Final Draft

Expert Review of
Brian A. Branfireun, PhD

Of the NorthMet Mining Project and Land Exchange Final Environmental Impact Statement

Prepared for:

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Brian Branfireun at London Ontario Canada, December 2, 2015

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1 Introduction

My name is Brian A. Branfireun, and I am a full-time Professor in the Department of Biology, and Canada Research Chair in Environment and Sustainability at the University of Western Ontario in London, Ontario, Canada. In this role, I manage a university research program, and serve as the Director of an analytical facility that specializes in the ultra-trace (part-per-trillion/quadrillion) detection of mercury species in air, water, soil, sediment and biological materials. On October 28, 2013 I was contacted by Paula Maccabee, Counsel and Advocacy Director for WaterLegacy to form an opinion on the NorthMet Mining Project and Land Exchange Supplemental Draft Environmental Impact Statement (henceforth, SDEIS) with specific attention to the adequacy of the SDEIS in documenting potential impacts of the NorthMet project on the changes to the environmental methylation of mercury through either hydrological or chemical modifications/impacts. I provided this opinion in final form on March 10, 2014. Since that time, I have reviewed the PolyMet Preliminary Final Environmental Impact Statement (henceforth PFEIS), a document that was revised to incorporate some public and stakeholder comment and other technical supporting documents, and portions of the PolyMet Final Environmental Impact Statement (FEIS) pertinent to my opinions. I was asked to determine whether or not the FEIS adequately addressed shortcomings raised in in my 2014 opinion, and if any additional thoughts or concerns arose from my review of these additional materials and recent research.

1.1 Qualifications

I received my PhD in Geography from McGill University, Montreal, Canada in 1999 with a specialization in hydrology, mercury biogeochemistry, and wetland science. I was subsequently employed as a Professor at the University of Toronto Mississauga campus in Mississauga Ontario, Canada for 10 years, establishing an internationally recognized research program on hydrology and mercury in the environment. In 2010, I was recruited by the University of Western Ontario and successfully nominated for a Canada Research Chair in Environment and Sustainability. The Canada Research Chairs program "stands at the centre of a national strategy to make Canada one of the world's top countries in research and development. In 2000, the Government of Canada created a permanent program to establish 2000 research professorships—Canada Research Chairs—in eligible degree-granting institutions across the country." (http://www.chairs-chaires.gc.ca/home-accueil-eng.aspx). My research Chair position was renewed in 2015. I am considered an internationally recognized expert in the field of watershed hydrology, biogeochemistry and the environmental cycling of mercury. Details of my qualifications and experience are outlined in my Curriculum Vitae (Appendix 1 - CV).

1.2 Peer-Reviewed Publications

I have authored or co-authored 57 peer-reviewed scientific papers or volume chapters, and have made or contributed to significant discoveries concerning the role of wetlands on the production and export of methylmercury (e.g. Branfireun et al., 1996; 1998; 1999; 2001; 2005 and others) and urban systems as sources of mercury to surface waters (e.g. Eckley and Branfireun, 2009). I have been involved in high-impact state-of-the-science publications that have provided significant direction to the mercury research community (Harris et al., 2007; Munthe et al., 2007). Details of my publications and other scholarly activities are outlined in my Curriculum Vitae (Appendix 1 - CV).

2 Comments Concerning Revisions and Additions to the FEIS

In the FEIS and related documents, there are revisions and additions that relate to opinions presented in my previous expert opinion regarding the SDEIS (see previous opinion in materials referred). I have reviewed my previously submitted opinion, the PFEIS, the PFEIS Appendix A that documents responses to comments on the SDEIS, pertinent portions of the FEIS, several PolyMet and Barr documents related to mercury, and other related documents. My prior opinions identified a range of issues that concerned background data, reporting of data, a failure to adequately consider hydrological and biogeochemical impacts on certain wetland types, an understatement of the potential for mercury and sulfur discharges that would impair downstream waters and a failure to characterize or consider the known impact of hydrological changes in wetlands and sediments in the formation of methylmercury and the transport of methylmercury to downstream waters.

2.1 Previous Opinion 1 (SDEIS)

It is my opinion that the background site-specific analyses provided in the SDEIS concerning total mercury and methylmercury in surface and groundwater associated with, and potentially impacted by, the proposed NorthMet Mining Project are not sufficient to either adequately characterize the current mercury methylating environment, nor to evaluate the potential for impact due to changes in hydrology, water quality, or both, as a result of the proposed project.

