Toddler	4	0.0625	0.0367	0.0472	0.146	<2
M Child	4	0.0248	0.0242	0.0260	0.03	<2
M Teen	3	0.0885	0.0864	0.0826	0.115	<2
M Adult	22	0.5406	0.2076	0.2350	2.2	<5
Mud Lake						
F Toddler	1	0.1340	0.1340	0.1340	0.134	<2
F Child	1	0.2880	0.2880	0.2880	0.288	<2
F Teen	0	0.0000	0.0000	0.0000	0.0000	<2
F Adult	12	0.5086	0.3664	0.4975	1.03	<2
M Toddler	1	0.1400	0.1400	0.1400	0.14	<2
M Child	0	0.0000	0.0000	0.0000	0.0000	<2
M Teen	0	0.0000	0.0000	0.0000	0.0000	<2
M Adult	5	0.6420	0.5718	0.4620	1.27	<5
North West River						
F Toddler	1	0.1240	0.1240	0.1240	0.124	<2
F Child	4	0.1015	0.0685	0.0557	0.267	<2
F Teen	4	0.1057	0.0997	0.1105	0.146	<2
F Adult	22	0.7242	0.3724	0.4600	4.12	<2
M Toddler	0	0.0000	0.0000	0.0000	0.0000	<2
M Child	1	0.0140	0.0140	0.0140	0.014	<2
M Teen	1	0.1680	0.1680	0.1680	0.168	<2
M Adult	20	1.3095	0.9366	1.3300	4.34	<5
Sheshatshiu						
F Toddler	3	0.0406	0.0308	0.0310	0.0788	<2
F Child	12	0.0271	0.0171	0.0106	0.0733	<2
F Teen	3	0.0122	0.0121	0.0111	0.0148	<2
F Adult	33	0.0772	0.0412	0.0440	0.705	<2
M Toddler	1	0.0140	0.0140	0.0140	0.0140	<2
M Child	4	0.0327	0.0180	0.0106	0.1000	<2
M Teen	4	0.0126	0.0115	0.0140	0.0170	<2
M Adult	11	0.0668	0.0460	0.0500	0.2440	<5

Golder also analyzed a subset of individual hair samples using only the 3 cm closest to the scalp. Golder (2015) provides the following in Section 7.4.2:

> *Out of the 293 samples, 19 samples with the highest reported total Hg concentrations were re-analyzed using the three centimetres (3 cm) closest to the scalp.*

The average (arithmetic mean) concentrations of total Hg in the 3-cm length hair samples for all 19 participants (1.6529 mg/kg) were compared to the average concentrations in the full length hair samples from the same individuals (i.e., 2.0732 mg/kg). The results of a t-test using a 5% level of significance are shown in Table F-7 of Appendix F. There was no significant difference in the means of the two groups, indicating that exposures are similar for both the previous three months of exposure (represented by the 3-cm hair length) and the months represented by the full hair lengths.

OEHM notes that Golder text appears to incorrectly refer to Table F-7, as the results of the t-test are in Table F-5. Given that the p value (0.120) > 0.05 there was no significant difference between THg in either hair length. Therefore, the THg concentrations reported using total hair length are representative of both longer term and three-month exposure.

5.1.7 Conclusions and Reporting

The report provided only factual conclusions and made no recommendations with respect to consumption of country foods.

5.2 Calder et al. 2016

Calder et al. (2016) undertook the second human biomonitoring program for the Muskrat Falls Project. It was funded by the Nunatsiavut Government (NG), and supported by funding from the US National Science Foundation, the Canadian Northern Contaminants Program (NCP), ArcticNet Inc., and Tides Canada Oak Marine Fund Program. Colloquially it has become known as the 'Harvard' work as several researchers involved in the investigation are from Harvard University or the NG work. For the purposes of this report it will be referred to as the Calder work.

The study included a dietary survey and two rounds of human biomonitoring for THg in hair from Inuit residents of Happy Valley-Goose Bay, North West River and Rigolet. However, the main focus of the paper was a prospective risk assessment of the potential increase in MeHg in Inuit diets from the flooding of the Muskrat Falls reservoir.

5.2.1 Ethics Approval

The study team submitted their research protocols, consent procedures and the survey instrument for review and approval by the Nunatsiavut Government Research Advisory Committee, the Newfoundland and Labrador Health Research Ethics Authority and the Harvard Office of Human Research. OEHM finds that the appropriate consultations and ethics approval were sought and obtained prior to start of work.

5.2.2 Recruitment and Representative Sampling

Although not explicitly stated, it is believed that the Calder study attempted to recruit as many participants as possible from the three NG communities. Recruitment was initiated using NG membership rolls that are limited to persons with demonstrated Inuit identity/ancestry.

The final Food Frequency Questionnaire (FFQ) included participation of 1145 unique individuals and captured 38% of the Inuit individuals from the three communities. This is a very high response rate for such and undertaking and OEHM believes that it provides sound dietary consumption data for these

communities. OEHM notes that the majority of the questionnaires were completed in the Fall survey (Table 7).

