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Technical Memorandum

Date: **July 31, 2017**
To: **Peter Madden, Nalcor Energy**
From: **Randy Baker**
Our File: **NE 16-01**

RE: **Relationship Between Muskrat Falls Reservoir Elevation and Mercury Concentrations in Downstream Water – May 2017**

Scope of Work and Assumptions

Azimuth Consulting Group Partnership (Azimuth) has been asked to provide an opinion on the relationship between water level elevation within the Muskrat Falls Reservoir, Labrador and key downstream water quality parameters, with a focus on mercury. The temporal period of this memo is from late December 2016 to present, when water level in the reservoir has been sustained above its long-term historic baseline elevation. We would like to point out that the discussion of 'mercury' relates to both total and dissolved 'total' mercury, which includes total and dissolved methylmercury concentrations (in parts per trillion or ng/L). In addition, we address those parameters that may strongly influence water column mercury and methylmercury concentrations, particularly total suspended solids (TSS) and total organic carbon (TOC) concentrations (mg/L).

Base or natural elevation of the Lower Churchill River at Muskrat Falls dam site is approximately 17 m above sea level (asl); full supply elevation is 39 m asl. Total reservoir area at full supply is 101 km^2, of which 56.9 km^2 (57%) is original river area and 6.9 km^2 is gravel bar. An additional 6.5 km^2 is classified as 'riparian habitat' that is periodically inundated, but has a very thin organic layer (AMEC 2017a). Excluding riparian habitat, approximately 64 km^2 (6382 ha) or 64% of the total area forecast for inundation consists or riverine habitat that will not supply a source of 'new' carbon that would be available for methylmercury generation. The flooded riparian zone represents

another 6% of the reservoir area with very low organic content, which will have a negligible contribution to overall methylation potential of the new reservoir.

In November 2016, water elevation was raised to 21.5 m asl behind the dam for a period of about one month, before being dropped back to baseline. Beginning in mid-February 2017, reservoir elevation was again raised to just over 21 m asl and has been sustained at this elevation (4.5 m above baseline or about 20% of full supply) until the present. The total area of the reservoir at this elevation is 6929 m, of which approximately 423 ha consists of flooded terrestrial and riparian habitat with well-developed humic soils (i.e., excluding gravel bars and riparian soils with negligible organics). This represents only a 6% increase in surface area of the river upstream of the dam site.

It is our understanding that there is concern regarding the potential for increased export of and/or generation of methylmercury downstream of the reservoir and extending to the estuary at Lake Melville. The intent of this memo is to examine water quality data of the system between the reservoir and Lake Melville, in relation to water level elevation changes and comment on mercury and methylmercury concentrations in water and likelihood of bioaccumulation by biota.

Quantitative Assessment

On March 21, 2017 Azimuth reviewed water quality data collected between October 2016 and February 2017, focusing on TSS, total mercury, total and dissolved methylmercury and total organic carbon (TOC) concentrations. As noted above, there was a temporary impoundment to 22 m elevation in November. This did not cause any changes to concentrations of unfiltered (i.e., total) mercury and methylmercury, 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). Methylmercury concentrations were low and confined within a narrow range around 0.02 ng/L on all occasions, including before and after the month-long period of inundation (Azimuth 2017).

Since mid-February (a period of 5 months), water level of the reservoir has been elevated and maintained at an average of 21.3 m asl – the same elevation as in November. Water quality data have been collected by AMEC approximately every week between upstream (N1), above and below the dam (N4, N5 respectively) and downstream at Goose Bay (N8), as well as from the estuary. On May 23, 2017, AMEC produced a short report summarizing water quality results for TSS and total and dissolved methylmercury for each of these stations, relative to water level elevation (AMEC 2017b). Chemistry data for these parameters between October 2016 and April 26, 2017 are documented and plotted in several key figures, which are reproduced here. Since this report was published, we have also received data for the May 2 event, which is discussed.

To understand the relevance of water-borne mercury data, it is worthwhile providing the following statements for context.

- Analysis of total mercury in water was by AGAT Laboratories (NL) with a detection limit (DL) of 1.9 ng/L. For perspective, many northern, pristine river and

lake systems typically have total mercury concentrations of around 1 – 5 ng/L, which is near the DL used here.

