MEMO

TO: Jackie Wells
FROM: Rob Willis
DATE: November 20th, 2018
SUBJECT: Lower Churchill Hydroelectric Generation Project (LCHGP) Supplementary Human Health Risk Assessment (HHRA) Technical Memo – Overview of HHRA Program Status and Supplementary Assessment of Potential Future Human Exposures and Risks Due to Methylmercury
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Lower Churchill Hydroelectric Generation Project (LCHGP) Supplementary Human Health Risk Assessment (HHRA) Technical Memo – Overview of HHRA Program Status and Supplementary Assessment of Potential Future Human Exposures and Risks Due to Methylmercury

1.0 Introduction

Since the LCHGP was released from EA, Nalcor has engaged in ongoing efforts to refine and update predictions about the potential for methylmercury (MeHg) levels to increase in LCHGP study area aquatic biota, and the potential for increased future MeHg exposure and health risk among human consumers of locally harvested aquatic country foods. Several external experts have been retained over the past several years to assist Nalcor in conducting various studies, programs and assessments that improve and refine predictions of potential future MeHg impacts within the LCHGP study area. This work has also enabled responses to a number of outcomes and statements reported or claimed by a Harvard University-led research program conducted on behalf of the Nunatsiavut Government (NG). This research focused on potential MeHg impacts among Lake Melville Inuit communities that were attributed to the LCHGP. The main published work from this Harvard research program (i.e., Calder et al. 2016) predicted that creation of the Muskrat Falls Reservoir would considerably increase MeHg levels in fish and ringed seals of Goose Bay and Lake Melville. Calder et al. also suggested that this predicted change may be sufficient to pose human health risks to frequent consumers of fish and seals.

As is described in the following sections of this technical memo, the various studies and programs conducted by the external experts predict with reasonably high confidence that no significant future increases in MeHg levels (relative to baseline) would occur in aquatic biota downstream of the Muskrat Falls Reservoir, and consequently, no significant increase in human MeHg exposure or risk (relative to existing current baseline exposure and risk levels) would be anticipated in the future.

These studies and programs also refute or question many of the outcomes and conclusions reported in Calder et al., (2016). In general, the authors of Calder et al. appear to have greatly overestimated and exaggerated the potential for future MeHg impacts on downstream aquatic resources and communities. Unfortunately, they also appear to have failed to recognize and communicate the conservatism and high degree of uncertainty in their work. The dissemination of their findings without the context of uncertainty and conservatism has led to considerable fear and misperception of the actual risk posed by

MeHg among Lake Melville Inuit communities. Expert technical reviews and critiques of Calder et al. and other Harvard-led work are available under separate cover. Briefly, these reviews/critiques identified numerous technical flaws/issues/deficiencies or errors, many unsupported assumptions and decisions, various examples of inappropriate data use, a high degree of speculation, and a profound lack of transparency and documentation. The level of transparency to date has been inadequate to enable any independent verification or validation of the work reported in Calder et al. Work that cannot be validated cannot be considered scientifically defensible or credible, and should never be relied upon for any type of science-based or public health decision-making. However, details regarding the outcomes of expert reviews of Calder et al. are not the focus of this technical memo and are not addressed further herein.

This technical memo provides a brief status report that summarizes the major activities and studies conducted within the LCHGP HHRA program to date. This includes brief summaries of modelling efforts, field programs, EEM data evaluations, and other studies that have been conducted in 2017 and 2018 (by several independent technical experts with extensive knowledge and expertise pertaining to numerous aspects of MeHg) to refine the understanding of MeHg dynamics within the LCHGP study area, and to more accurately and robustly predict (relative to previous modelling and assessment conducted in support of the EA), the following:

- Future rates of MeHg formation within the study area;
- Future fate and transport of MeHg within the reservoir, and in the downstream Lower Churchill River system, Goose Bay and Lake Melville;
- Future **peak** (worst case) uptake rates of MeHg into study area aquatic biota (particularly species that are harvested for human consumption within the LCHGP study area);
- Potential future peak (worst case) MeHg exposures within study area communities, where residents may consume locally harvested aquatic country food items; and,
- Potential future health risks that may result from increased peak MeHg exposures within the study area communities.

Previous HHRA work conducted within the LCHGP HHRA Program (i.e., Dillon, 2016a,b) focused on the assessment and characterization of baseline MeHg exposure and risk. The prediction of potential future MeHg exposure and human health risk herein, builds upon the modelling framework developed within the comprehensive 2016 final baseline HHRA (i.e., Dillon, 2016b), and also incorporates and/or builds upon the outcomes of the various modelling studies, field programs, EEM data evaluations, and other studies that were conducted by independent technical experts throughout 2017 and 2018.

Forthcoming documentation from the LCHGP HHRA Program will develop recommendations towards refining human health-based monitoring programs for MeHg, and will also develop future risk management and/or mitigation programs and plans that would address public health concerns associated with MeHg. This is expected to include the development of a consumption advice and advisory program.

2.0 LCHGP HHRA Program Overview and Status

The LCHGP HHRA Program was initiated in 2013 and is ongoing. Creation of the HHRA program was a regulatory requirement and a condition for release of the LCHGP from the EA process.

Key HHRA program components and milestones to date are briefly summarized in the following bullets. Further details are provided within a number of HHRA program documents posted to the Muskrat Falls Generation website (i.e., https://muskratfalls.nalcorenergy.com/environment/generation/), under the "Human Health Risk Assessment Plan" header, including: the HHRA Plan, the Final Baseline HHRA report, and the Baseline Dietary Survey and Human Hair Sampling Program report. This memo does not elaborate on information that is covered in detail within these previous HHRA program documents.

- **Fall of 2013:** Development of the HHRA Plan (HHRAP) and initiation of the Baseline HHRA Program. The HHRAP was submitted to NLDEC in February of 2014. It was also submitted at that time for review and consultation with LCHGP study area aboriginal organizations and Health Canada. Comments received by Health Canada and the Aboriginal organizations on the HHRAP were reviewed and responded to, and modifications were made to the HHRAP. Such modifications were reflected in the final HHRAP version that is posted to the above noted Muskrat Falls website. The final HHRAP was approved by NLDEC on **June 14th, 2016** as per NL Reg. 18/12, subject to the following condition: "Should downstream methylmercury monitoring identify the need for consumption advisories as a result of the project, Nalcor shall consult with relevant parties representing Lake Melville resource users. Based on the location of the consumption advisories these users could include Aboriginal Governments and organizations as well as other stakeholder groups. Following consultation, Nalcor shall provide reasonable and appropriate compensation measures to address the impact of the consumption advisory."

- **Spring to Fall of 2014:** Preparation of Baseline Diet Survey (DS) and Human Biomonitoring Program (HBP) Work Plans, and associated ethics approval processes and consultation with Health Canada. Aboriginal consultations (i.e., Innu Nation; NunatuKavut Community Council Research Advisory Committee (NCC RAC); Nunatsiavut Government Research Advisory Committee (NGRAC)), and consultation with NLDEC, NLDHCS and Labrador-Grenfell Health also occurred over this period, as did the notification and planning process for the DS and HBP in LCHGP study area communities. NGRAC did not grant approval, and as a consequence, one of the study area communities of interest (i.e., Rigolet) could not be included in the Baseline HHRA program studies.

- **November 2014 to February 2015:** The Baseline DS and HBP programs were conducted in the participating LCHGP study area communities. Data compilation and reporting was conducted by Golder Associates from early to late 2015.

- **December 2015:** The Final Baseline DS and HBP Report was posted to the Muskrat Falls Generation website (i.e., Golder, 2015).

- **April 2016 to October 2016:** The Final Baseline HHRA study was conducted, building on and incorporating the outcomes of the Final Baseline DS and HBP Report.

- **March 2016 and August 2016**: Two MeHg workshops were held (St. Johns, NL and Happy Valley-Goose Bay, NL) which were attended by representatives of several provincial and federal government departments, Nalcor Energy and their independent experts, Labrador-Grenfell regional health authority, and Labrador Aboriginal organizations (Happy Valley-Goose Bay workshop only; included representatives of NG, Innu Nation and NCC, and their experts). The workshops enabled all attendees to be informed and updated on current and previous studies relevant to understanding MeHg dynamics and effects within the LCHGP study area. In March of 2016, a technical memo (Dillon, 2016a) was prepared to address specific concerns raised about the potential health risks from consuming ringed seal meat and liver.