Of the 1154 participants in the FFQ, 571 unique individuals provided 656 hair samples across the two sampling periods for the biomonitoring program. This was reported to capture 19% of the total Inuit population in the three communities. The highest participation rate was for Rigolet (40%), which have also been reported as the highest consumers of country foods. No explanation was provided in the Calder et al. (2016) paper as to why hair samples were not collected from all individuals who participated in the FFQ survey. The highest number of hair samples was collected during the Fall event (Table 8).

Table 7. Food frequency questionnaire (FFQ) data collected in the Calder study (Calder, 2016).

Table S9. Food frequency questionnaire (FFQ) data collected from Inuit individuals from the communities downstream from the Muskrat Falls reservoir in March/April (winter), June/July (spring/summer) and September/October (fall) 2014. Dietary survey data collection overlapped with hair sampling (Table S8) in the spring and fall.

Demographic Group	Winter (*n*)	Spring/ Summer (*n*)	Fall (*n*)	Total (*n*)	Unique Individuals (Percent Inuit Population[a])
All individuals	231	294	1054[b]	1579[b]	1145[b]
Non-Inuit household[c] members	34	49	167	250	188
Inuit individuals	197	245	882	1324	952 (38%)
Communities					
Happy Valley-Goose Bay[d]	170	217	667	1054	745 (31%)
North West River	30	34	158	222	167 (43%)
Rigolet	31	43	229	303	233 (87%)
Demographic Group[e]					
Women of childbearing age (16-49)	59	77	278	414	306
Children ≤12 years	55	59	166	280	179
Women of childbearing age (16-49 & children ≤ 12 in Rigolet	15	19	100	134	101
All male >12 years	74	108	387	569	406
All female > 49 years[f]	28	37	191	256	200

[a] Data from some individuals are for multiple survey periods. Total Inuit population is based on the 2011 Census and National Household Survey (65, 66).
[b] Total includes three individuals who did not report Inuit status.
[c] Non-Inuit individuals who share a household with a registered Inuit beneficiary identified by the Nunatsiavut Government were included in the survey.
[d] Includes the nearby community of Mud Lake (*n*=22).
[e] Combined data for all three communities.
[f] As defined by the U.S. National Health and Nutrition Examination Survey (67).

OEHM believes the recruitment of 571 individuals, representing 19% of the Inuit population, provides adequate sample size and statistic power to ensure that the results can be used to make general conclusions for the community as a whole.

Table 8. Hair mercury sample recruitment from Inuit communities (Calder, 2016).

Table S8. Hair mercury sampling from Inuit individuals in the communities downstream of the Muskrat Falls reservoir in June/July (spring/summer) and September/October (fall) 2014.

Demographic Group	Spring/ Summer (*n*)	Fall (*n*)	Total (*n*)	Unique Individuals (Percent Inuit Population[a])
All individuals	157	499[b]	656[b]	571[b]
Non-Inuit household members[c]	21	84	105	94
Inuit individuals	136	412	548	474 (19%)
Communities				
Happy Valley–Goose Bay[d]	96	265	361	325 (13%)
North West River	37	133	170	139 (37%)
Rigolet	24	101	125	107 (40%)
Demographic Group[e]				
Women of childbearing age (16-49)[f]	52	149	201	173
Children ≤ 12 years	15	29	44	40
Women of childbearing age (16-49 & children ≤ 12 in Rigolet	12	36	48	39
All male >12 years	56	174	230	200
All female >49 years	27	140	167	147

[a] Hair was collected for some individuals during both sampling periods. Total Inuit population is based on the 2011 Census and National Household Survey (65, 66).
[b] Including three individuals who did not report Inuit status
[c] Hair samples were collected from non-Inuit individuals if they shared a residence with registered Inuit beneficiary identified by the Nunatsiavut Government.
[d] Includes the nearby community of Mud Lake (*n*=22).
[e] Combined data for all three communities.
[f] As defined by the U.S. National Health and Nutrition Examination Survey (67).

5.2.3 Dietary Survey (Food Frequency Questionnaire (FFQ)) Methodology

The FFQ was designed as an overlapping 24-h, 1-month and 3-month recall period. It was collected in March/April 2014 and then again in September/October 2014. This means that dietary information was available for December-April and for June-October. OEHM does not believe that the gap of a couple of months in FFQ recall would significantly impact the results.

Focus group sessions were held with the NG Community Research Advisory Committees to ensure "*comprehensiveness of country foods listed, local names and preparation methods*". The FFQ were administered with in-person interviews and the use of visual aids for identification of meal sizes and species.

Unique to the Calder work was analysis of baseline MeHg concentrations in locally harvested foods from the Lake Melville region with assistance from a community-led harvesting program. Concentrations of MeHg in these species are reported in a series of tables contained in the Supplementary Information (SI) that accompanies the paper.