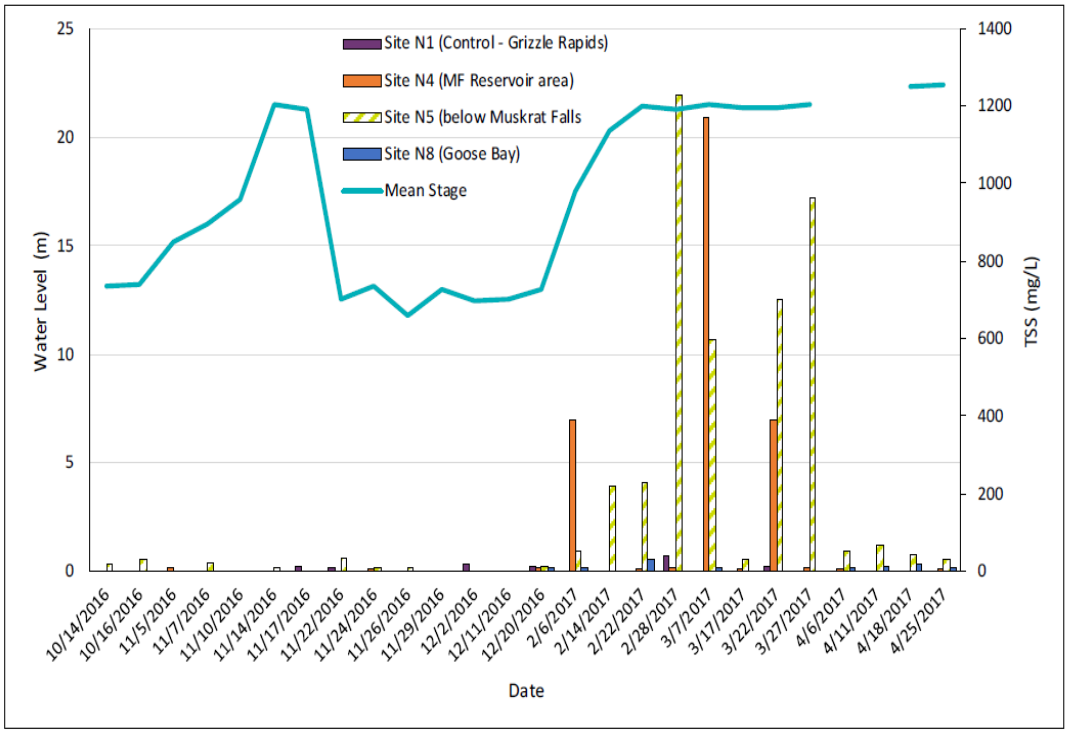
- Analysis of methylmercury was by Flett Research, a laboratory that specializes in low level detection of this parameter. Their methylmercury DL is 0.01 ng/L (parts per trillion), which is the lowest achievable DL of all commercial laboratories. For perspective, remote, pristine lakes and rivers have methylmercury concentrations that range from 0.04 to 0.8 ng/L (St. Louis et al. 1995, Hurley et al. 1995, Krabbenhoft et al. 1999, Bodaly et al. 2004 and others), which is up to 80x the Flett DL. The concentration of methylmercury as a fraction of the total mercury concentration is typically only 1 – 5%.
- In large riverine systems TSS concentrations can range widely from baseline levels of 2 – 5 mg/L into the hundreds of mg/L or higher, such as during freshet or erosional events. High TSS events can cause total mercury as well as many other metals (copper, arsenic, lead, zinc, etc.) to become elevated above baseline due to adsorption of metals onto suspended sediment particles. Metals and mercury bound to sediment particles are generally not 'available' being tightly bound to the particle. Typically, only a very small fraction occurs in the dissolved phase (usually <2 – 5%).
- Prior to inundation 'baseline' concentrations of methylmercury downstream in the estuarine / marine environment of Goose Bay and Lake Melville were measured by Harvard and summarized by Schartup et al. (2015). They recorded mean concentrations of methylmercury at 40 femtomolar (fM; 10^{-15} moles/L) in tributary streams, Goose Bay and Lake Melville during September 2012. Forty fM is equivalent to 0.008 ng/L, or just less than the Flett DL of 0.01 ng/L. Deep water, marine concentrations were much less than at surface.
- In June 2013, mean methylmercury concentrations were higher in streams (68 fM), Goose Bay (84 fM) and Lake Melville (91 fM), presumably reflecting the influence of freshet. These fM concentrations are equivalent to 0.014, 0.017 and 0.018 ng/L respectively, which are within the range of concentrations measured by Flett Research in the river and in the estuary of Lake Melville (AMEC 2017b).