- **October 18th, 2016:** The Final Baseline HHRA report (Dillon, 2016b) was submitted to NL DEC and NL DHCS and forwarded to Health Canada for review and comment. Submission of the baseline HHRA report to Health Canada fulfilled EA commitments made by the LCHGP and also fulfilled regulatory requirements regarding the release of the LCHGP from the EA process.

- **October 2016 to April 2017**: The Final Baseline HHRA report and its technical appendices underwent a detailed technical review by various Health Canada personnel with expertise and experience in HHRA and the human health effects of mercury (Hg) and methylmercury (MeHg) exposure. Health Canada's technical review of the baseline HHRA was coordinated by the Environmental Health Program, Regulatory Operations and Regions Branch, and included input from Health Canada personnel within this Branch, as well as input from personnel within various bureaus and divisions of the Safe Environments Directorate, and the First Nations and Inuit Health Branch.

- **April 2017**: Health Canada written comments on the baseline HHRA report were received by representatives of the LCHGP HHRA Program on April 20th, 2017. In addition, the lead HHRA Program consultant met with Health Canada representatives shortly prior to receipt of the Health Canada letter of April 20th, 2017, to informally discuss their comments, opinions, impressions and advice. This meeting and discussion (held on April 12th, 2017) resulted in agreement and consensus that Health Canada's review of the baseline HHRA documentation does not necessitate any modifications to the baseline HHRA report or its technical appendices. While Health Canada expressed some expected concerns regarding certain data gaps and uncertainties, and made some recommendations towards addressing such items, it was agreed that these concerns were best addressed in future monitoring or assessment work (where/if possible).

- **July 2017**: Formal responses to Health Canada technical comments on the baseline HHRA were prepared and submitted by the LCHGP HHRA Program. Review of the April 20th, 2017 Health Canada letter by LCHGP HHRA Program personnel confirmed that the items and issues raised within the letter necessitated no changes to the baseline HHRA report or its supporting technical appendices. Review of the Health Canada technical comments revealed that there were many areas of agreement where Health Canada reviewers concurred with the approaches, assumptions and data used to conduct the baseline HHRA. However, as is commonplace for complex and comprehensive HHRAs of this nature, there were a number of areas of uncertainty and a number of data gaps that required various assumptions to be made to address such uncertainties and data gaps. It is common and expected for there to be some differences of opinion amongst HHRA experts regarding how such gaps and uncertainties may best be addressed within the context of a HHRA, and the assumptions that may be considered appropriate. During the April 12th meeting and discussion, and as reflected in the April 20th Health Canada letter, it was clear that the majority of Health Canada technical comments comprised Health Canada suggestions or recommendations for addressing data gaps and uncertainties, and/or reflected differences of scientific opinion between Health Canada and the LCHGP HHRA experts regarding certain HHRA approaches and assumptions. The majority of responses to Health Canada comments were points of clarification and/or directing to sections and appendices of the baseline HHRA report that already adequately addressed a given comment or concern. The LCHGP HHRA program was in general agreement with most Health Canada recommendations (referred to as "proposed actions" in the April 20th, 2017 letter) that pertain to data gaps and uncertainties, and is working towards addressing/implementing such recommendations to the extent possible/practical/appropriate in future monitoring and assessment work. Health Canada consultation on various topics related to the LCHGP HHRA Program is ongoing and has occurred throughout the entirety of the HHRA Program (as summarized in the response memo and in the Dillon (2016b) baseline HHRA).

- **August 2017 to April 2018**: The Independent Expert Advisory Committee (IEAC) for the Muskrat Falls Project was formed to provide advice, guidance and recommendations related to MeHg health effects and MeHg mitigation. The IEAC mandate was to: i) use the best available scientific research and Indigenous knowledge to assess and limit methylmercury impacts; ii) to review all monitoring plans and results to inform mitigation of methylmercury impacts; and, iii) to direct research activities and recommend additional monitoring and mitigation measures, where required, for the protection of the health of Indigenous and local populations. The IEAC had the following overall objectives:

    - To review and direct scientific and Indigenous knowledge research that will help make evidence-based recommendations for the protection of health of the Indigenous and local populations who harvest and consume country foods in the Churchill River and Lake Melville.
    - To review human health monitoring plans and, if necessary, recommend additions or changes to those plans that will make them robust and integrated, and result in the protection of human health as it relates to the exposure to methylmercury.
    - To review the results of all monitoring plans, measures, and programs, and all relevant research, studies and assessments that relate to the protection of human health.
    - To make recommendations to the responsible Ministers and regulators regarding mitigation, monitoring and management measures that will protect the health of the Indigenous and local population who harvest and consume country foods in the Churchill River and Lake Melville.

    Further details of IEAC objectives, research, activities and recommendations are available at: http://ieaclabrador.ca/.

    A brief summary of IEAC activities and recommendations with respect to human health effects of MeHg is provided in **Section 5.0** of this memo. Shortly after the IEAC was formed, the LCHGP HHRA Program provided the IEAC chair a detailed summary of the Program to date, and provided copies of all relevant HHRA Program documentation. HHRA Program representatives also offered to make themselves available for any questions that may arise on the provided documentation and offered to collaborate with the IEAC in fulfilling their human health objectives and mandate.

- **Winter of 2017 to Summer of 2018 (and on-going):** The Nalcor LCHGP has engaged various consultants and technical experts to conduct independent monitoring, modelling and assessment programs and studies that have improved and continue to improve the understanding of MeHg formation, MeHg dynamics, trophic transfer of MeHg, and potential human MeHg exposures within the LCHGP study area. This has included the programs and studies listed below, as well as ongoing EEM programs. Documentation of the methods and outcomes for these programs and studies, as well as the data collected from them, are available at: https://muskratfalls.nalcorenergy.com/environment/generation/methylmercury-monitoring/.

    - Ongoing comprehensive water and sediment sampling and analytical programs at 11 locations throughout the study area. Parameters include filtered and unfiltered THg, MeHg, and various other parameters relevant to MeHg formation and transport.
    - **Harris (2018) Updated Analysis of Predicted Increases in Methylmercury Concentrations and Downstream Export from Muskrat Falls Reservoir**. This study involved the application of updated and refined field estimate-based, mechanistic, and regression modelling approaches to characterize and predict potential future increases in MeHg concentrations and mass flux in water and biota within the Muskrat Falls Reservoir, and also downstream of the reservoir in Goose Bay and Lake Melville. This work advanced previous modelling studies conducted during the EA period of the LCHGP. Various study area monitoring data collected since the EA were used to refine, update and calibrate the models and modelling approaches that were applied. The results of this work were subsequently used by Baird & Associates (i.e., Brunton, 2018) in a hydrodynamic modelling study to predict potential future increases in water MeHg concentrations within Goose Bay and Lake Melville.
    - **Brunton (2018) Technical Memorandum RE: Lake Melville Model Setup and Results**. In this study, two numerical hydrodynamic simulation models were used to predict the downstream fate of MeHg generated and exported from the Muskrat Falls Reservoir. A high-resolution 3D hydrodynamic model of Goose Bay and Lake Melville was developed and applied using the Delft3D model. This model accounts for a comprehensive set of hydrodynamic factors, including: wave action, currents, wind speed and direction, density, salinity, stratification, tides, temperature, bathymetry, river and watershed discharge volumes. Study area-specific information was used where available to develop the Delft3D Goose Bay and Lake Melville hydrodynamic model. This model was applied to examine the effects of downstream mixing and dilution of MeHg exported from the reservoir. An associated box model was also created to account for MeHg losses from the water column due to photodegradation and settling. Both models used five-year predictions of MeHg entering the lower Churchill River following reservoir filling. These predictions were based on estimates of MeHg flux (loadings) from the reservoir as predicted by Harris (2018). The models were applied to determine area-weighted changes in water MeHg concentrations over time within Goose Bay and Lake Melville.

These outcomes were subsequently used by Wood (2018) to estimate potential future increases in MeHg concentrations in resident aquatic biota within Goose Bay and Lake Melville.

