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March 31, 2018

Ken Reimer, PhD, Chair
Independent Expert Advisory Committee
PO Box 2129, Station B
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Re: Technical analysis of "Evaluation of MeHg Production by Muskrat Falls Reservoir and Implications for Lake Melville – A Top-Down, Mass-Balance Approach" by Azimuth Consulting Group Partnership

Dear Dr. Reimer:

I am attaching my comments on the document produced to the IEAC by Azimuth in February 2018. In my opinion this document produces no usable information.

Please do not hesitate to contact me to discuss this or anything else.

Sincerely,

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1. Summary

Azimuth Consulting Group Partnership ("Azimuth") has produced a document claiming that the forecasts and risks assessments for methylmercury (MeHg) associated with the ongoing Muskrat Falls hydroelectric development cannot be substantiated by available data (Azimuth 2018). The document mainly addresses the modeling work of Calder et al. (2016), but its conclusions also contradict past and ongoing work by other parties (e.g., Harris and Hutchinson 2008; Harris et al. 2010). The claims are accompanied by some calculations that have not been externally reviewed and map only loosely to standard environmental modeling methods in my opinion.

My careful reading of the document has led me to identify a number of misrepresentations and misconceptions about the nature of MeHg production and bioaccumulation that combine to produce conclusions that cannot be scientifically substantiated. In my opinion, the principal errors are (1) the claim, repeated throughout the document, that peak MeHg fluxes from flooded soils must be sustained over the timeframe of increases in biota; (2) the representation that Calder et al. (2016) forecasted MeHg fluxes over a timescale of ten years and that this is necessary to achieve peak impacts across trophic levels; (3) mass balance calculations that assume MeHg is simultaneously accumulated in all biota following flooding instead of allowing for biomagnification across trophic levels; and (4) misrepresenting the magnitude of uncertainties in its presented mass balance calculations relative to other externally reviewed analysis. These errors are woven together, again in my opinion, with misrepresentations and misinterpretations of the scientific literature that trivialize the environmental significance of soil Hg for MeHg impacts in the water column.

2. Factual errors and misrepresentations

This section identifies what are in my opinion the most significant and errors of fact and misinterpretations of the published literature including of Calder et al. (2016).

"According to Calder et al., this flux will cause 'the annual flow-weighted mean MeHg concentration in the Churchill River to increase 10-fold … relative to baseline' and that 'these changes represent substantial increase in the freshwater environment that will be magnified in local food webs.'" (p. 2)

- "Mean" here refers to the mean (expectation) of the distribution of modeled peak values and not a temporal mean.

"Calder et al. (2016) predicted that when the MFR (101 km^2) is fully inundated, decomposition of organic matter by mercury methylating microbes will generate and sustain a mean flux rate [sic] of 664 $ng/m^2/day$…" (p. 2)

- This is incorrect. This is the flux corresponding to the peak post-flooding MeHg concentration in the water column that is in equilibrium with the MeHg dissolved in flooded soil porewater. As described in Calder et al. (2016), the underlying relationship between soil organic carbon and soil MeHg is based on peak post-flooding levels.

"The key premise of the Calder et al. (2016) paper is that the MFR is capable of generating and sustaining a flux rate [sic] of 664 $ng/m^2/d$ of MeHg, requiring a sustained load over a period of

up to 10 years to achieve this new 'steady state equilibrium' (Calder et al. 2016) in biota of Lake Melville." (p. 8)

- This is false, and this quote does not appear in Calder et al. (2016). The peak flux is modeled as an instantaneous equilibrium between flooded soils and the overlying water column. The assumption implicit in this approach is that the timescale of changes in MeHg concentrations in soil and water column after flooding (on the order of years) is long relative to the timescale of equilibration between soil and water. Kelly et al. (1997) noted that water column MeHg equilibrates "almost immediately" with MeHg in flooded soils in an experimental reservoir. This is true also in full-scale reservoirs where net fluxes are greater due to large-scale erosional processes (Mucci et al. 1995). The timescale of MeHg peaks in top trophic levels can be as short as 2 years (Bodaly et al. 2007). Available evidence suggests that even when the timescale of peaks in fish substantially exceeds the timescale of peaks in water column MeHg, the magnitude of the peak is not diminished and is indeed amplified, possibly due to food web effects, as described below.