It is also not entirely clear whether the FFQ also included dietary consumption rates of store-bought seafood or other species. In addition, the Calder work does not provide any specific details on consumption patterns or rates of consumption in either the article or the SI. This is not a criticism of the study, rather it is understood that this could not have been possible within the confines of the journal article. However, if the NG and Calder would be willing to share the consumption pattern data it could be of benefit to the IEAC in the future. In the event that NG elects not to do so, OEHM recommends that NG have a comprehensive database of the FFQ that can be drawn upon in future years. It would also be advantageous to ensure that the database for the harvested and analyzed foods for MeHg is either available to the IEAC or properly stored by the NG.

5.2.4 Hair Sampling and Analytical Methodology

Hair sampling and analytical protocols were reported in Calder (2016):

> *"Hair samples were used as biomarkers of MeHg exposure for individuals in three Inuit communities (Happy Valley−Goose Bay, North West River, and Rigolet) downstream from the Muskrat Falls development area (SI Figure S2). Samples were obtained from the occipital region of the scalp with the assistance of 26 Inuit research assistants. Participants were recruited by the Nunatsiavut Government using membership rolls, which is limited to persons with demonstrated Inuit identity/ancestry. Samples were collected in both the June/July 2014 and September/October 2014 to account for any seasonal variability in MeHg intake and ensure overlap with the peak harvest season for seals in the spring. 656 hair samples were analyzed across these two periods, representing 571 unique Inuit individuals and 19% of the total Inuit population in the region (SI Table S8).*
>
> *Total Hg was analyzed in the two centimeter proximal end of hair using thermal decomposition, amalgamation, and atomic absorption spectrophotometry (EPA method 7473) with a Nippon MA-3000 or Milestone DMA-80 at Harvard University. Most of the Hg in hair is present as MeHg (>90%) and potential demethylation in the hair follicle means that total Hg is the best indicator of internal MeHg exposure.[38] At least one method blank and one certified hair reference materials (GBW-07601 and ERM-DB001) were tested every 10 samples and all recoveries were within certified ranges. Precision, calculated by replicate analysis of the duplicate hair samples (RSD) was better than 8.6%."*

Standard analytical protocols and methods were used in analysis of THg in hair and good precision of replicates was achieved. Therefore, OEHM places a high degree of confidence in the analytical results.

5.2.5 Results of the Food Frequency Survey (Dietary Survey)

The results of consumption patterns or frequency of country food consumed were not reported in Calder. It is surmised that this is likely the result of the restriction of pages limits for scientific manuscripts. However, Figure 4 of the Calder paper does include a list of species that comprise the top 20 MeHg exposures for community members. Further details of food frequency, meal size and consumption patterns for these top 20 contributing species would be beneficial.

The SI does include a series of data tables for MeHg in various caught country food species (Table 9). Such information is valuable to understand the relative concentrations of MeHg in foodstuffs being consumed by the local Inuit populations. It can be useful to further evaluate the results of the human biomonitoring hair program.

Table 9. Example of MeHg concentration data in country foods (Calder, 2016).

Table S6a. MeHg concentrations in aquatic species harvested from the Lake Melville region. Fish and bird concentrations are for fillets/muscle unless noted.

Species	MeHg ($\mu g\ g^{-1}$) Mean ± SD	*n*	Data Source
Seal (*Phoca hispida*)			
<1 year (80%) [a]			
Muscle	0.11 ± 0.09	34	This study
Liver	0.13 ± 0.16	50	This study
Kidney	0.24 ± 0.12	14	This study[b]
Seal 1-4 years (10%) [a]			
Muscle	0.21 ± 0.17	18	This study, Brown et al. (27)
Liver	0.28 ± 0.29	n/a	Mean of age classes < 1 year
Kidney	0.31 ± 0.15	n/a	and > 4 years.
Seal > *4 years (10%)* [a]			
Muscle	0.39 ± 0.51	68	This study, Brown et al. (27)
Liver	0.43 ± 0.37	3	This study
Kidney	0.38 ± 0.17	3	This study[b]
Atlantic Salmon (*Salmo salar*)			
Fillet	0.07 ± 0.02	12	Li et al. (26)
Roe	0.01 ± 0.004	n/a	This study[c]
Liver	0.09 ± 0.02	n/a	This study[d]
Atlantic cod (*Gadus morhua*)	0.19 ± 0.06	5	Li et al. (26)
Arctic char (*Salvelinus alpinus*)			
Fillet	0.06 ± 0.04	4	Li et al. (26)
Roe	0.01	n/a	This study[c]
Liver	0.08	n/a	This study[d]
Sculpin (*Myoxocephalus scorpius*)			
Fillet	0.23 ± 0.09	10	Li et al. (26)
Liver	0.11 ± 0.11	10	This study[e]
Brook trout (*Salvelinus fontinalis*)			
Fillet	0.10 ± 0.03	48	Li et al. (26)
Liver	0.10 ± 0.03	18	This study[f]
Roe	0.05 ± 0.02	17	This study
Ouananiche (*Salmo salar m. sebago*)	0.15 ± 0.11	18	Jacques Whitford Environment Ltd (28)
Lake trout (*Salvelinus namaycush*)	0.99 ± 0.46	28	Jacques Whitford Environment Ltd (28)