- **Wood (2018) Predicted Increases in Fish Methylmercury Muscle Tissue Concentrations In Goose Bay and Lake Melville.** This report summarizes three studies/programs conducted over 2017 and 2018, which provided study area-specific information on life history, ecology, and aquatic habitat utilization for key aquatic species identified as being important in local human diets (from the diet surveys conducted within the HHRA Program) and that are commonly harvested from Goose Bay and Lake Melville. The focus of these studies was Goose Bay and Lake Melville as most of the fish and seal harvesting occurs within these water bodies. Very limited fish or seal harvesting has been reported to occur in the area of the reservoir and within the Lower Churchill River. Appended to the above noted report are the reports for two supporting studies: i) Wood. 2018b. Aquatic Species Habitat Utilization Overview: Churchill River, Goose Bay, and Lake Melville; and ii) AMEC-FW. 2018; AMEC-FW. 2018. Memo Re: Summary of Isotope and Stomach Data, Goose Bay/Lake Melville Estuary. Collectively, these three reports substantially refine and improve the understanding of aquatic habitat utilization within the LCHGP study area, as well as the foraging behaviour, prey preferences and trophic positions within the local aquatic food web for the species of greatest interest with respect to human harvesting and consumption. Wood (2018) incorporated the outcomes of these studies with the outcomes from Harris (2018) and Brunton (2018) to estimate predicted future increases in MeHg concentrations within edible fish and seal tissues. Essentially, life history and diet information was used to determine the relative degree to which aquatic biota may be exposed to water where MeHg concentrations have increased in Lake Melville in the future, post-reservoir impoundment. The peak increase in water MeHg concentrations over three years was used to determine the maximum degree to which biota may theoretically respond. It was conservatively assumed that aquatic biota tissue concentrations of MeHg would increase in direct proportion to the predicted future increase in water MeHg concentrations, for the harvested species that occur in Goose Bay and Lake Melville. While this is a common assumption in many risk assessments and environmental assessments, in reality, MeHg uptake into biota is not linear with water concentration changes, and the assumption ignores numerous factors known to influence MeHg bioaccumulation and biomagnification in aquatic ecosystems.
- **Azimuth (2018a) Technical Memorandum RE: Summary of Post-Exposure Human Health Risk Assessment from Methylmercury in Seafood in Goose Bay and Lake Melville, Labrador.** This technical memorandum summarizes the outcomes of Harris (2018), Brunton (2018) and Wood (2018) and predicts the impact of these outcomes on the Dillon (2016b) baseline HHRA results and conclusions. This memorandum was developed as a provisional interim assessment of potential future human exposures to MeHg and the potential health risks posed by such exposures, as the lead Dillon risk assessor was unavailable at the time this report and the Harris, Brunton and Wood reports were being submitted to NLDEC. Based on the predicted future changes in MeHg concentrations in fish and seals (from Wood, 2018), the implications for human health were discussed.

- **Azimuth (2018b) Technical Memorandum RE: Evaluation of MeHg Production by Muskrat Falls Reservoir and Implications for Lake Melville – A Top-Down, Mass-Balance Approach**. This report evaluated the Calder et al. (2016) assumptions which underpin these authors' findings and conclusions regarding the rate and duration of MeHg flux from the flooded soils of Muskrat Falls Reservoir, and the associated potential for MeHg levels to increase in the downstream food web of Lake Melville. The evaluation was based on: i) a comparison of the physical and chemical conditions of the Muskrat Falls Reservoir to those of other northern latitude reservoirs, and, ii) application of a top-down mass balance analysis for MeHg within Lake Melville.
- **Azimuth (2017a) Technical Memorandum RE**: **Relationship Between Muskrat Falls Reservoir Elevation and Mercury Concentrations in Downstream Water – May 2017.** The relationship between water level elevation changes within the Muskrat Falls Reservoir, and key downstream water quality parameters that relate to potential MeHg formation and transport, were evaluated. The temporal period focused on was October, 2016 to February, 2017, a period when the water level in the reservoir was sustained above its long term historic baseline elevation (temporarily up to 22 m asl in November 2016). The evaluation was conducted in response to concerns regarding the potential for increased export of and/or generation of MeHg downstream of the reservoir and into Lake Melville. Azimuth examined water quality data for the aquatic system located between the reservoir and Lake Melville.
- **Azimuth (2017b) Technical Memorandum RE**: **Relationship Between Muskrat Falls Reservoir Elevation and Mercury Concentrations Lower Churchill River October 2016 – September 2017**. Using empirical water quality data collected by AMEC between October 2016 and September 2017, Azimuth updated their previous technical memorandum (i.e., Azimuth, 2017a). The updated evaluation also considered the nature of the soils flooded at different river elevations, possible seasonal effects (e.g., related to water temperature), and possible effects of ancillary water quality parameters linked to MeHg cycling and transport, including total and dissolved organic carbon (TOC/DOC) and total suspended solids (TSS). The updated evaluation also investigated the potential for temporal/seasonal changes with respect to MeHg and other parameters in surface waters at the Goose Bay station (N8) that may be related to upstream changes in MeHg concentration. This latter exercise was partially undertaken to address the concern expressed by the Nunatsiavut Government and the IEAC that there was "inconclusive evidence linking increases in water levels in the headpond and MeHg production, downstream and in Lake Melville". The updated evaluation considered the impoundment in early November 2016 (with an elevation of roughly 16 m to 21.5 m asl for about one month), and the impoundment in early February 2017 (where water elevation was raised back to around 21 m, and where it has since been held). Empirical water quality data were analysed using a series of plots and tables, supported by statistical analyses. For the data analysis, it was assumed that station N1, located upstream of the impoundment, represented 'baseline' conditions against which downstream changes were evaluated. Stations N5, N6 and N7 – located 0.1 km, 20 km and 40 km downstream of the Muskrat Falls dam respectively, were assumed to represent 'fully mixed' conditions downstream of the impoundment, and were also assumed to represent discharges to Goose Bay.

- **Azimuth (2017c) Technical Memorandum RE: Quantitative Measurement of Labile Carbon in Organic Soils of the Lower Churchill River**. In this study, six soil samples were randomly chosen from within the inundation zone of the Muskrat Falls Reservoir (prior to flooding) and analyzed for labile carbon. Each sample had the litter and fermentation layers removed, to focus on the humic soil horizon, with measured total organic carbon (TOC) content ranging from 28% to 48%. "Labile" refers to the fraction of TOC that is easily decomposed by microorganisms. The study used exhaustive sequential distilled water extractions at ambient temperature to measure the progressive release of dissolved organic carbon (DOC) over time. The scientific literature indicates that this method gives results that are reasonably comparable to longer soil incubation studies.
- **AMEC-FW (2017) Muskrat Falls Soil Sampling Program**. This program sampled, analyzed and characterized the soils located within the reservoir area of Muskrat Falls (prior to inundation). Soil types within the reservoir area were characterized by ecological land classification, as well as by soil stratigraphic and mineralogical observations and properties. A total of 41 soil samples were collected from within the reservoir area and analyzed for THg, MeHg, and total organic carbon. Soil total organic carbon concentrations were used to estimate the organic carbon mass that is present within reservoir area soils.

3.0 Key Outcomes of 2017 and 2018 Studies and Programs

The key outcomes of the programs and studies conducted throughout 2017 and 2018 that are most relevant towards estimating potential future human exposure to MeHg (and the potential health risks that may result from such MeHg exposure), are briefly summarized below. The studies are addressed in the same order as in the previous section.

- Water and sediment monitoring outcomes to date show that concentrations of THg and MeHg in study area water and sediment samples have generally remained low following partial reservoir impoundment. While some stations within the reservoir showed small increases in aqueous MeHg concentrations, the increases were seasonal (higher during warmer months, as expected) and were not consistently elevated at the sampling stations throughout the sampling period conducted to date. The monitoring programs to date have shown no evidence to indicate that MeHg fluxes from the reservoir are resulting in increased MeHg concentrations in downstream water bodies. No cumulative trend in measured downstream MeHg concentrations is evident at this time.
- The **Harris (2018)** study showed that both mechanistic RESMERC and field-based FLUDEX approaches had good agreement. Estimates of MeHg concentrations in water from all modelling approaches used within Harris (2018) were much lower than the predicted increase in water MeHg concentration within the reservoir that was reported in Calder et al. (2016). The modelling approaches used in Harris (2018) to predict the magnitude and timing of the downstream export of MeHg from reservoir water to Goose Bay and Lake Melville showed good agreement with each other, and with empirical data collected from existing reservoirs in Canada. Mechanistic model and field-based FLUDEX predictions were averaged for the purposes of downstream MeHg hydrodynamic modelling (conducted by Brunton, 2018). The predicted increases in water MeHg concentrations exported from the Muskrat Falls Reservoir were 4.6 times to 8 times lower than the 0.16 ng/L increase above baseline predicted by Calder et al.