"For this magnitude of change to occur, especially in higher trophic levels, the flux rate [sic] of dissolved MeHg from the sediment to surface water of the Lower Churchill River (LCR) and Lake Melville must be sustained for a period of many years. In reservoirs, this has been well documented, where peak fish MeHg concentrations are realized between 6 and 10 years after inundation (Schetagne et al. 2003, Bodaly et al., 2007 and others)." (p. 3)

- This is false and not supported by the references cited. In the South Indian reservoir, Manitoba, piscivorous (high trophic level) walleye Hg levels peaked within two years (Bodaly et al. 2007). The lag between flooding and peak biotic Hg levels is a function of site-specific food web effects, with higher trophic level species manifesting peak Hg levels generally later than lower trophic level species. For instance, in the La Grande complex, Quebec, Hg levels in non-piscivorous and piscivorous species peaked within four to 11 and nine to 14 years respectively (Schetagne and Therrien 2013). Meanwhile, it is known from extensive field study that water column MeHg values peak within the first three years of flooding (St. Louis et al. 2004; Hall et al. 2005). Crucially, ***the ratio between peak post-flooding and baseline Hg levels tends to be positively correlated with trophic level***. For example, in the Robert-Bourassa reservoir, lake whitefish Hg concentrations increased by a factor of 4.2 while northern pike Hg concentrations increased by a factor of 5.4 ***even though the peak in northern pike occurred six years after the peak in lake whitefish*** (Schetagne and Therrien 2013). Empirical data suggests that considering a common peak increase factor is more likely to underestimate rather than overestimate impacts on top trophic level species.

  Calder et al. (2016) use MeHg bioaccumulation factors measured at baseline and apply these to calculate post-flooding MeHg levels in downstream biota. Waters downstream of rivers receive (1) disproportionately high-MeHg bottom waters from stratified reservoirs (Kasper et al. 2014) and (2) fish stunned and killed by hydroelectric turbines, ingested preferentially by semi-piscivorous fish, increasing the magnitude of biomagnification of MeHg relative to baseline (Brouard et al. 1994). For instance, lake whitefish downstream from the Robert-Bourassa reservoir were found to have fish Hg concentrations more than

five times higher than in the reservoir itself (Brouard et al. 1994). Because the approach of Calder et al. (2016) does not account for likely increases in bioaccumulation factors triggered by impacts on the structure of local food webs, this approach is more likely to underestimate rather than overestimate peak biotic MeHg levels relative to peak water column MeHg levels.

"However, it is important to note that a portion of the MeHg delivered to the estuary is eventually dispersed to all marine biota of Lake Melville; you can't cherry pick where it will end up. As well, another and perhaps very large portion will be demethylated, sequestered by particles or be lost in tidal exchange. These factors were not quantitatively addressed by Calder et al. and we do not address them either." (p. 3)

- These loss mechanisms were indeed quantitatively addressed by Calder et al. (2016) based on the Hg budget first reported by Schartup et al. (2015) as described extensively in the main text and supporting information of the publication. Peak food web MeHg impacts are modeled with baseline measured bioaccumulation factors. This may underestimate the biotic peak relative to the water column peak as described above.

"This Hg methylation process is especially important during early stages of reservoir creation, when MeHg is initially present at much higher concentrations in porewater than overlying surface water and is the mechanism driving MeHg flux. This process diminishes over time as carbon as the fuel source, becomes exhausted (Kelly et al. 1997, Ravichandran 2004, Hall et al. 2005)." (p. 4)

- The references cited directly contradict the claim that carbon limits the total amount of MeHg produced in flooded reservoirs. ***Kelly et al. (1997) specifically notes that carbon supply in the experimental wetland studied could sustain the rate of microbial decomposition observed for 2,000 years***. Hall et al. (2005) report post-flooding MeHg concentrations roughly seven orders of magnitude lower than soil organic carbon stores. The most widely agreed limiting factor on Hg methylation in flooded soils is the supply of sulfates for microbial respiration and binding of Hg, while the availability of sulfides is in turn a function of overall carbon availability (Harmon et al. 2004; Hall et al. 2005; Jeremiason et al. 2006; Coleman Wasik et al. 2012). Ravichandran (2004) describes how production and bioavailability of MeHg depends on the presence of dissolved organic matter (DOM), commenting that "binding of mercury to DOM under natural conditions is controlled by a small fraction of DOM molecules containing reactive thiol functional groups" and that "several studies have concluded that mercury speciation in anoxic environments is controlled by sulfide and not by DOC".