[a] Fraction of total seal harvest in each age class estimated by Inuit seal hunters in 2015.
[b] Fraction of total Hg as methylmercury in kidney estimated as 26% from Northern Quebec ringed seals; moisture content estimated as 29% (29).
[c] Estimated from salmon fillet:roe ratio (30).
[d] Estimated from salmon fillet:liver ratio (30).
[e] Estimated as 50% MeHg as a fraction of total Hg from literature values (31).
[f] Estimated 62% MeHg as a fraction of total Hg based on salmon liver (30).
[d] Estimated from salmon fillet:liver ratio (30).
[e] Based on 44% MeHg as a fraction of total Hg as for molluscs (32).
[f] Converted from dry weight using moisture content from gull samples.

Such information could also be valuable to use as baseline in the EEM program. The results of this FFQ should also help guide which species should be targeted in the EEM program.

5.2.6 Results of Hair Biomonitoring

Only limited information on the human biomonitoring of THg in hair in the Inuit communities was provided in Calder. The following is reported in the results section of Calder:

> *"Measured hair Hg concentrations in 474 individuals from the three Inuit communities downstream of Muskrat Falls show over 90% of baseline (ca. 2014) MeHg exposures are below regulatory guidelines for MeHg in the U.S. and Canada (Figure S4). Highest exposures are found in the most northern community of Rigolet, where 24% of individuals presently exceed the U.S. Environmental Protection Agency's (U.S. EPA) Reference Dose for MeHg (RfD, 0.1 µg kg^{-1} body weight day^{-1}), and 3% are above Health Canada's (HC) provisional tolerable daily intake (pTDI, 0.20−0.47 µg kg^{-1} body weight day^{-1}). Mean exposure levels in Rigolet in 2014 were similar to those reported in the 2007−2008 Inuit Health Survey for other communities along the Labrador coastline.[53] All three Inuit communities downstream of Muskrat Falls have higher MeHg exposure levels than the general Canadian population due to greater consumption of aquatic foods.[54]*

Unfortunately the Calder (2016) paper does not provide a table of summary statistics, similar to the Golder work, for evaluation. This makes refined data interpretation somewhat more challenging. However, in the SI Calder did provide Figure S4 (Figure 2). This allows for some additional interpretation of the data. The original figure was reproduced as Figure 2, with OEHM adding the Health Canada Guidelines (in red) onto the figure for refined interpretation and comparison.

The comparison line for the Canadian median (from the Canadian Health Measures Survey (CHMS) 2007-2009) provided by Calder can be compared to the line contained within the box plots, which is also a median value (or 50th percentile) of the data. Further examination of the plots reveals that median for all M/F <12 years old was less than the Canadian median. Also the median values for F16-49 years old (women of childbearing age) appear to be similar to the Canadian median. However, the median THg in hair for Rigolet (F16-49 and M/F<12) and all F>49 and M>12 were greater than that of the Canadian median. What this suggests is that overall values of THg in hair are similar to the Canadian median for the sensitive groups when the data is taken as a whole. However, Rigolet community member data should be examined more closely. These higher levels in F>49 and M>12 likely represent the older population that has, and continues to, consumption higher levels of country foods than typical Canadian.

The box plot provides individual THg levels for the individual highest results for each demographic breakdown. It can be seen that comparison of these results to the Health Canada benchmarks indicates that there was only one F16-49 years old from Rigolet (<0.5% of samples) that was slightly above the 2 mg/kg (or ug/g) guideline and only one M>12 years was above the 6 mg/kg benchmark (<0.3% of samples). As discussed further in Section 6.3 these rates of exceedances of the guidelines are lower than the general Canadian population and much lower than have been reported for other northern indigenous populations.