(2016). Mechanistic and regression models both produced very similar predictions of peak fish MeHg concentrations in the reservoir in a model fish species. The Harris (2018) study concluded that MeHg concentrations in waters exported downstream from the reservoir would be expected to peak at roughly 2 times to 3 times baseline concentrations, when averaged over time periods relevant to potential bioaccumulation in adult fish. The outcomes from the Harris (2018) modelling study are believed to be conservative and likely to overestimate potential water MeHg concentrations that may be transported from the reservoir to downstream water bodies. Given the agreement observed between the results of the applied modelling approaches, there is a reasonably high degree of confidence in the modelled predictions for future water MeHg concentrations that may be exported to water bodies located downstream of the reservoir.

- The **Brunton (2018)** hydrodynamic modelling work predicted that increases in water column MeHg concentrations will decline with increasing distance from the reservoir, due to the effects of dilution, photodegradation and particle settling. The creation of Muskrat Falls Reservoir is predicted to increase MeHg concentrations (maximum 3 year averages) in the top 20 m of the water column by 0.019 ng/L in Goose Bay, and by 0.005-0.006 ng/L in Lake Melville. Water MeHg concentrations were predicted to increase less at depths >20 m (i.e., by up to 0.013 ng/L in Goose Bay, and 0.002-0.003 ng/L in Lake Melville). For both the top 20 m of the water column, and at depths >20 m, the predicted relative peak increase over the baseline water MeHg concentration of 0.017 ng/L was approximately 2 times in Goose Bay and 1.3 to 1.4 times in Lake Melville. The applied hydrodynamic models underwent calibration efforts against available measured data (from Goose Bay and Lake Melville) for a number of hydrodynamic parameters. These calibration exercises showed that modelled outcomes agreed reasonably well with available measured data for the hydrodynamic parameters that were considered. As per the outcomes of Harris (2018), the Brunton (2018) predictions are believed to be conservative and likely to overestimate potential future water MeHg concentrations in Goose Bay and Lake Melville. Given the outcomes of model calibration, there is a reasonably high degree of confidence in these predictions.
- For the studies and programs reported in **Wood (2018)**, key outcomes were as follows:
  - A significantly improved understanding of aquatic habitat utilization, habitat preferences, foraging preferences and behaviour, life history, distribution, abundance, and prevalence within the LCHGP study area, for the species of greatest interest with respect to human consumption.
  - Confirmation of the species most affected by the LCHGP (based on their aquatic habitat utilization and foraging behaviour), and the species most likely to experience increases in MeHg accumulation within their tissues, as a result of the LCHGP. It was determined from both Wood (2018) and the HHRA Program dietary surveys that brook trout, rainbow smelt and ringed seal are the locally harvested and consumed aquatic species that are most abundant and most likely to be affected by the LCHGP, such that MeHg concentrations may increase in their edible tissues. Given the outcomes of Wood (2018) and the HHRA Program diet surveys, all other fish species known to occur within the LCHGP study area are either not harvested/consumed (based on diet survey results), or, if they are harvested and consumed, are unlikely to be influenced by the LCHGP, given their habitat preferences, distribution, foraging preferences, life history, and prevalence and abundance within LCHGP study area water bodies. These other fish species are unlikely to be harvested and/or are unlikely to be present in LCHGP-influenced water

bodies to any significant extent, and would therefore be unlikely to experience LCHGP-related increases in MeHg tissue concentrations.

- Brook trout, rainbow smelt and ringed seal are therefore the only species that merit consideration regarding potential future increases in edible tissue MeHg concentrations, and are the species focused on both herein and in the Azimuth (2018a) interim HHRA update technical memorandum.
- Stomach content analysis and stable isotope analysis (conducted as part of the ongoing aquatic EEM Program) showed that brook trout in Goose Bay and Lake Melville feed primarily on marine prey items such as sand lance, rainbow smelt, amphipods, and other benthic invertebrates. Brook trout are one of the top predators within the estuarine food web. For rainbow smelt, these analyses showed that smelt are also among the top predators within the estuarine food web and feed primarily on marine prey items such as sand lance, other rainbow smelt, amphipods/decapods, and other marine zooplankton species. The stomach content analysis for ringed seals identified only rainbow smelt as prey; however, seals are sampled after the whelping period and foraging may be more limited at this time relative to other times of the year. Seal pups feed only on milk until whelped. Stable isotope data for ringed seals showed that this species is the apex predator in the local estuarine food web and feed on a variety of marine fish species.
- Wood (2018) incorporated the information on aquatic habit utilization, habitat preferences, foraging preferences and behaviour, life history, distribution, abundance, and prevalence, for brook trout, rainbow smelt and ringed seal, with the information on predicted future water MeHg concentrations from Harris (2018) and Brunton (2018), to estimate predicted future increases in fish and seal edible tissue MeHg concentrations. It was assumed that biota tissue MeHg concentrations increase in direct proportion to increased water MeHg concentrations. This assumption is common but simplistic and ignores many factors which influence MeHg uptake into aquatic biota. However, this assumption was also the basis of the approach used within Calder et al. (2016).

- In the **Azimuth (2018a) HHRA Technical Memorandum**, Azimuth summarized the information from the 2018 Harris, Brunton and Wood studies from a HHRA perspective and also reiterated key features and outcomes of the baseline HHRA (i.e., Dillon, 2016b). A standard Health Canada equation for fish consumption exposure to MeHg was applied to determine the total number of fish servings per week (by species) that would be permissible for human receptors. It was shown that a considerable number of fish meals are permissible per week under both baseline and future post-impoundment scenarios. For example, it was found that an adult can currently safely consume 23 meals per week of brook trout harvested from Goose Bay, diminishing to 13 meals per week post-impoundment. For Lake Melville brook trout, an adult can currently consume 40 weekly meals, diminishing to 32 meals post-impoundment. For perspective, the number of weekly servings of canned tuna was found to be more restrictive, at about half of the permissible brook trout meals. These examples and results are illustrative only and actual recommendations for the permissible number of fish or seal meals per week will be determined in a future consumption advice and advisory program. Azimuth concluded that there is an extremely low likelihood of risk to human health from the consumption of fish and seals from Goose Bay or Lake Melville, assuming peak future MeHg levels. It was also concluded that the original conclusions of the Dillon (2016b) baseline HHRA remain valid with respect to predicted future human health risks.

- The **Azimuth (2018b)** mass balance evaluation reached the following conclusions, all of which are well supported by the scientific literature and empirical evidence:
    - Baseline physical and chemical conditions at the Muskrat Falls Reservoir are characteristic of a system with a weak mercury (Hg) methylation potential.
    - The available mass of inorganic Hg in humic soils in the reservoir that is available for Hg methylation and transfer to the food web is limited and is insufficient to support the mass of MeHg predicted to be generated from flooded soils by Calder et al. (2016).
    - Based on empirical data and evidence from the scientific literature, the reservoir can potentially only generate a total mass of 2.35 kg of MeHg, amortized over a period of at least 10 years. This contrasts markedly with Calder et al. (2016), who assumed there would be 7.5 kg of MeHg generated every year from the reservoir area, extending over a period of up to 10 years.
    - Azimuth also concluded that the reservoir cannot generate the mass of MeHg necessary to support the increase in MeHg in the biotic food web of Lake Melville that was predicted by Calder et al. (2016).
    - Overall, the mass balance analysis showed that the assumptions and findings of Calder et al. (2016) are not supported, and that Calder et al. greatly overestimated the potential for the Muskrat Falls Reservoir to generate MeHg.
    - The mass balance analysis also showed that if any changes in MeHg levels were to occur in Lake Melville aquatic biota, the changes would be very small and unlikely to be measurable. The large biomass present within the Lake Melville estuary would be expected to readily assimilate any future increases in MeHg loadings.
- The **Azimuth (2017a)** and **Azimuth (2017b)** technical memoranda reported the following results and observations that are considered relevant to potential human MeHg exposure scenarios:
    - Temporary reservoir impoundment to 22 m asl in November of 2016 did not cause any changes to concentrations of unfiltered Hg and MeHg, TSS and TOC between the upstream reference station N1, above the dam site (N4), just below the dam site (N5), and further downstream to Goose Bay (N8). MeHg concentrations remained low (around 0.02 ng/L), for all sampling events, including before and after the month-long period of inundation.
    - While episodic spikes in TSS at some stations during erosional events caused spikes in total MeHg concentrations, dissolved MeHg levels remained relatively constant throughout the monitoring events.
    - It appeared that much of the TSS material was inorganic in nature, rather than organic soil.
    - All stations (as expected) showed a distinct seasonal pattern in dissolved MeHg concentrations, with the highest concentrations in summer months and the lowest concentrations in winter months.
    - Temporary impoundment activities did not produce a clear increased MeHg water column signal in the reservoir until May, 2017.
    - Dissolved water MeHg concentrations from June to September were slightly higher at station N4 (within the impoundment) relative to the upstream station, N1.
    - The evaluation of stations downstream of N4 showed that the magnitude of change in water MeHg concentrations was very small to negligible.
    - It was concluded that given the absence of a detectable increase in MeHg in Goose Bay surface water as a result of the impoundment, no detectable or meaningful change in