"Water pH was circum-neutral year-round (7.0 in winter, 7.14 in summer). Much research confirms that lower pH (≤ 6.5) is positively correlated with Hg methylation potential (Miskimmin et al. 1992, Branfierun [sic] et al. 1999, Kelly et al. 2003). Water pH of the LCR is not associated with strong methylating conditions." (p. 5)

- The observation of relatively high pH in the lower Churchill River is not evidence that post-flooding MeHg impacts on biota will be lower than forecasted and may in fact suggest the opposite. The references cited by Azimuth argue that negative correlation

between pH and Hg uptake and net methylation rates may explain observations that fish Hg levels tend to be higher in acid-stressed natural lakes (Rodgers et al. 1987). ***It is however widely known that increased DOC concentrations from decomposing vegetation usually cause pH in flooded reservoirs to drop, thus enhancing methylation and uptake rates relative to baseline (Mailman et al. 2006)***. Because Calder et al. (2016) used baseline bioaccumulation factors (i.e., not accounting for stimulated uptake induced by a fall in pH), this presents another mechanism by which peak biotic impacts may be greater than forecasted. Furthermore, if relatively high pH at baseline implies relatively low baseline fish Hg values, then a given flux of MeHg from flooded sediments would have a greater impact on biota in previously high-pH environments than low-pH environments where the baseline biotic Hg levels are higher. Indeed, lower than expected environmental MeHg values at Muskrat Falls contributed significantly to early underestimates of the expected increases in fish Hg (Harris et al. 2010; Schartup et al. 2015). Finally, the association between pH and net methylation is confounded by sulfate decomposition, itself a function of many variables, explaining the inconsistency of these associations across environments (French et al. 1999).

"The above figure also supports this, as only 1 – 4% of inorganic Hg is present in the methyl form." (p. 11)

- This figure is reproduced from Kainz et al. (2003) which studies Hg and MeHg in the sediments of Lake Lusignan, Quebec. While the fraction of Hg as MeHg is usually small in natural sediments, it is much larger in flooded soils***. For example, St. Louis et al. (2004) reported that the fraction of soil Hg as MeHg increased from 5–10% to up to 80% after experimental flooding. Hall et al. (2005) report MeHg yields ranging from 22% to 84% THg yields. Kelly et al. (1997) reported that flooding caused the fraction of water column Hg as MeHg to increase from 4% to up to 73%.*** Even in unflooded, natural wetlands, fraction of soil Hg as MeHg up to 70% have been reported (Selvendiran et al. 2008).

"The studies that have examined this are categorical however, suggesting a small (≤5%) loss of Hg over at least a decade. Grondin et al. (1995) examined Hg profiles in flooded podzols in unflooded lakes and at La-Grande 2 Reservoir in Quebec 13 years after flooding. Both lakes and LG-2 had similar lead (Pb) and Hg profiles that were uniform over the entire depth of the core, with 'average concentrations of C and Hg, comparable to those in pristine podzols.' Following impoundment, Grondin et al. (1995) stated that Hg burdens of flooded wetland soils remain almost intact and that "in the case of flooded peat soils, no significant physical changes in the Hg and Pb profiles could be detected following inundation." They concluded that 'Upon inundation, soils in reservoirs support intense bacterial activity ... redistribution of nutrients, the production of CH4 and CO2 and the methylation of Hg... If direct release of Hg from flooded soils occurs, it is not evidenced by a marked decrease in the initial burden of Hg in the organic horizon. This study suggests that the initial reserves of Hg in the LG-2 reservoir have been only slightly depleted after 11 to 13 years of impoundment'." (p. 11)