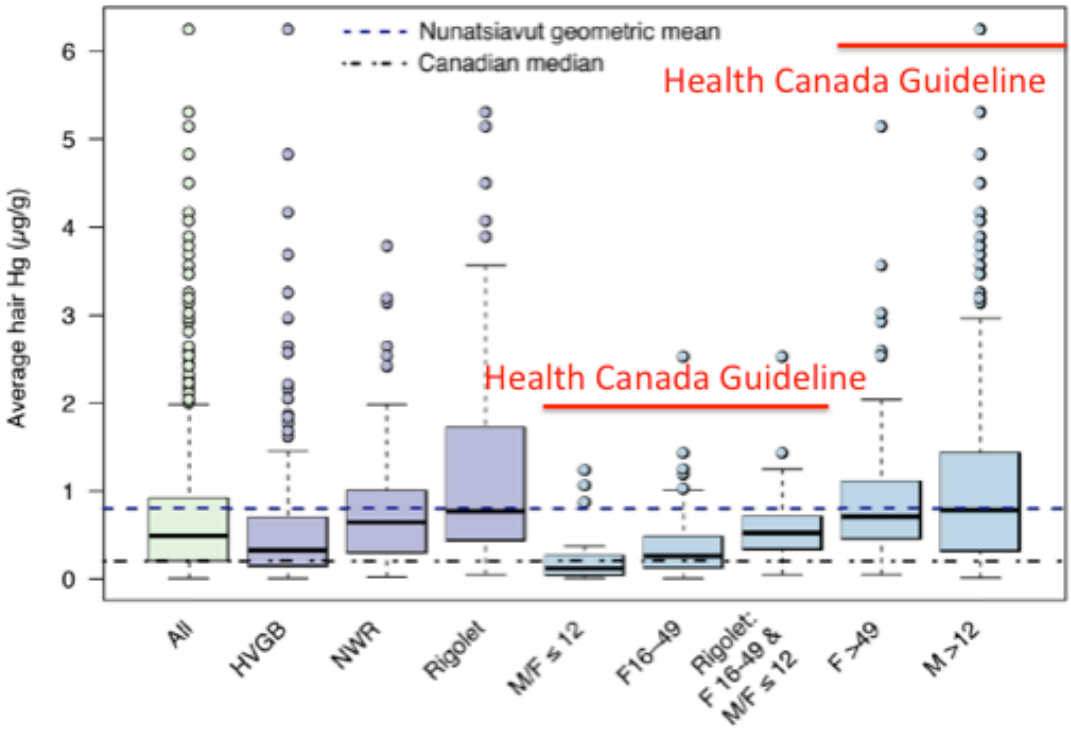


Figure S4. Measured concentrations of total Hg in hair samples from individuals in three Inuit communities downstream from the Muskrat Falls hydroelectric facility (HVGB = Happy Valley – Goose Bay; NWR = North West River) and among demographic groups (all communities together). Canadian median (6–79 years old) (72) and Nunatsiavut mean (73) are estimated using a mean blood-to-hair partition coefficient of 250 L g^{-1} (74). Most of the Hg in hair is present as MeHg (>90%) and potential demethylation in the hair follicle means that total Hg is the best indicator of internal MeHg exposure (75). At least one method blank and one certified hair reference materials (GBW-07601 and ERM-DB001) were tested every 10 samples and all recoveries were within certified ranges. Precision, calculated by replicate analysis of the duplicate hair samples (RSD) was better than 8.6%.

Figure 2. Measured concentrations of THg in hair (Calder, 2016).

5.2.7 Conclusions and Reporting

The Calder study provides only limited comment in the paper on the results of the dietary survey or the hair biomonitoring program. This is likely due to the fact that the focus on the paper was on the prospective risk assessment.

6 OEHM Conclusions of Biomonitoring Surveys

OEHM offers the following conclusions after review of the Golder and Calder studies and their data:

- The studies conducted appropriate regulatory consultation and received appropriate ethics approvals.
- Golder dietary survey was conducted using standard approaches and methods for a seasonal one year recall survey. This has some limitations when asking individuals to recall their consumption rates over a year. The Calder FFQ was conducted as a 24-hr, 1-month and 3-month recall period over two events in spring and fall. This may allow for increased recall ability for individuals surveyed.
- The human biomonitoring study of THg and MeHg in hair sampling was done in both studies using internationally recognized protocols and analytical methods.
- The dietary surveys provide meaningful results for the communities' consumption patterns and can be used in the future.
- The results of the THg hair biomonitoring study results indicate that existing consumption patterns of country and store-bought foods have resulted in MeHg exposures typically below the Health Canada guidelines.

They are complementary datasets, with Calder focused on the Inuit communities and Golder on the remaining communities (including some Inuit participation).

6.1 Feasibility of combining/consolidating the results of the two programs into one dataset for analysis (assuming that an agreement could be reached by the parties involved to share data). Would there be any added value in doing this?

They are complementary datasets, with Calder focused on the Inuit communities and Golder on the remaining communities (including some Inuit participation). OEHM believes taken as a whole the datasets can be used to make meaningful assessment for all communities in the area harvesting country food.

Collectively they provide excellent insight into the level of MeHg exposure for all communities with the Muskrat Falls Project area. The results of each program have been reviewed within this document, but OEHM does not believe that at this point there would be further benefit of combining the datasets for reanalysis. Such and undertaking would provide no greater understanding of the safety of eating country and store-bought foods in the area.

It would be ideal if both parties could provide their raw data (under the constraints of their ethics approvals) to the IEAC, such that the datasets can be preserved and combined for future use.

6.2 Is the existing data sufficient to form a reliable baseline? Are the data sufficient to draw conclusions about all population groups in the Lake Melville area?