Figure 1 below from AMEC (2017b) depicts the relationship between TSS concentration (mg/L) and water elevation (m asl) between mid-October and the end of April, 2017. TSS concentrations were routinely low (<5 mg/L) at all stations between upstream (N1) and the estuary (N8). The trend in concentrations depict pulses of elevated TSS in surface water at stations N4 and N5 that are clearly associated with damming of the river and presumably, due to erosion or slumping of riparian terrestrial soils.

TSS spiked to concentrations as high as 1,170 mg/L on 7 March as river elevation was raised and held at 21.3 m asl. High riverine concentrations are likely associated with sampling within erosional plumes running along and nearshore, rather than in fully mixed conditions within the middle of the river. Nevertheless, TSS concentrations of this magnitude should be expected to cause elevations in total mercury and other metals – but not necessarily large increases in dissolved concentrations of metals or mercury. However, as depicted at N8 in **Figure 1**, despite episodic elevations in TSS

concentration within the river, TSS concentrations at Goose Bay remained near baseline and below the DL (<5 mg/L).

Figure 1. *Relationship between water level elevation and total suspended solids (TSS) at key stations.*



Water elevation data from October 14-November 18, and April has been provided by Environment Canada (Station Number 03OE015). Data post November 18 has been provided by Nalcor. Missing dates have been estimated based on data provided by Nalcor.

Table 1 below depicts measured weekly concentrations of key parameters during all episodes where TSS exceeded 50 mg/L, as well as more recent data beyond March 27, when TSS had more or less returned to near background. Key parameters include total and methylmercury (total and dissolved forms), TSS and TOC at stations N4, N5 and N8 at Goose Bay during period of inundation from early February until the most current available data (May 2).

Consistent with **Figure 1**, the pattern in TSS can be clearly observed with the general trend of diminishing concentrations from up- to downstream within each weekly collection event. Importantly, there is no change in TOC concentration – either spatially or over time. This suggests that the suspended material in the river consists of inorganic silts and clays and not terrestrial organic matter. Schartup et al. (2015) postulated that inundation would result in increased export of allochthonous material and dissolved organic carbon to the estuary where it could settle and/or be vulnerable to methylation in the mid-water column. These data indicate that this has not occurred at the elevation that the reservoir is currently being maintained at (~21 m) – likely because of the minor increase in surface area of the reservoir (6%) relative to baseline.

Table 1. *Temporal trend of total and dissolved methylmercury (MeHg) and total mercury concentration (ng/L), TOC and TSS at N4 (reservoir), N5 (downstream) and N8 (estuary).*

Sample Site	Sample Date	Parameter				
		Total MeHg (ng/L)	Dissolved MeHg (ng/L)	Total Mercury (ng/L)	TOC (mg/L)	TSS (mg/L)
N4	6-Feb-17	0.025	0.010	<1.9	4.7	389
N5	6-Feb-17	0.019	<MDL	<1.9	4.6	50
N8	7-Feb-17	0.013	0.010	3.5	4.6	<5
N5	15-Feb-17	0.038	0.010	<1.9	4.2	221
N8	15-Feb-17	0.012	0.010	<1.9	3.8	28
N4	22-Feb-17	0.021	0.010	<1.9	4.2	5
N5	22-Feb-17	0.037	0.014	<1.9	3.9	227
N8	22-Feb-17	0.010	0.011	3.4	3.9	9
N4	7-Mar-17	0.14	0.016	4.9	3.4	1170
N5	7-Mar-17	0.064	0.011	<1.9	3.3	594
N8	8-Mar-17	0.014	<MDL	3.1	4	<5
N4	22-Mar-17	0.021	0.011	<1.9	3.1	388
N5	22-Mar-17	0.083	0.010	<1.9	3.2	700
N8	23-Mar-17	0.010	0.010	<1.9	3.8	<5
N4	27-Mar-17	0.010	0.013	<1.9	3.1	9
N5	27-Mar-17	0.185	0.012	<1.9	3.9	962
N8	27-Mar-17	<MDL	0.010	<1.9	3.7	<5
N4	11-Apr-17	0.076	0.040	<1.9	4.2	<5
N5	11-Apr-17	0.037	0.020	<1.9	3.4	67
N8	12-Apr-17	0.010	<MDL	<1.9	4.4	11
N4	25-Apr-17	0.027	0.010	<1.9	3.5	4
N5	25-Apr-17	0.024	0.010	<1.9	2.8	28
N8	26-Apr-17	0.016	0.012	<1.9	4.2	7
N4	2-May-17	0.012	0.010	<1.9	4.5	5
N5	2-May-17	0.017	0.010	<1.9	3.5	10
N8	2-May-17	0.010	0.013	<1.9	4.4	<3

The next two figures depict relationships between total (**Figure 2**) and dissolved methylmercury (**Figure 3**) concentrations relative to water level elevation, from October 2016 to April, 2017 at N4, N5 and at Goose Bay (AMEC 2017b). Recall that the Flett DL for methylmercury is 0.01 ng/L.