- This is an incomplete and misleading summary of Grondin et al. (1995) who concluded not that there was little transfer of Hg from flooded soils to the water column but that this transfer is heterogeneous. For instance, they also find that: "Significant losses in organic

C, Hg, and Pb burdens are indeed revealed by data for the flooded podzol from station 92-24 (Table 3). In addition, *Cladina sp.* flooded podzols are an ideal habitat for burrowing insect larvae, which may be important vectors for the transfer of Hg to higher levels of the food chain". ***They do not conclude that Hg in flooded soils is permanently sequestered but rather that zones of low Hg flux may prolong the duration of impacts:*** "This study suggests that the initial reserves of Hg in the LG-2 reservoir have been only slightly depleted after 11 to 13 years of impoundment. The potential for contamination of aquatic organisms living in the reservoir could therefore remain high for a considerable length of time."

This line of reasoning is consistent with other authors who have concluded that physical transport processes (e.g., erosion, shear-mediated turbulent diffusion) are likely important mechanisms in the vertical flux of MeHg from soil to the water column in full-scale reservoirs (Louchouarn et al. 1993; Mucci et al. 1995). ***Regardless, a flux representing even a small fraction of the soil MeHg pool can represent a large change as a fraction of baseline water column MeHg concentration.*** For instance, peak water column MeHg reported by Hall et al. (2005) reflected a roughly ten-fold increase relative to baseline (Medium-C reservoir, Year 2) while 89% of MeHg remained in the flooded soils (Table 8, p. 261).

"Mucci et al. (1995) reported a similar result from LG-2. They found that organic carbon and nitrogen content of flooded soils remained high even after 14 years of impoundment, possibly because microbial degradation of terrestrial organic matter is slow at northern latitudes. They also concluded that 'the organic horizon of submerged soil, unaffected by erosion, remains enriched in Hg, indicating that chemical remobilization of the metal to the overlying waters does not deplete its Hg burden significantly'." (p. 11)

- This is an incomplete and misleading summary of Mucci et al. (1995) whose main point was to demonstrate the importance of mechanical erosion for overall fluxes of MeHg to the water column. ***They conclude that erosional events mobilize >70% of MeHg from flooded soils where it equilibrates with particulate matter at the sediment-water interface.*** Regardless, as above, this point conflates MeHg fluxes as a fraction of the pool in sediment with the fraction in the water column.

"In summary, MeHg generated within the top 0 – 3 cm of flooded soils is most vulnerable to being fluxed from the sediment to the overlying water column, where it is available to be accumulated by biota. While Hg methylation may occur at deeper depths in flooded soils, it appears that most of the MeHg is sequestered and/or demethylated there and does not appear to migrate to the surface. Furthermore, a limited proportion (likely ≤5%) of the mass of inorganic mercury in organic soils within the top few cm is methylated, fluxed to surface or upper porewaters and absorbed into the aquatic food web and/or transported downstream. This has clear and important implications regarding the mass of inorganic Hg that is ultimately available and accumulated by biota as MeHg." (p. 12)

- Overall, this is false. This vastly underestimates the likely fraction of Hg that is available for methylation, misrepresents the literature on the magnitude of fluxes from flooded soils to the water column and conflates the magnitude of changes of MeHg pools in

flooded soils with the impact of MeHg concentrations in overlying waters. Each of these points is described in greater detail above.

3. Canadian Reservoirs Comparison Matrix

Azimuth developed a "Canadian Reservoirs Comparison Matrix" (CRCM) that aims to classify reservoirs according to magnitude of post-flooding methylmercury (MeHg) impacts using available physicochemical reservoir characteristics (Azimuth 2012). The CRCM assembles pre- and post-development physicochemical data from 15 hydroelectric and experimental reservoirs and compares these predictor variables to the realized MeHg impact across sites. For instance, Azimuth observes that reservoirs with greater MeHg impacts tend to have greater flooded area, hydraulic residence time and carbon content than sites with lesser MeHg impacts. These correlations are indeed well known (Jackson 1991; Harris et al. 2010; Calder et al. 2016). The CRCM enumerates observations about the typical values of these and other variables for projects according to whether observed Hg impacts in fish fall above or below a cutoff for "high magnitude increase", which the authors have chosen for qualitative reasons to be three times baseline values.