2.1.1 Lack of Background Data for Surface Waters

In my previous opinion (in section 4.1.1), I identified a lack of data on background methylmercury in the SDEIS specifically noting that in the SDEIS Section 4.2.2.1.4 Mercury (4-37) there was an overview of mercury in the Embarrass and Partridge Rivers, with little discussion of methylmercury. The SDEIS stated, in addition to total Mercury, that "Methylmercury concentrations in the Partridge River at SW-005 average 0.4 ng/L and in the Embarrass River average 0.5 ng/L at PM-12 and 0.4 ng/L at PM-13 over the same period." This was the only reference to methylmercury in natural surface waters that I located in the SDEIS, and Table 4.2.2-4 (4-41) that was referred to in this section did not present MeHg data (only THg).

Updated Mercury and Methylmercury: The FEIS addresses this deficiency by including the MeHg data for the two tributaries in tabular form. However, a close look at the data reveals questionable and inconsistent data as well as a high proportions of total mercury as methylmercury, indicative of a strongly methylating environment.

FEIS **Table 4.2.2-14** presents existing water quality concentrations in the Partridge River and also includes additional data points. Total Mercury shows that mercury was detected in approximately 70% of the samples. This alone is a surprising finding, calling into question the sampling, reporting, or analytical methodology. Applying the detection limit of 0.25 ng/L, it is highly unlikely that the Minnesota streams had no detectable mercury; in my decades of experience, even samples from remote northern locations rarely have mercury levels below this detection limit. Even with the questionable non-detect results, the maximum value of 18.5 ng/L of total mercury is quite elevated, with an increasing trend in mean concentrations moving downstream, with ~2x higher concentrations downstream than upstream. Methylmercury data (new in FEIS) has nearly all samples detected (93%) and an error in the range of concentrations reported (A maximum concentration of 560 ng/L is not environmentally possible here). This is a surprising error that would be unlikely if the mercury data had been carefully reviewed. Mean concentrations also increase in a downstream fashion.

FEIS **Table 4.2.2-32** presents updated average existing water quality in the Embarrass River. Despite being apparently reported from the same source (Barr 2014d), Mercury is reported with 28 of 34 samples detected, and a reported lower limit of <1 ng/L, a detection limit inconsistent with that used for the Partridge River. The range of concentrations at PM-12 is indicated as "<1 to <10" which indicates no upper bound and makes no sense numerically, with a mean of 5.1 ng/L. There is only one other downstream station with mercury data reported (PM-13, mean= 4.3 ng/L). Methylmercury is reported for the two stations, in both cases with 13 of 13 samples detected, and mean concentrations of 0.53 and 0.38 ng/L with similar ranges).

Percentage Methylmercury: The percentage methylmercury of total mercury can be used as an indicator of the efficiency with which a sediment or landscape can methylate inorganic mercury. If we accept that the mean concentrations of both mercury species in this data reasonably reflect environmental conditions, then the percentage of total mercury that is methylmercury in the Partridge River increases from **2.2%** at SW-001 to **14.6%** at SW-004a and remains **~10%** at the last two stations. I consider any percentage over **3%** MeHg to be clear evidence of net methylmercury production in the watershed. For the Partridge River, these increasing and very high percentages of methylmercury at the downstream stations can only be attributable to significant sources of methylmercury to the River from the watershed contributing additions of methylmercury to surface waters. For the two stations on the Embarrass River, and accepting the mean concentrations, the percentages of methylmercury are **10.4%** and **8.8%** respectively, indicating that strong sources of MeHg are in the upstream locations as well as downstream.

Peer-reviewed literature has indicated that only watersheds characterized as "wetland and forest" have percent methylmercury of >10 in surface waters. As initially reported by Hurley et al.

(1995) with reference to Wisconsin watersheds that are analagous to those in Minnesota, when the fraction of total mercury that is methylmercury exceeds 10%, the source is likely wetlands. In the past 20 years, the attribution of wetlands as the source of this methylmercury in watersheds has been confirmed.

Additional data has also been added to other PolyMet data tables such as FEIS Table **4.2.2-15** (Partridge Tributaries) which updates mercury data with additonal samples, and increasing the reported maximum mercury concentration in water to 28.1 ng/L, a strikingly high maximum.