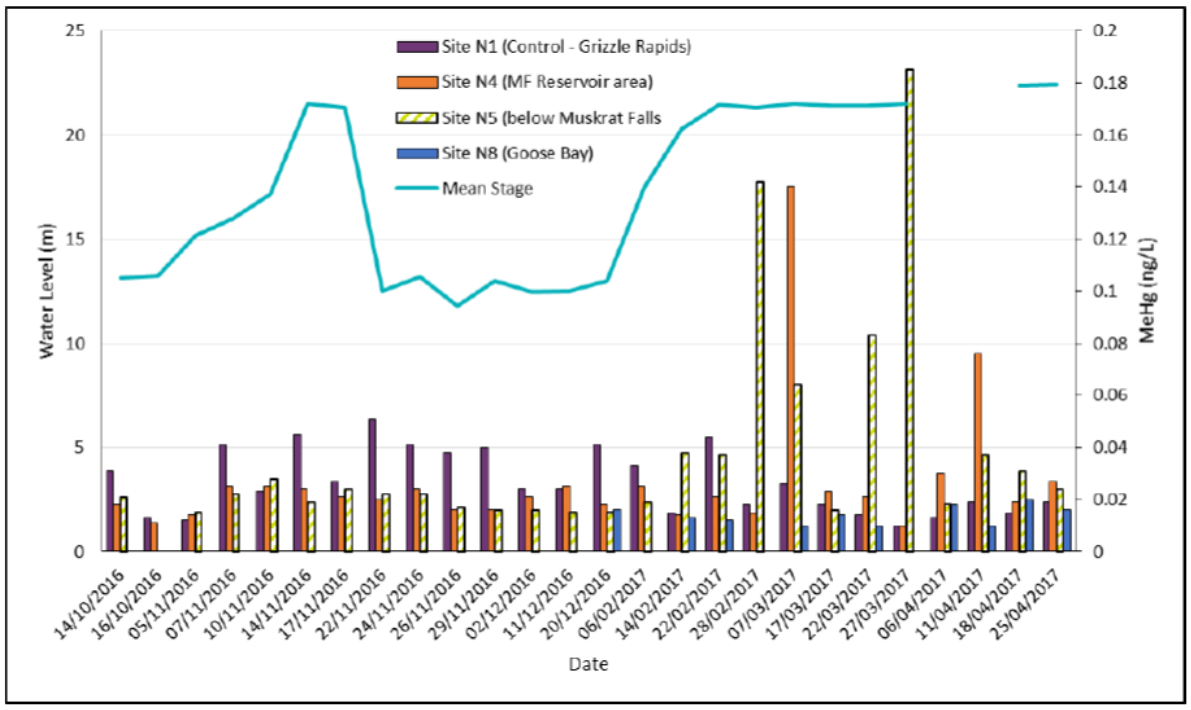


Figure 2. *Relationship between water level elevation and methylmercury concentration (ng/L) at key stations.*