The utility of the CRCM as a predictive tool is very limited because the ability of variations in predictor variables (e.g., flooded area, pH) to explain variations in fish Hg levels is not described. For instance, Azimuth reports that all sites in the CRCM where fish Hg increased by more than three-fold relative to baseline, pH < 6.5 and concludes that pH ≥ 6.5 is therefore indicative of low potential for Hg increases in fish. However, the only pH < 6.5 reservoirs where it is possible to calculate post-flooding fish Hg also differ from other inventoried reservoirs in terms of flooded area which is many times greater among pH < 6.5 reservoirs than others. It is therefore not possible at a statistical level to isolate the role of pH in the role of fish Hg increases from the role of flooded area. These statistical limitations are exacerbated by a lack of mechanistic reasoning. It is difficult to distinguish between observed trends with plausible causal associations and confounded or chance correlations. For instance, it is unlikely that Hg levels in aquatic food webs in high-pH waters will have a smaller response than food webs in low-pH waters for reasons described above.

Formal statistical analysis is required to develop a model that can plausibly use correlations from past sites to predict impacts elsewhere. For instance, Harris and Hutchinson (2008) applied statistical relationships from the literature (e.g., Johnston et al. 1991) to forecast the potential for Hg impacts at Muskrat Falls using data that was available at the time. These relationships use some of the variables identified as meaningful by the CRCM and apply mechanistic reasoning to determine the appropriate functional form of regression equations. They calculated peak post-flooding Hg levels up to five times baseline concentrations. This analysis is however limited by a lack of baseline data and differences in soil organic carbon between Muskrat Falls and the sites for which the statistical relationships was derived and has been superseded by modeling with a more explicit mechanistic basis (e.g., Harris et al. 2010; Calder et al. 2016).

"It is worth noting that among the 15 Canadian reservoirs examined by Calder et al., as being planned or under construction, they also placed Site C into the lowest increase category among all reservoirs examined, based on a forecast [sic] peak water MeHg concentration of 0.04 ng/L. Their forecast [sic] peak MeHg concentration at MFR is 0.19 ng/L, nearly 5x higher than at Site

C. There is no rationale presented for this large difference in water concentration – and by extension, the much higher peak fish Hg concentration forecast at MFR." (p. 8)

- This is false. MeHg forecasts at Site C (and other reservoirs in the cross-Canada analysis) in Calder et al. (2016) are based on site-specific organic carbon, flooded area and flow rate, with other parameters based on measurements at Muskrat Falls as described extensively in the publication.

"The data from MFR, weighed by the CRCM clearly place this reservoir into the same low increase category as Site C. In light of this, we see no reason to place MFR and Site C on the opposite ends of the spectrum of possibilities." (p. 8)

- The reader is referred to Calder et al. (2016) for a description of the mechanisms responsible for the magnitude of post-flooding water column MeHg increases and the differences between Site C and Muskrat Falls.

"Site C fell into the category of 'low methylating', defined as <3x increase in peak fish Hg relative to baseline. When the same key parameters from MFR are plugged into the CRCM, the two reservoirs overlap nearly completely. Given their great similarity, Calder et al. do not provide sufficient justification to place them at opposite ends of the spectrum of possibilities, especially as Calder et al. agreed with the findings related to the Site C project." (p. 1)

- This line of reasoning represents the forecast of Calder et al. (2016) for Site C as evidence in support of the CRCM and the forecast of the CRCM for Muskrat Falls as evidence against Calder et al. (2016). This is internally inconsistent. The observation that the CRCM and Calder et al. (2016) align for Site C but diverge for Muskrat Falls is neither evidence (1) in support of the CRCM nor (2) against Calder et al. (2016).

4. Mass balance calculations

The evaluation by Azimuth of the soil Hg budget implied by Calder et al. (2016) is based on the flawed premise that peak instantaneous equilibrium fluxes forecasted by Calder et al. (2016) are sustained over ten years. It is well known that the timescale of increases in top-trophic level species can be substantially shorter (e.g., 2 years) and that even when they are longer (e.g., 11–14 years, exceeding the documented duration of peak fluxes from soil), increased biomagnification through the food web usually amplifies the magnitude of impacts at higher trophic levels. These considerations are described above. As described extensively in Calder et al. (2016), forecasted MeHg levels in soils, the water column and fluxes between these compartments are within the range of reports by other authors.