downstream biota MeHg concentrations should be expected, either within the Lower Churchill River, or extending into Goose Bay and beyond.
   - Measured post-impoundment MeHg concentrations in water have been much lower than those predicted by Calder et al. (2016), suggesting that these authors assumptions and/or methods greatly overestimated MeHg production and flux.
- The **Azimuth (2017c)** soil labile carbon study found that only 0.8% or less of the total organic carbon in reservoir area soil samples was readily extracted and measured as DOC using the distilled water extraction procedure. This suggests that only a very small fraction of the organic carbon in these soils is labile and capable of supporting the growth of microorganisms that can methylate inorganic mercury. These results are not atypical or surprising and indicate that the soil characteristics within the LCHGP study area are similar to those in other northern boreal forest environments.
- The **AMEC-FW (2017)** soil program enabled the estimation of realistic organic carbon mass within reservoir soils and the potential for organic carbon flux from flooded reservoir soils. Measured soil TOC concentrations were within typically observed ranges for northern boreal forest areas. Soil THg concentrations were very low with most samples containing non-detectable THg concentrations. In samples with sufficient THg to estimate the MeHg proportion, it was found that MeHg generally comprised <1% of the THg in the soil sample. This is an expected and common finding for Hg in soils.

4.0 Summary of the Final Baseline HHRA (Dillon, 2016b)

As the final baseline HHRA study (i.e., Dillon, 2016b) is a key component of the HHRA program and serves as a key point of reference for future MeHg monitoring and assessment programs, the baseline HHRA study is briefly summarized below. Further details are available in the HHRA report itself and within its technical appendices and are not reproduced herein.

The Dillon (2016b) baseline HHRA is the only comprehensive HHRA available that evaluates baseline MeHg exposures and risks in a comprehensive, scientifically defensible and transparent manner. This study was reviewed by several HHRA and MeHg experts within Health Canada, and independently, by a HHRA professional hired by the IEAC. Any suggestions made by the reviewers (none of which were significant) have been considered within the HHRA Program. This baseline HHRA is the only HHRA study that can serve as the basis for estimating potential future MeHg exposures and risks within the LCHGP study area communities.

It is acknowledged that a somewhat similar HHRA study was supported by NG and conducted by a Harvard University PhD student (Ryan Calder). Some of the HHRA work was reported in Calder et al. (2016), to a limited degree. However, to date, there are no publications or reports from this group that provide sufficient details on HHRA methods, assumptions, or outcomes, that would enable their HHRA work to be verified or validated. Given this and the numerous deficiencies noted in expert reviews/critiques of Calder et al. (2016), the HHRA work conducted by Harvard cannot be used to supplement or complement the LCHGP HHRA program studies at this time, and cannot be used as a defensible basis for estimating potential future MeHg exposures and risks. If adequate documentation of the HHRA approaches and outcomes from Calder et al. (2016) could be made available, such that they could be verified/validated, then it may become possible to incorporate some of these authors approaches or outcomes (if deemed suitable and of adequate quality) into the LCHGP HHRA program.

The final baseline HHRA built upon a number of previous studies and documentation conducted/prepared during the EA of the LCHGP, and post-EA. The HHRA focused on the evaluation of potential human exposures and risks associated with the presence of methylmercury (MeHg) and inorganic mercury (Hg) in a variety of country food and store-bought food items that are commonly consumed by residents of the LCHGP study area communities. Various food ingestion-based exposure pathways and routes were assessed for male and female human receptors of all age classes, in the participating LCHGP study area communities.

A study area-specific dietary survey (DS) and human biomonitoring program (HBP; which involved human hair sampling and analysis for THg and MeHg) were key aspects of the final baseline HHRA. The DS outcomes were the basis of the assessed food item consumption rates and frequencies, and the HBP outcomes provided a line of evidence regarding current baseline Hg exposures for residents of the study area communities.

The final baseline HHRA was conducted according to standard regulatory guidance including HHRA guidance documentation developed and endorsed by Health Canada. The HHRA was also conducted in a highly conservative manner that applied/used various approaches, models and assumptions which tended to overestimate (to a substantial degree) MeHg and inorganic Hg exposures and risks for the assessed human receptors.

Within its major steps, the final baseline HHRA evaluated multiple lines of evidence (LOEs). These LOEs (as follows) comprised the main outcomes of the HHRA.

- Calculated human health risk estimates for each of the assessed human receptors, in each study area community, expressed as hazard quotients (HQs). HQs in this HHRA are the estimated total exposures to both MeHg and inorganic Hg divided by the applicable regulatory toxicological reference value(s) (TRVs) for these substances.
- Relative exposure contributions of the assessed human exposure pathways and food items to total MeHg and inorganic Hg exposure for the assessed human receptors, and the relative proportion of MeHg and inorganic Hg exposure that is attributed to country food consumption versus market basket (store-bought) food consumption.
- Consideration of the conservative assumptions and uncertainties (including data variability) within the exposure assessment and hazard (toxicity) assessment steps of the HHRA and their impact on human health risk estimates.
- Consideration of the potential impact of key toxicological interactions on predicted human health risk estimates, and the relationship of predicted risk estimates to the health benefits of including locally harvested fish, seal and game species in traditional diets. This consideration was only treated in a brief and cursory manner in the HHRA as it will be addressed in greater detail in a forthcoming consumption advisory/advice protocol and program.
- Evaluation of human biomonitoring data (i.e., measured hair THg and MeHg concentrations) from the baseline HBP conducted in LCHGP study area communities, and comparison of the hair THg and MeHg data to regulatory toxicological guidelines for THg/MeHg in hair.
- Comparison of the measured hair THg and MeHg data from the HBP to predicted hair MeHg concentrations estimated using a widely accepted one compartment toxicokinetic model (developed by the World Health Organization) with extensive global regulatory precedent, that converts estimated MeHg exposures (expressed as a dose) to blood MeHg concentrations. Blood

MeHg concentrations were then converted to hair concentrations using a common and widely accepted blood to hair conversion factor of 250.

- Comparison of estimated human receptor blood MeHg concentrations (from the toxicokinetic model) to Health Canada blood MeHg guidance values (i.e., Legrand et al., 2010).
- Comparison of predicted hair MeHg concentrations to regulatory toxicological guidelines for THg/MeHg in hair.
- Comparison of estimated fetal blood MeHg concentrations to Health Canada blood MeHg guidance values (i.e., Legrand et al., 2010).
- Comparisons of LCHGP study area fish THg concentration data against regulatory human health-based fish tissue residue guidelines for THg/MeHg.
- General comparisons of study area fish muscle, seal muscle and liver, and wild bird egg THg concentrations to selected fish, seal and egg THg data reported in the literature for various northern locations within Canada, the U.S., and northern Europe.

Some other features of the baseline HHRA included: the development of HHRA exposure (consumption) scenarios from baseline DS outcomes; validation of country food intake rates against literature values and leading North American regulatory agency HHRA guidance resources; the use of study area-specific data (where available) on locally harvested country food item Hg concentrations (e.g., the aquatic EEM program has extensive data on Hg levels in numerous fish species and ringed seal); the use of reasonable and representative surrogate data from other northern subarctic locations (a common and standard HHRA practice for country food items that lack study-area specific data); the use of store bought food item Hg data from established Health Canada and USFDA publications and datasets; the use of established and widely accepted regulatory toxicity values and toxicological benchmarks for MeHg and inorganic Hg.

Based on the outcomes of the HHRA LOEs, the final baseline HHRA concluded that there is a low to negligible potential for human health risk resulting from MeHg exposure, and a negligible potential for human health risk resulting from inorganic Hg exposure. The calculated MeHg and inorganic Hg exposures and risks are similar to what would be expected in numerous communities in North America where food consumption patterns comprise the ingestion of both store-bought foods and country food items that are of aquatic origin. A brief summary of the key final baseline HHRA LOE outcomes follows.