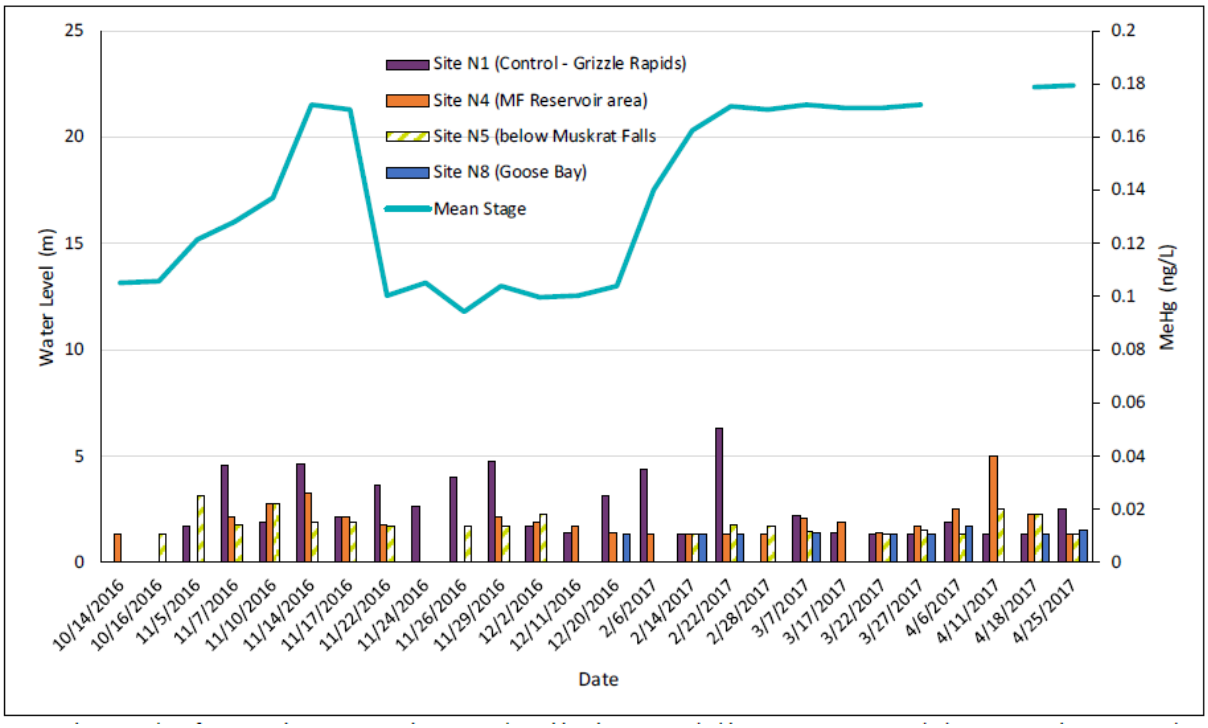


Figure 3. *Relationship between water level elevation and dissolved methylmercury concentration (ng/L) at key stations.*

Concentrations of total methylmercury (i.e., particulate bound and dissolved) ranged from the DL of 0.01 ng/L to 0.025 ng/L during periods of non-impoundment at N4 and N5, with concentrations routinely up to 0.04 ng/L at the upstream (reference) location N1. The concentration of dissolved methylmercury was at or just above the DL, comprising about 80% of the total.

Since mid-February when water levels increased behind the dam, total methylmercury concentrations increased at N4 and/or N5 between 0.06 and 0.18 ng/L with a peak on March 27, coinciding with elevated TSS values on the same date. Despite increases in total methylmercury (**Figure 2**), there was no change in dissolved methylmercury concentration at any station (**Figure 3**), indicating that the increase was associated with suspended particles in the water column to which the methylmercury was adhered. Dissolved methylmercury concentrations continue to be higher at the upstream reference station (N1) than downstream.

Since late March, total methylmercury concentrations appear to have returned to baseline concentrations (0.01 – 0.02 ng/L) (**Table 1**). In addition, although not depicted in **Figures 2** and **3**, total mercury concentration in the river and estuary are consistently below the AGAT DL (1.9 ng/L), even during high TSS events. The concentrations of total and methylmercury are very low – even at peak levels, are well within the range commonly found in pristine waters (Bodaly et al. 2004, Krabbenhoft et al. 2007) and unchanged from values reported by Schartup et al. (2004).

Summary

In summary, impoundment of the Lower Churchill River to a sustained elevation of 21.3 m asl, caused brief, episodic increases in TSS concentrations in the river for a period of about six weeks. Despite elevated TSS concentrations at N4 and N5, TSS at Goose Bay has remained near baseline during all monitoring events. While elevated TSS caused an increase in total methylmercury concentration (but not dissolved) in the river, these concentrations are still within the range of what is found in pristine systems. Furthermore, there was no evidence of elevated total or dissolved methylmercury at Goose Bay (N8) in relation to TSS, or water elevation changes within the reservoir.

Finally, total mercury and total organic carbon (particulate bound or dissolved) concentrations remained low and are similar to baseline values, both within the river and at the estuary, with no influence related to TSS or water elevation changes.

Stability in key water quality parameters is likely due to the relatively low amount of flooding of terrestrial habitat (6% increase in surface area from baseline) and lack of organic material transported downstream. Absence of changes to total and methylmercury concentrations downstream in Goose Bay relative to baseline suggests that no changes to biota methylmercury concentrations should be expected.

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