Azimuth's estimate of the mass of MeHg available to biota is based on the flawed premise that 5% of soil Hg can be methylated in reservoirs (see above). ***If this is increased to 84% (Hall et al. 2005), the available mass of MeHg increases from 2.25 kg to 37.8 kg.*** Azimuth's estimate of the mass of MeHg required for impacts forecasted at Lake Melville is based on the premise that impacts accrue at lowest and highest trophic levels simultaneously. For instance, Azimuth uniquely count MeHg in echinoderms (accounting for 41% of all biomass in the system and occupying trophic level 2 in this analysis) and MeHg in seals (trophic level 4.36). This may be

the case if the timescale of peak impacts is short relative to peak fluxes from soils but if it is longer, e.g., ≥10 years considered by Azimuth, then MeHg biomagnification across trophic levels is likely to be important for overall mass balance (e.g., Bodaly et al. 2007; Schetagne and Therrien 2013).

Azimuth estimates the mass of MeHg required to achieve the impacts forecasted by Calder et al. (2016) according to the expression $\Sigma_i m_i(c_{i2} - c_{i1})$ where m is biomass, c_1 and c_2 are MeHg concentrations at present-day and after flooding respectively and i is biotic category or species where $i \in \{1, \ldots, 28\}$. This model for biotic MeHg mass increase therefore has 84 unique parameters, each subject to considerable uncertainty.

The mass of MeHg required to produce peak impacts (estimated by Azimuth at 31.1 kg) is therefore a linear function of total biomass for a given food web composition. Azimuth takes values for parameters m from Bundy et al. (2000), who modeled biomass off the Labrador Coast over the period 1985-87. Besides the fact that food web structure and relative composition is highly site-specific, ***Bundy et al. (2000) report that uncertainty in the biomass of certain lower trophic species accounting for roughly 60% of biomass in the system may be 75–100% of the reported values, noting that "neither model simulates these lowest trophic levels well."*** There is furthermore strong evidence that the Labrador Coast is much more productive than Lake Melville, meaning biomass is likely to be overestimated here even without taking into account uncertainties from initial values from the Labrador Coast. For example, ***Cardoso and deYoung (2002) report September chlorophyll-a levels of roughly 32 mg m^{-2} in Groswater Bay, at the outer edge of Lake Melville, as compared to 60.1 mg m^{-2} reported by Bundy et al. (2000). Because Bundy et al. (2000) relate biomass to chlorophyll linearly, this correction could, for instance, roughly halve Azimuth's estimates of MeHg mass required to sustain peak impacts from 31.1 kg to 16.9 kg,*** even allowing simultaneous MeHg impacts across trophic levels and without accounting for any of the uncertainties inherent in this analysis. This value is 43% of the total mass corrected for methylatable fraction of soil Hg.

Overall, uncertainties associated with the total biomass estimate are much greater. For instance, Azimuth presents a wide range of plausible values for biomass from various other temperate and Arctic marine ecosystems (57 to 3,786 t km^{-2}), each of which would present various similarities and differences with Lake Melville, and each of which is derived from analyses with different strengths and limitations. From these values, the possible range of values of MeHg mass required to sustain peak biotic impacts ranges from 17% to 1,141% of the maximum MeHg content of the soil as calculated by Azimuth (corrected for maximum methylatable fraction as above). There are further uncertainties associated with the relative composition of the food web for any given value of total biomass, which I will not address here.