The combined results of the two biomonitoring programs provide more than enough statistical power to form an excellent baseline of MeHg exposure in the communities surrounding the Muskrat Falls Project, including for those consuming country foods from Lake Melville. The Golder study achieved adequate recruitment for those community's studies. The Calder study had very high participation rates and also

reportedly captured individuals with the highest country food consumption in the area (Rigolet). Therefore, combined these studies form an excellent baseline for community MeHg exposure.

6.3 How do the biomonitoring results from the study area compare to the general Canadian population, more highly exposed populations and other susceptible subgroups?

The results of the biomonitoring programs indicate that overall the level of MeHg exposure in the Muskrat Falls Project study area are mostly below the Health Canada guidelines. The question then becomes "*what is the relative exposure of the study area participants to other Canadian populations?*".

The Canadian Mercury Science Assessment Report (Environment Canada, 2016) provides a good overview of Canadian Hg biomonitoring studies that have been completed. Typically they report the results as MeHg concentrations in blood, which can be divided by a factor of 4 to provide hair equivalent concentrations. They state:

> *"From these data, it is estimated that only 1.61% of Canadian pregnant women, women of childbearing age, and children, combined, exceed the proposed blood Hg concentration guidance value of 8 µg L^{-1} (Table 14.5), while 2.22% of pregnant women and women of childbearing age, combined, exceed this value (Health Canada, 2011, special analysis). These data suggest that only a very small percentage of women of childbearing age and children in Canada have blood Hg concentrations that may require followup testing, dietary advice, or other further action.*

In the Calder study, 0.5% (1 individual) of the pregnant women, women of childbearing age, and children, combined, exceeded the guidance value of 2 mg/kg THg in hair, while 0.6% of pregnant women and women of childbearing age exceed this value. None of these groups exceeded the guideline in the Golder study. In addition, the median concentration of MeHg in hair from the Calder study (Figure 2) for the pregnant women, women of childbearing age, and children was similar to that of the Canadian population. Overall the exposure of the sensitive subgroups to MeHg in the Muskrat Falls Project area is similar than that of the Canadian population.

Additional comparison to biomonitoring studies in other northern indigenous populations is also warranted. The EC (2016) reports:

> *In 1997, 53.3% of Inuit mothers exceeded this guidance value; in 2005–2007, this decreased to 20%. A decrease was also observed in Inuit mothers from Inuvik. In 1998 and 1999, the proportion of these women with Hg concentrations exceeding the guidance value was 10%, which decreased to 1.9% in 2005 and 2006.*

It is acknowledged that these studies are typically a decade old. However, they do provide perspective that indicates that current exposure in the study area is lower than typically reported values for northern, high consumers of country food (Table 10). In addition, none of the Muskrat Falls Project study participants was above the 20 ug/L^{-1} blood equivalent action level.

Table 10. Material Guidance Value exceedances for blood concentrations (EC, 2016)

TABLE 14.6 Maternal guidance value exceedances for blood concentrations of total mercury

Region/ethnicity	Sample size	Year	Mercury (total)	
			% of samples exceeding 8 µg L^{-1} [a]	% of samples exceeding 20 µg L^{-1} [b]
Baffin region of Nunavut/Inuit	30	1997	53.3	10.0
	100	2005–2007	20.0	2.0
Inuvik/Inuit	30	1998–1999	10.0	3.3
	54	2005–2006	1.9	0.0
Inuvik/Dene/Métis	42	1998–1999	0.0	0.0
	19	2005–2006	0.0	0.0
Inuvik/Non-Aboriginal	22	1998–1999	0.0	0.0
	6	2005–2006	0.0	0.0
Nunavik/Inuit	11	1992	NA	36
	25	1996	NA	20
	53	1997	NA	19
	27	1998	NA	3.7
	16	1999	NA	13
	29	2000	NA	17
	19	2001	NA	26
	31	2004	NA	6.5
	42	2007	NA	2.1

[a] Data source: Northern Contaminants Program, Health Canada, special analysis, 2011 (unpublished)

[b] Data source: Northern Contaminants Program, Donaldson *et al.* 2010

NA = Not available

Lemire et al. (2015) published a more recent study of MeHg levels in women of childbearing age from the Nunavik Innuit Health Survey in 2004. The study involved the 14 communities of Nunavik along eastern coast of Hudson Bay, the coast of the Hudson Straight and Ungava Bay in Quebec Canada. As can be seen in Table 11, the geometric mean concentration of THg in blood was 10.7 ug/L, which is greater than the Health Canada benchmark. More notably between 43.4 to 78.4% of women of childbearing age had blood levels greater than the guidelines. The maximum level was 129.4 ug/L or the hair equivalent to 32 mg/kg in hair, whereas the highest concentration of THg in hair in the Muskrat Falls Project study area was ~2.5 mg/kg in a female of childbearing age. In addition, approximately 50% of all Nunavik men had THg concentrations greater than the guideline of 20 ug/L, whereas only one man in the Muskrat Falls Project study area was above this level.