- Calculated HQs for inorganic Hg suggested a negligible potential for human health risk.
- Calculated HQs for MeHg suggested a negligible to low potential for human health risk.
- All calculated HQs are considered to be substantial overestimates of potential human health risk due to the various and numerous conservative approaches and assumptions that were used/applied in the HHRA. In particular, the HHRA did not quantitatively account for the numerous interactions between MeHg and inorganic Hg and other substances in the assessed food items that would likely reduce the bioaccessibility, bioavailability and toxicity of these substances, nor did the HHRA account for other factors (such as cooking processes) that also likely reduce the bioaccessibility, bioavailability and toxicity of MeHg and inorganic Hg.
- Country food items dominate as potential sources of MeHg and inorganic Hg exposure in some, but not all LCHGP study area communities.
- Comparisons of measured hair THg and MeHg concentrations (for baseline DS and HBP participants) against regulatory toxicological guidelines for THg/MeHg in hair indicated no human health concerns.

- LCHGP study area DS and HBP participants had hair THg concentrations that were similar to those observed in a number of other First Nations communities located across Canada.
- Predicted hair MeHg concentrations in the assessed receptors (which are conservative overestimates) had a low frequency of exceedance and low margins of exceedance over regulatory toxicological guidelines for THg/MeHg in hair, and do not suggest a potential human health concern.
- Predicted blood MeHg concentrations in the assessed receptors (which are conservative overestimates) also had a low frequency of exceedance and low margins of exceedance over regulatory toxicological guidelines for THg/MeHg in blood, and do not suggest a potential human health concern.
- There was a generally low frequency of exceedance for LCHGP study area fish muscle THg concentrations over conservative human health-based fish tissue residue guidelines for THg/MeHg.
- LCHGP study area THg concentrations in fish, seal and wild bird eggs are not elevated relative to reported THg concentrations in these food items for numerous other northern locations in Canada, the U.S., and Europe.

Final baseline HHRA outcomes did not indicate a need for corrective action or risk management (such as specific consumption advisories) at this time. However, precautionary recommendations were made, as were recommendations related to potential future risk management measures and/or future follow-up studies that may be necessary after the LCHGP is operational.

4.1 Final Baseline HHRA Recommendations

While final baseline HHRA outcomes did not indicate a need for corrective action or risk management, standard precautionary measures related to MeHg or THg in fish and other country foods of aquatic origin are considered to be prudent.

For example, despite the conservatism and the high likelihood that the HHRA substantially overestimated MeHg exposures and risks to nursing mothers, breast-feeding infants, females of child-bearing age and the developing fetus, standard universal advice that pregnant women and nursing mothers avoid, restrict or temporarily cease their consumption of certain country and store-bought food items that tend to be elevated in MeHg, is prudent, and should apply within the LCHGP study area communities. It must be recognized that this well -established precautionary advice applies to pregnant women and nursing mothers anywhere, and is not made for the study area communities because of final baseline HHRA outcomes.

It must also be recognized that there are numerous and universally well-established benefits (to both the infant and mother) of breast-feeding, and HHRA outcomes indicate no reason whatsoever for there to be concerns regarding breast-feeding in relation to baseline levels of Hg exposure within LCHGP study area communities. In general, breast-feeding should never be stopped due to fears over chemical exposure unless specifically recommended by a physician. Even in rare situations where a mother does have elevated exposures to certain chemicals that can accumulate in breast milk (which is not the case in the final baseline HHRA), the benefits of breast-feeding far outweigh the potential health risks from chemical exposure in the overwhelmingly vast majority of cases.

Given the conservative HHRA outcomes, there is no cause for concern in relation to potential infant MeHg exposures that may be incurred via breast-feeding. Thus, any new or soon-to-be mothers within the study area communities should continue to be encouraged to breast-feed their infants and young toddlers, if they are able to. Following the standard universal precautionary measures will further minimize what is an already negligible to very low potential for exposure and risk.

In addition (as noted previously in the interim assessment of seal meat and liver consumption; Dillon, 2016a), it may be prudent to recommend to those study area residents that consume ringed seal meat and organs, that only younger ringed seals be harvested for human consumption (as older seals tend to have higher THg concentrations in both their muscle and liver tissue). Typically, it is the younger seals that are preferentially harvested, but encouraging this practice would likely reduce the Hg exposures that may be incurred from seal meat and liver consumption.

4.2 A Note on the Lack of Consideration of Potential Future MeHg Exposure Within the Baseline HHRA

The baseline HHRA did not attempt to estimate potential future MeHg exposures and risks. It is not typically within the scope of any baseline HHRA study to assess potential future conditions. Rather, the focus of the assessment effort is on baseline (or current) conditions.

It is acknowledged that some attempts were made during the EA process to estimate peak fish MeHg increase factors in selected fish species (e.g., Nalcor, 2009; JRP, 2010; Harris and Hutchinson, 2008). These increase factors were reviewed during the baseline HHRA process but were deemed too uncertain and of insufficient confidence to apply within the HHRA. Furthermore, the peak MeHg increase factors were available for only three study area fish species.

Since the EA, there has been updated and refined field-based, mechanistic, regression and hydrodynamic modelling conducted, as well as extensive aquatic environmental effects monitoring data collection and a detailed assessment of LCHGP study area aquatic ecology, aquatic habitat utilization and trophic dynamics (as described **in Sections 2.0** and **3.0** of this technical memo). These updated and refined modelling and assessment activities and programs have culminated in what are believed to be reasonably accurate and realistic (yet conservative) estimates of potential future peak MeHg increase factors (i.e., from Wood, 2018) for harvested and consumed study area fish species, and for ringed seal.

Potential future human MeHg exposures and corresponding human health risks, that are based on the application of the Wood (2018) peak MeHg increase factors, are described and discussed in **Section 6.0**.

5.0 IEAC Human Health-Related Activities and Recommendations

The information presented in this section represents the independent opinion of the LCHGP HHRA Program HHRA Subject Matter Expert (SME).

While a description and discussion of the IEAC reports and activities that relate to human health is not within the scope of this technical memo, a few important observations regarding IEAC activities, documents and other materials are relevant to the overall LCHGP HHRA Program and are briefly commented on below.

Based on a review of all the human health-related documents and other materials posted to the IEAC website (conducted by the LCHGP HHRA Program HHRA Subject Matter Expert (SME)), as well as discussions between the SME and the contractor hired by the IEAC to review certain aspects of the Calder et al. and LCHGP HHRA Program HHRA studies, some major issues have been identified, including: failing to consider the numerous major limitations of the Harvard-led work; failing to adequately consider the more comprehensive, transparent and expert-reviewed LCHGP HHRA Program and Aquatic EEM Program documentation and data; and, an apparent misunderstanding of the important differences between a "peer-reviewed" journal publication and expert-reviewed and expert-conducted detailed technical studies.

A more detailed discussion of IEAC human health-related activities and documents can be made available upon request.

Despite the identified issues, the final April 2018 IEAC recommendations that pertain to human health are generic and standard, such that they can be considered reasonable, in a general manner.

The LCHGP HHRA Program suggests that the IEAC have no further role in any human health or public health program going forward. Rather, the LCHGP study area communities would be better served by the creation of a new committee or body with membership that represents all key stakeholders and that includes qualified and unbiased individuals with demonstrated expertise and experience in the disciplines of human health risk assessment, traditional country food nutritional science, human toxicology of MeHg, public health, and MeHg EEM program design and implementation. Other relevant disciplines may also merit consideration and inclusion.

6.0 Potential Future MeHg Exposures and Risks Within the LCHGP Study Area

This section addresses potential future MeHg exposures that may be incurred by study area community members due to the harvesting and consumption of fish and seal, and the potential health risks that may be anticipated as a result of such exposures. Assessment of these potential future exposures and risks is supplemental to the final baseline HHRA (Dillon, 2016b), and incorporates the outcomes from the various studies and programs conducted in 2017 and 2018 (as described previously in **Sections 2.0** and **3.0**), particularly the outcomes from Harris (2018), Brunton (2018), Wood (2018), and Azimuth (2018a). Potential future MeHg exposures and risks were estimated using the exposure and risk model developed for the final baseline HHRA.