Of the other 56 parameters describing pre- and post-flooding MeHg concentrations, 22 are based on measurements and forecasts presented by Schartup et al. (2015) or Calder et al. (2016) (11 biotic categories). According to Aziumuth's estimates, these biotic categories account for 33% of total biomass in Lake Melville. For the 17 biotic categories accounting for the remaining 67% of biomass, Azimuth estimates pre-flooding baseline MeHg concentrations (c_1) as a nonlinear function of trophic position $c_1 = f(TP)$. Azimuth reports an R^2 value of 0.81 for this relationship (81% of the variability in the response is explained by variability in the predictor) for its model, but this value is wrong. $R^2 = 0.81$ corresponds to a linear regression performed on their predicted

model, f(TP). In this case, $R^2 < 1$ only because the model they retained is nonlinear. Therefore, this value is meaningless and misleading. ***If the 11 modeled values from f(TP) are plotted against the values reported by Schartup et al. (2015) or Calder et al. (2016), the R^2 value is 0.55, meaning just over half the variability in the measured data can be explained by the model retained*** (see Fig. 1). Therefore, these values are subject to their own large uncertainties independent of biomass. These uncertainties have been mischaracterized. Azimuth estimates 17 post-flooding values for biotic MeHg according to $c_2 = c_1 * 2.65$, propagating forward the uncertainties in baseline MeHg content (c_1).

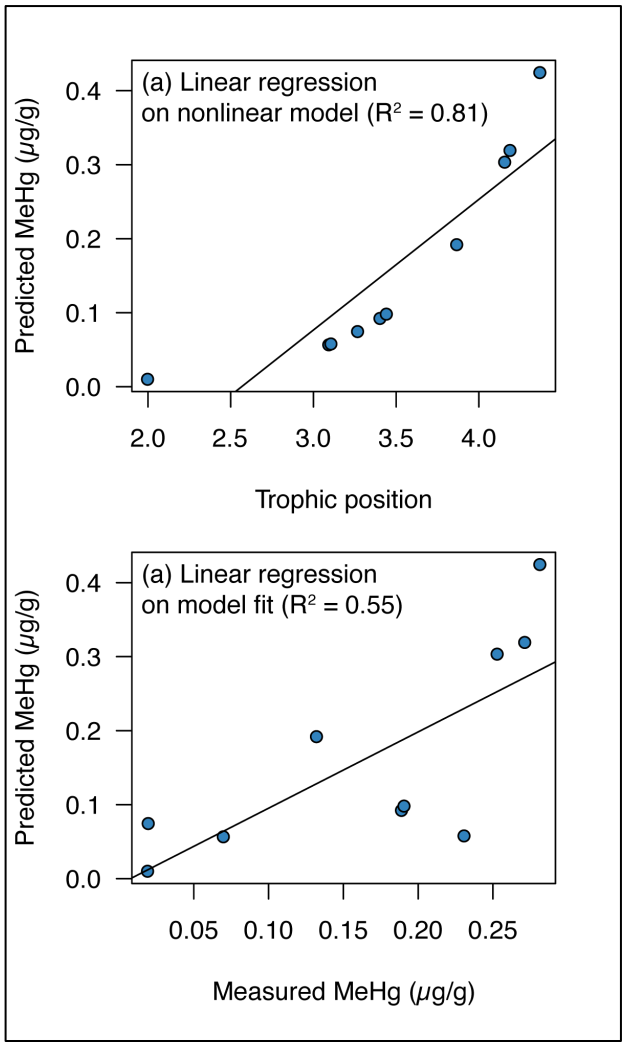

Fig. 1: Model performance reported by Azimuth vs. actual model performance for prediction of biotic MeHg.

The estimate of MeHg mass required to sustain impacts forecasted by Calder et al. (2016), expressed as $\Sigma_i m_i(c_{i2} - c_{i1})$, is therefore highly suspect. Plausible values for m vary by several orders of magnitude, and there is evidence that the values retained are overestimates. For nearly 70% of the biomass, the difference term $(c_2 - c_1)$ reduces to $1.65c_1$, and c_1 could plausibly vary by ± 50% for each trophic category producing a very wide range of possible cumulative error across the 17 biotic categories for which this analysis was done.

When combined with the other limitations, misrepresentations and errors in analysis outlined above, in my opinion, this work produces no usable information.