Overall, the concentrations of THg in the Muskrat Falls Project area participants appear to be generally similar levels to those of the general Canadian population and far less than some other northern Inuit populations.

Given the relatively high consumption rate of country food in the Muskrat Falls Project area this may seem surprising to some. However, a very high level review of the concentrations of MeHg reported in country foods from Calder (Table S6a) indicates that baseline levels of MeHg local foods are similar to, or less than, those reported in store-bought fish (Table S10).

Table 11. MeHg Blood results for Nunavik Inuit (Lemire, 2015).

Table 1
Study population characteristics and blood biomarkers concentrations, by region of residence.

	All regions (n = 702)	Eastern Hudson Bay (n = 261)	Hudson Strait (n = 181)	Ungava Bay (n = 260)
Women (n, weighted %)	387 (48.2)	153 (49.1)	95 (46.9)	139 (48.1)
Age (years)				
GM	34	34	34	34
(range)	(18–74)	(18–72)	(18–73)	(18–74)
Weight (kg)				
GM[1]	68.4	65.2[b]	71.0[a]	70.5[a]
(range)	(38.2–129.4)	(38.2–122.0)	(42.5–119.8)	(43.1–129.4)
Whole blood Hg (μg/L)				
GM [1]	10.7	10.1[b]	18.4[a]	7.7[c]
(range)	(0.2–240.7)	(0.4–96.3)	(0.6–240.7)	(0.2–70.2)
Whole blood Hg concentrations above guidance values (weighted %)[2]				
Women 18–39 years old	53.3	47.7[b]	78.4[a]	43.4[b]
Men 18–39 years old	15.6	10.1[b]	37.5[a]	5.9[c]
Women ≥ 40 years old	52.3	53.2[b]	73.1[a]	34.0[c]
Men ≥ 40 years old	52.3	53.9[b]	72.8[a]	31.9[c]
Whole blood Se (μg/L)				
GM [1]	271	235[c]	396[a]	260[b]
(range)	(126–3571)	(126–1111)	(166–3571)	(150–1111)
Red blood cells long-chain n−3 PUFA (as % of total fatty acids)[3]				
GM [1]	8.5	7.9[b]	8.8[a]	8.9[a]
(range)	(1.7–20.2)	(1.6–18.2)	(2.7–20.2)	(2.1–18.3)

Different letters represent statistically significant differences between regions.
[1] GM by region are adjusted for age and gender.
[2] Canadian blood guidance values: ≥8 μg/L for childbearing age women (<40 years old) and ≥20 μg/L for other adults.
[3] Sum of eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA) and docosahexaenoic acid (DHA) fatty acids.

In addition, it is understood that Rigolet members primarily consume yearling seals that had an average of 0.11 mg/kg MeHg in muscle. The level of MeHg in tissue, liver and kidneys of most country foods in the Muskrat Falls Project area are relatively low compared to other Inuit or indigenous populations. For example, Lemire et al. (2015) report that greater than 66% of the MeHg exposure for Nunavik Inuit is from Beluga muscle and liver with MeHg concentrations >1 mg/kg, or 10 times that of seal in the Muskrat Falls Project study area. In addition, seal liver in Nunavik contained >1 mg/kg MeHg and muscle levels were also greater than those in Muskrat Falls Project area.

This may serve to explain why the communities around the Muskrat Falls Project area have comparatively low MeHg concentrations in hair to other indigenous northern populations.

6.4 Do the results permit reliable comments on the 'safety' of the country foods that are being consumed? Can individuals find themselves within this data given their own dietary habits?

Based on the study results, OEHM believes strongly that current practices of country food consumption in the communities surrounding the Muskrat Falls Project are safe and not leading to undue exposure to MeHg. This includes the most susceptible populations, young children and, most importantly, pregnant mothers.

The combination of the Golder and the Calder datasets provide a high level of confidence that the exposure to MeHg for all community members within the Muskrat Falls Project area have been captured. This is largely due to the fact that the Calder study included the highest consumers of country food from the Rigolet community. The statistical power of the data allows the results to be extrapolated to all community members in the area.

6.5 Identify any significant data gaps and propose how additional work could fill these gaps and provide a more comprehensive understanding of exposure/health at the present time.

At this point no additional work is recommended in terms of baseline biomonitoring to determine the safety of local foodstuffs. The following recommendations could be considered for ensuring data integrity and maintenance for the future:

- In OEHM's experience datasets collected in baseline assessments can often be lost, or not readily available, in future years when they are required. It is recommended that the primary (raw) datasets of all THg biomonitoring programs from both the NG and Nalcor be requested and combined by the IEAC for future reference and use. Such an undertaking will likely require merger of Excel databases and perhaps the requirement of creating a new database. For hair biomonitoring data this should likely be a relatively simple process and not required a considerable amount of effort. In the event that a single database is not desired by the study leads, then it is suggested that IEAC confirm with both Nalcor and the NG that they have secured the raw data from the study authors for their own records.
- Both dietary survey programs appear to give significant insight into community member's harvest and seasonal consumption of country foods. Again it would be beneficial to house this data under one collective database, if the collecting parties agree. It appears from their report that Golder already compiled their results into an EXCEL database. Similar to the biomonitoring data it would be ideal if the IEAC could ensure long-term storage of this information. In addition, the Calder work contains a number of statistical summaries of concentrations of MeHg in harvested country food. It is hoped that the NG houses the raw data. It would also be ideal if this information could be shared with the IEAC for future use.
- Additional work could be undertaken with the communities to understand not only the consumption rate of specific country foods, the abundance of these species for harvest, the species of particular cultural importance and food security issues. The results of dietary surveys should also help guide which species should be targeted in the EEM program.
- It would be ideal to initiate a pre-established community-based solution/program that could then be implemented in the event that the EEM program indicates that recommendations and interventions are required to continue to promote country food benefits, while minimizing the risk of MeHg exposure to a particular species are required.

7 Overall Conclusion

Based on the study results, OEHM believes strongly that current practices of country food consumption in the communities surrounding the Muskrat Falls Project are safe and not leading to undue exposure to MeHg. This includes the most susceptible populations, young children and, most importantly, pregnant mothers.

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Appendix A

Response to IEAC Comments on Draft Report

Feb 27, 2018

Comments from IEC on the report entitled "Review of Methyl Mercury Biomonitoring Programs for the Muskrat Falls Project" by Ollson Environmental Health Management dated February 16, 2018

P. 4: It is not meant to be a review of the current state of the science of MeHg toxicity, so the qualification using the word "exhaustive "should be deleted.
Response: "exhaustive" deleted from sentence

P 9 and 20: The Golder survey likely underestimates hair MeHg due to hair sampling technique (whole hair of undetermined length).
Response: There was an oversight in the draft OEHM report. The following text will be added to the report after Table 6.

Golder also analyzed a subset of individual hair samples using only the 3 cm closest to the scalp. Golder (2015) provides the following in Section 7.4.2

> Out of the 293 samples, 19 samples with the highest reported total Hg concentrations were re-analyzed using the three centimetres (3 cm) closest to the scalp.
>
> The average (arithmetic mean) concentrations of total Hg in the 3-cm length hair samples for all 19 participants (1.6529 mg/kg) were compared to the average concentrations in the full length hair samples from the same individuals (i.e., 2.0732 mg/kg). The results of a t-test using a 5% level of significance are shown in Table F-7 of Appendix F. There was no significant difference in the means of the two groups, indicating that exposures are similar for both the previous three months of exposure (represented by the 3-cm hair length) and the months represented by the full hair lengths.

OEHM notes that Golder text appears to incorrectly refer to Table F-7, as the results of the t-test are in Table F-5. Given that the p value (0.120) > 0.05 there was no significant difference between THg in either hair length. Therefore, the THg concentrations reported using total hair length are representative of both longer term and three month exposure.

P. 11: "Perhaps of greatest interest in this Golder dataset is that not only are individuals below the Health Canada guidelines, in most cases they are an order of magnitude below the guideline. " The *exception cases* according to the Table 6 refer to the most vulnerable subgroups – worth highlighting.
Response: Table 6 indicates that all children are an order of magnitude less than guidelines. However, the maximum THg concentrations in hair of a few individuals (F>20) and M (>20) are approaching the guideline.

The following sentence to be added to the report.
However, there are a few exceptions where the maximum concentration of THg in an individual F>20 and M>20 are approaching the guidelines.

6.1 They may be complementary datasets but not directly comparable. The fact that the dietary survey of Golder was carried out in the winter means that it does not represent maximum MeHg burden, in contrast to the NG study in which survey timing was designed to capture the effects of the season of greatest country food consumption.

*Response: The report is clear that they are complementary. OEHM will remove the following language from the second sentence "These datasets can be combined, and" the important takeaway message is "*I believe taken as a whole, can be used to make meaningful assessment for all communities in the area harvesting country food." OEHM has been clear throughout the report about the potential limitations of both studies.

6.2 and 6.4 Reliable baseline? "High level of confidence that the exposure to MeHg for all community members within the Muskrat Falls project area have been captured" Survey numbers were designed to achieve adequate recruitment (Golder) versus sampling the number of participants required to capture the population variability (NG), which helps to identify those most at risk to health effects.

Response: OEHM does not agree with this comment. The Golder study targeted 300 people in recruitment to provide enough statistical power to capture sample population variability and to drawn meaningful conclusions across the entire population. It is acknowledged that the NG study did have a higher participation rate. It is through these complementary datasets that overall conclusions can be drawn.

Section 7: The report focuses on the safety of the country foods that are being consumed today. It is not within its mandate to comment on Prospective Risk Assessments for which access to up-to-date knowledge is incomplete. Consideration should be given to removing section 7.

Repsonse: OEHM will leave this to the discretion of the committee. OEHM was provided with the risk assessments and hence commented on in the report on that basis.