The predicted peak MeHg increase factors reported in Table 2-3 of Wood (2018) for Goose Bay and West Lake Melville were utilized to estimate potential future MeHg exposures and risks within the LCHGP study area communities. These increase factors represent the current best available estimates of potential future increases in MeHg concentrations within the edible tissues of locally harvested fish species and ringed seal. However, these peak MeHg increase factors were derived in a manner that is believed to be highly conservative, such that their application within the LCHGP HHRA model likely substantially overestimates future dietary MeHg exposures and risks within the LCHGP study area communities. The peak MeHg increase factors are temporary and are expected to occur within 2 to 3 years following reservoir impoundment. MeHg concentrations in study area aquatic biota are anticipated to gradually increase such that they would peak by post-reservoir impoundment years 2 or 3, persist for potentially 1 year at most, and then gradually decline thereafter back towards baseline levels.

As previously noted in Dillon (2016b) and Wood (2018), brook trout, rainbow smelt and ringed seal (meat and liver) are focused on with respect to the assessment of potential future MeHg exposure and risk. These species are the most commonly consumed (as reported in HHRA program diet surveys), are among the most abundant harvested species within the study area, and are the only harvested and consumed species likely be affected by the LCHGP.

While peak MeHg increase factors were also developed for East Lake Melville (and reported in Table 2-3 of Wood (2018)), these factors were not used to estimate potential future MeHg exposures and risks within the study area HHRA model. The East Lake Melville increase factors are most representative of potential MeHg exposures to Rigolet community members, and do not represent potential exposures to residents of the other study area communities (Happy-Valley Goose Bay, Churchill Falls, Mud Lake, North West River, Sheshatshiu). As discussed in Dillon (2016b), Rigolet was not a participating community in the LCHGP HHRA Program. Furthermore, the peak increase factors for East Lake Melville are lower than those derived for Goose Bay and West Lake Melville. Use of the East Lake Melville increase factors would have slightly reduced estimates of potential future MeHg exposure and risk for the study area communities.

The predicted peak MeHg increase factors for Goose Bay and West Lake Melville were averaged together as it is considered likely that fish or seals harvested by members of the study area communities could occur and forage anywhere within both Goose Bay and the western portion of Lake Melville. These averaged peak MeHg increase factor values are summarized below in **Table 1**.

TABLE 1: PEAK MeHg INCREASE FACTORS FOR BROOK TROUT, RAINBOW SMELT AND RINGED SEAL

Species/Harvested Food Item	Goose Bay (Wood, 2018)	West Lake Melville (Wood, 2018)	Average
Brook Trout	1.78	1.25	1.52
Rainbow Smelt	2.12	1.5	1.81
Ringed Seal Muscle	1.32	1.21	1.27
Ringed Seal Liver	1.32	1.21	1.27

Of the study area communities considered in the baseline HHRA, all but Churchill Falls (CF) merit consideration with respect to potential future MeHg exposures and risks. CF is excluded as the fish harvested and consumed by CF residents are extremely unlikely to come from Goose Bay or Western Lake Melville (given the distance between CF and these water bodies; >250 km), and CF residents did not report the consumption of ringed seal meat or liver. Thus, for CF community members, future MeHg exposures and risks as a result of the LCHGP are expected to equal baseline MeHg exposures and risks.

The averaged Goose Bay and West Lake Melville peak MeHg increase factors (**Table 1**) for brook trout, rainbow smelt and ringed seal (meat and liver) were applied to the MeHg exposure point concentrations (EPCs) that were evaluated in the baseline HHRA model. All other sources and rates of MeHg exposure evaluated in the baseline HHRA model remained constant or unchanged from what was assumed for baseline conditions.

The outcome of applying the averaged peak MeHg increase factors to brook trout, rainbow smelt, and ringed seal meat and liver EPCs was a minor and insignificant increase (relative to baseline) in the MeHg hazard quotients, predicted hair MeHg concentrations, and predicted blood MeHg concentrations for the assessed human receptors and study area communities. **Tables 2 to 5** summarize the changes in these key HHRA outcomes (relative to baseline) that result from the application of the peak MeHg increase factors. On average, the application of these MeHg increase factors produced a less than 10% increase above the baseline HQs, and predicted baseline blood and hair MeHg concentrations. This increase is not significant and is well within the bounds of expected variability and uncertainty in the baseline MeHg exposure and risk estimates.

Application of the peak MeHg increase factors does not alter any of the conclusions made within the baseline HHRA. The results presented in **Tables 2 to 5** should be considered in the same context and perspective that was provided in the final baseline HHRA (i.e., Dillon, 2016b).

TABLE 2: SUMMARY OF METHYLMERCURY (MeHg) HAZARD QUOTIENTS (HQs) FOR LCHGP STUDY AREA EXPOSURE/CONSUMPTION SCENARIOS (COMMUNITIES) – BASELINE AND POTENTIAL FUTURE CONDITIONS

Human Receptor Type	Baseline Happy Valley-Goose Bay (HVGB)	Potential Future HVGB	Baseline Sheshatshiu (SH)	Potential Future SH	Baseline North West River (NWR) and Mud Lake (ML)	Potential Future NWR and ML
M Toddler	**HQ1 = 1.3**	**1.39**	HQ1 = 1.0	**1.1**	**HQ1 = 1.5**	**1.7**
	HQ2 = NA	NA	HQ2 = NA	NA	HQ2 = NA	NA
	HQ3 = 0.64	0.69	HQ3 = 0.50	0.53	HQ3 = 0.77	0.82
M Child	**HQ1 = 1.5**	**1.6**	**HQ1 = 1.4**	**1.5**	**HQ1 = 1.6**	**1.7**
	HQ2 = NA	NA	HQ2 = NA	NA	HQ2 = NA	NA

Human Receptor Type	Baseline Happy Valley-Goose Bay (HVGB)	Potential Future HVGB	Baseline Sheshatshiu (SH)	Potential Future SH	Baseline North West River (NWR) and Mud Lake (ML)	Potential Future NWR and ML
	HQ3 = 0.77	0.8	HQ3 = 0.71	0.73	HQ3 = 0.80	0.83
M Teen	**HQ1 = 1.2**	**1.2**	HQ1 = 0.95	0.97	**HQ1 = 1.2**	**1.3**
	HQ2 = 0.25	0.26	HQ2 = 0.20	0.21	HQ2 = 0.25	0.27
	HQ3 = NA	NA	HQ3 = NA	NA	HQ3 = NA	NA
M Adult	**HQ1 = 2.5**	**2.6**	**HQ1 = 2.1**	**2.1**	**HQ1 = 2.5**	**2.7**
	HQ2 = 0.53	0.55	HQ2 = 0.44	0.45	HQ2 = 0.54	0.57
	HQ3 = NA	NA	HQ3 = NA	NA	HQ3 = NA	NA
F Toddler	**HQ1 = 1.4**	**1.5**	**HQ1 = 1.1**	**1.1**	**HQ1 = 1.6**	**1.8**
	HQ2 = NA	NA	HQ2 = NA	NA	HQ2 = NA	NA
	HQ3 = 0.68	0.74	HQ3 = 0.54	0.56	HQ3 = 0.82	0.88
F Child	**HQ1 = 1.6**	**1.7**	**HQ1 = 1.5**	**1.5**	**HQ1 = 1.7**	**1.7**
	HQ2 = NA	NA	HQ2 = NA	NA	HQ2 = NA	NA
	HQ3 = 0.79	0.83	HQ3 = 0.73	0.76	HQ3 = 0.83	0.86
F Teen	**HQ1 = 1.3**	**1.4**	**HQ1 = 1.1**	**1.1**	**HQ1 = 1.4**	**1.4**
	HQ2 = 0.28	0.29	HQ2 = 0.23	0.23	HQ2 = 0.29	0.30
	HQ3 = 0.65	0.69	HQ3 = 0.54	0.55	HQ3 = 0.68	0.71
F Adult	**HQ1 = 3.0**	**3.1**	**HQ1 = 2.5**	**2.5**	**HQ1 = 3.0**	**3.2**
	HQ2 = 0.63	0.66	HQ2 = 0.53	0.54	HQ2 = 0.64	0.68
	HQ3 = 1.5	**1.6**	**HQ3 = 1.2**	**1.3**	**HQ3 = 1.5**	**1.6**
Infant with F Teen Mother	**HQ1 = 2.6**	**2.7**	**HQ1 = 2.1**	**2.1**	**HQ1 = 2.6**	**2.8**
	HQ3 = 1.3	**1.4**	**HQ3 = 1.1**	**1.1**	**HQ3 = 1.3**	**1.4**
Infant with F Adult Mother	**HQ1 = 5.8**	**6.1**	**HQ1 = 4.9**	**5.0**	**HQ1 = 5.9**	**6.2**
	HQ3 = 2.9	**3.1**	**HQ3 = 2.4**	**2.5**	**HQ3 = 2.9**	**3.1**

Notes:
M=Male; F=Female.
HQ values are rounded to two significant figures.
Bolded values indicate exceedance of target HQ value of 1.0.
HQ1 refers to HQ based on use of the U.S. EPA (2001a,b) and NRC (2000) TRV (See Dillon, 2016b).
HQ2 refers to HQ based on use of the Health Canada (2010c; 2007) TRV for the general adult population (See Dillon, 2016b). This TRV was also applied to M and F teen receptors (>12 to <20 years).
HQ3 refers to HQ based on use of the Health Canada (2010c; 2007) TRV for women of child-bearing age (considered to be both teen and adult life stages) and children <12 years of age (See Dillon, 2016b).
NA=not applicable for a given receptor; due to application of the gender and age-specific TRVs for MeHg from Health Canada.