"Based on a 5% conversion rate of Hg, a total mass of 2.25 kg of MeHg can be generated by MFR for a period of up to 10 years. Thus, no greater mass than this is ultimately available to the MFR and downstream environment of Goose Bay and Lake Melville. It is also important to note that delivery of this total mass is amortized over a period of at least 5 and possibly 10 years, with higher rates in the first 2-3 years than afterwards (Hall et al. 2005 and others). Thus, the probable maximum annual mass of MeHg delivered to the food web is no more than 0.5 kg/y." (p. 13)

- This calculation is based among other things on the incorrect assumptions that < 5% of Hg is available for methylation and that peak fluxes must be sustained for 10 years. The peak post-flooding soil MeHg concentration forecasted by Calder et al. (2016) is 10.4 ng g^{-1} averaged over 30 cm. At 41 km^2, a soil bulk density of 0.54 g cm^{-3} (Périé and Ouimet 2008), this corresponds to 0.7 kg. (A lower averaging depth, e.g., 8 cm, would decrease

the volume of the soil over which this is calculated but also increase the average soil MeHg since peak MeHg is negatively correlated with depth.) The expected mean of peak reservoir water column MeHg is forecasted to be 0.19 ng L^{-1}. At 41 km^2 and a mean water surface elevation of 16.8 m (Nalcor Energy 2009), this corresponds to 0.1 kg. The fraction of MeHg retained in soils as a fraction of overall mass of MeHg in the system is within the range reported by Hall et al. (2005) (78–97%).

"Calder et al. (2016) assumed a sustained annual flux rate of 664 ng/m^2 over the entire 41 km^2 of flooded terrestrial terrain. This amounts to 10.5 kg of MeHg annually." (p. 13)

- This is incorrect. As described throughout the text, this flux is the peak required to equilibrate peak soil MeHg with the overlying water column. It is not expected to be sustained on the order of ten years.

"Although the model is for the continental shelf, rather than a nearly enclosed estuarine embayment like Lake Melville, the latter is acknowledged to support a notably high productivity and species diversity (Schartup et al. 2016, Durkalec et al. 2016). Thus, the biomass estimate derived from the Ecopath model for the Labrador shelf, is considered a reasonable but conservative (i.e., low) estimate for Lake Melville." (p. 13)

- The qualitative observations cited here say nothing about the relative productivity of Lake Melville vs. the outer Labrador Coast. Evidence from chlorophyll-a, which is used by Bundy et al. (2000) to estimate biomass, suggests that Lake Melville is less productive. In either case, the range of plausible values is very large.

"Finally, the scientific literature suggests that much of the MeHg produced by the MFR and released to water, may not end up in biota. There are many partitioning mechanisms by which MeHg will be scavenged from water by a variety of processes after it leaves the reservoir, as spreads across Lake Melville. Much will be demethylated, adsorbed to sediment particles, DOC, or leave Lake Melville through tidal exchange. Although these processes are important, aside from acknowledging some demethylation, Calder et al. did not qualitatively address them." (p. 15)

- This is a complete mischaracterization of Calder et al. (2016), which conservatively measured peak biotic MeHg as a function of directly measured bioaccumulation factors between biota and water column MeHg, and which characterized post-flooding water column MeHg as the net process of production and loss processes measured at baseline and expressed probabilistically.

"When viewed from a top-down, mass-balance perspective, the assumptions and findings of Calder et al. (2016) are not supported." (p. 15)

- Given the limitations and errors in this analysis, I disagree with this assessment.

"While we are not saying 'no change will occur' in Lake Melville, the evidence presented here strongly suggests that if any increase in MeHg burden were to occur, it would be extremely small and probably difficult to measure, given the lack of a strong pre-flood, baseline dataset of MeHg

in lower trophic level biota in Lake Melville, where changes would be first observed (Hall et al. 1997)." (p. 15)

- The lack of data referenced here directly contributes to the unreliability of the calculations by Azimuth.

"Given the clear and unambiguous nature of our findings means that there is an urgent need to clarify the message to resource users and other residents of the local communities, that biota in Lake Melville will not be contaminated with MeHg generated by the MFR." (p. 16)

- In my opinion, decision-makers have been presented with clear evidence from a variety of analyses developed over many years that suggest that there will be material impacts on Hg levels in local wildlife but that that the magnitude of these impacts is uncertain. Given the limitations, misrepresentations and mistakes in the Azimuth analysis, I do not believe it contributes materially to the ongoing discussion about the range of impacts of benefits of mitigation measures.

5. References

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