TABLE 3: SUMMARY OF PREDICTED HAIR MeHg CONCENTRATIONS (mg/kg ww) FOR HUMAN RECEPTORS ASSESSED IN THE HHRA – BASELINE AND POTENTIAL FUTURE CONDITIONS

Receptor	Baseline HVGB	Potential Future HVGB	Baseline SH	Potential Future SH	Baseline NWR and ML	Potential Future NWR and ML
M Toddler	1.4	1.6	1.1	1.2	1.7	1.9
M Child	1.7	1.8	1.6	1.7	1.8	1.9
M Teen	1.3	1.4	1.1	1.1	1.3	1.4
M Adult	2.8	3.0	2.4	2.4	2.9	3.0
F Toddler	1.5	1.7	1.2	1.3	1.9	**2.0**
F Child	1.8	1.9	1.7	1.7	1.9	1.9
F Teen	1.5	1.6	1.2	1.2	1.5	1.6
F Adult	**3.4**	**3.5**	**2.8**	**2.9**	**3.4**	**3.6**
Pregnant F Teen	1.0	1.1	0.8	0.8	1.0	1.1
Pregnant F Adult	**2.3**	**2.5**	2.0	2.0	**2.4**	**2.5**

Notes:
F=female; M=male; ww =wet weight.
Bolded values denote an exceedance over the applicable "no action" Health Canada hair guidance value(s) for THg/MeHg (2 mg/kg ww for pregnant F; F 0-49 yrs; M≤18 yrs; and, 5 mg/kg ww for F≥50 yrs; M >18 yrs).

TABLE 4: SUMMARY OF PREDICTED BLOOD MeHg CONCENTRATIONS (µg/L) FOR HUMAN RECEPTORS ASSESSED IN THE HHRA – BASELINE AND POTENTIAL FUTURE CONDITIONS

Receptor	Baseline HVGB	Potential Future HVGB	Baseline SH	Potential Future SH	Baseline NWR and ML	Potential Future NWR and ML
M Toddler	5.8	6.3	4.6	4.8	7.0	7.5
M Child	7.0	7.3	6.5	6.6	7.3	7.6
M Teen	5.2	5.5	4.3	4.4	5.4	5.7
M Adult	11.2	11.8	9.4	9.6	11.4	12
F Toddler	6.2	6.7	4.9	5.1	7.5	8.0
F Child	7.2	7.5	6.6	6.8	7.5	7.8
F Teen	5.9	6.3	4.9	5.0	6.1	6.5
F Adult	**13.4**	**14.1**	**11.3**	**11.5**	**13.6**	**14.4**
Pregnant F Teen	4.0	4.3	3.3	3.4	4.2	4.4
Pregnant F Adult	**9.4**	**9.9**	7.9	8.0	**9.5**	**10**

Notes:
F=female; M=male.
Bolded values denote an exceedance over the applicable "no action" Health Canada blood guidance value(s) for MeHg (8 µg/L for pregnant F; F 0-49 yrs; M≤18 yrs; and, 20 µg/L for F≥50 yrs; M>18 yrs).

TABLE 5: SUMMARY OF PREDICTED FETAL BLOOD MeHg CONCENTRATIONS (µg/L) – BASELINE AND POTENTIAL FUTURE CONDITIONS

Community	Predicted Fetal Blood Concentration (µg/L) Based on Pregnant Female Teen	Predicted Fetal Blood Concentration (µg/L) Based on Pregnant Female Adult
Baseline HVGB	6.9	**15.9**
Potential Future HVGB	7.2	**16.8**
Baseline SH	5.6	**13.4**
Potential Future SH	5.8	**13.6**
Baseline NWR and ML	7.1	**16.2**
Potential Future NWR and ML	7.5	**17**

Notes:
Bolded concentrations exceed the Health Canada (Legrand et al., 2010) "no action" blood guidance value of 8 µg/L. Health Canada considers that <8 µg/L of MeHg in maternal blood is protective of the developing fetus as well as infants and young and older children (up to adolescence).

As shown in **Tables 2 to 5**, the application of the peak MeHg increase factors resulted in no significant changes (from no change to generally less than a 10% increase) to baseline HQs, and predicted baseline blood and hair MeHg concentrations. Where increases occur, the magnitude of the increase is not significant and is well within the bounds of expected variability and uncertainty in the baseline MeHg exposure and risk estimates.

Application of the conservative potential future peak MeHg increase factors does not alter any of the conclusions or recommendations made within the baseline HHRA. The final baseline HHRA had previously concluded that there is a low to negligible potential for human health risk resulting from current MeHg exposures, and that calculated MeHg exposures and risks are similar to what would be expected in numerous communities in North America where food consumption patterns comprise the ingestion of both store-bought foods and country food items that are of aquatic origin. The final baseline HHRA outcomes did not indicate a need for corrective action or risk management (such as specific consumption advisories). However, standard precautionary recommendations were made, as were recommendations related to potential future risk management measures and/or future follow-up studies that may be necessary after the LCHGP is operational.

Given the outcomes and conclusions described above and in the preceding sections, it is considered *extremely unlikely* that the LCHGP would significantly increase future human MeHg exposures and risks beyond what occurs under current, existing baseline conditions. Azimuth (2018a) reached a similar conclusion. Specifically, in the Azimuth (2018a) report, it was determined that there is an *extremely low* likelihood of risk to human health from the consumption of fish and seals from Goose Bay or Lake Melville, assuming peak future MeHg levels. These findings are well supported upon consideration of the conservatism that is inherent to the development of the future peak MeHg increase factors (**Sections 2 and 3**), the conservatism inherent within the overall HHRA approach and the final baseline HHRA model, and the numerous outcomes and lines of evidence from the various studies described in **Sections 2 and 3** that collectively suggest the LCHGP has a very low potential to increase MeHg loadings to areas downstream of the Muskrat Falls Reservoir.

While there is uncertainty in any estimate of potential future impact or risk, the conservatism applied throughout the HHRA Program and throughout the process of developing the future peak MeHg increase factors results in high confidence that future MeHg exposures and risks have been overestimated. However, predicted future risk estimates merely provide an indication of what may be anticipated in the future, when MeHg levels have peaked in LCHGP study area aquatic biota. Only continued environmental monitoring (such as the aquatic EEM program) will be able to determine true future MeHg exposure and risk levels.

For harvested and consumed species that did not have the peak increase factors applied to MeHg exposure point concentrations (i.e., species other than brook trout, rainbow smelt and ringed seal), as well as all store-bought foods considered within the final baseline HHRA, it is considered very likely that future MeHg exposures would equal baseline MeHg exposures. While there is some associated uncertainty with this assumption, it is not appropriate to apply MeHg increase factors for brook trout, rainbow smelt or ringed seal to these other species and/or food items. The ongoing aquatic EEM Program and other LCHGP EEM programs will determine if MeHg levels increase in the future in species or food items other than those focused on herein (i.e., those that are not directly affected by the LCHGP).

The aquatic EEM program has already generated an extensive dataset of THg and MeHg concentrations in the edible tissues of fifteen study area fish species and in ringed seal meat and liver. This program will continue indefinitely and can easily be modified (should it be deemed necessary) to collect additional data on these and potentially other country foods of aquatic origin. The aquatic EEM program's ongoing water quality monitoring efforts will also help track any potential future increases in MeHg levels within the LCHGP study area aquatic ecosystem. Ongoing monitoring and adaptive management principles provide the only reliable means of tracking and responding to potential future increases in aquatic country food MeHg concentrations within the study area.

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