All of the tributaries show exceedences of the evaluation criteria for total mercury. Curiously, despite the additional data being added regarding total mercury from more recent sampling and analyses, methylmercury data for these tributary streams contained in the Barr (2014d) data are not reported in the FEIS (I summarize this tributary methylmercury data in the table below). The failure to include these data when other tables have been made more complete through the addition of methylmercury data is problematic, particularly since some of these locations are proximal to the proposed mine site.

Location	**Mean Methylmercury (ng/L)**	**Mean %Methylmercury**
Longnose Creek (LN-1)	0.21	6.0
West Pit Outlet Creek (WP-1)	0.82	5.9
Wetlegs Creek (WL-1)	0.48	9.6
Wyman Creek (PM-5)	0.15	12.5
Wyman Creek (PM-6)	No data	No data

Source: Barr, 2014d

Like the stations on the Partridge and Embarrass Rivers, it is clear that the upstream tributaries, including those associated with the mine site, are draining a landscape with high mercury methylation potential (percentage of methylmercury >3%).

In this context, it is clear that the high mercury methylation potential of the proposed PolyMet mine site is associated with the high percentage of land cover that is associated with wetlands, and in particular ombrotrophic bogs and other peatlands that have been shown to be locations of strong methylation. The high percentage of methylmercury in these surface waters speaks to sensitivity of their watersheds to both a) hydrological impact from a change in either surface or subsurface hydrology, and b) deposition of any additional sulfate either from surface water flows, or wet/dry atmospheric deposition which are addressed later in this document.

2.1.2 No Mercury Data for Other Media

The PEIS does not provide any data regarding total mercury or methylmercury levels in sediments in lakes, rivers and streams, or wetlands proximate to the mine site or tailings site, despite the importance of solid phase mercury in supplying both mercury and methylmercury to downstream waters either through *in situ* methylation or solid-liquid phase partitioning.

I stand by my original opinion that failure to analyze and report solid phase mercury is a dramatic oversight in the EIS since methylmercury is not produced in the water column of streams and rivers, but in the soils and sediments in and adjacent to them. The absence of this data makes any conclusion that changes in hydrology at the PolyMet mine and tailings waste site would not affect downstream mercury and methylmercury unsupportable, particularly if this assumption is applied to wetlands. Moreover, there are no data on biological indicators of mercury or methylmercury exposure in any of the stream systems of concern. This is very inconsistent with other environmental impact studies that I am aware of in Canada where at the very least, benthic invertebrates are sampled as bioindicators of mercury exposure.

2.1.3 Inconsistencies in Reported Detection Limits and Addition of New Data

Since the SDEIS, efforts were made to address inconsistencies in reported data. However, the 'correction' of inconsistencies raises a new set of questions. On page A-213 of Appendix A, the response to comment 19680 concerning this issue includes the statement:

> "Data presented in the FEIS were gathered from various sources thereby leading to inconsistencies in the way the results are reported. The data presented in tables in the FEIS have been reviewed for consistency and updated as necessary."

However throughout the data tables in the FEIS where data from 'various sources' is reported, the apparent detection limits have all been resolved to 0.25 ng/L for total mercury and typically 0.015 ng/L for Methylmercury (some expressed as 0.028 and 0.0125 ng/L the latter of which is a level of artificial precision to the fourth decimal place that is not achievable analytically). In the SDEIS, these values were widely ranging. It would appear that the 'review for consistency and updating' has simply been a technical edit with relatively arbitrary (but more technically reasonable) values inserted to satisfy comments critical of the SDEIS, rather than a quality assurance review of the actual data associated presented in the tables.

In fact, upon review of Barr (2014d) it is clear that the reported ranges of data (with inferred lower detection limits as the "less than" lowest value), are **inconsistent** between the source data and the FEIS. For example, in FEIS **Table 4.2.2-15**, mercury values have a detection limit of 0.25 ng/L, whereas in Barr (2014d), non-detects are indicated as <0.0005 ug/L which equals 0.5 ng/L *for the same data.* This apparently arbitrary change in values affects subsequent calculations that include those below the limits of detection. Changing the non-detect level in the process of making calculations is an unacceptable practice.

It is also clear that additional data (as indicated by the total number of samples reported in the Detection column) has been included in many, if not all, of the data tables, at least for the analytes total mercury and methylmercury. These additions should, in principle, provide more robust estimates of the average condition, and possibly extend the range of data reported. Curiously, the addition of more data has created more confusion, rather than clarification in the FEIS. **Table 4.2.2-24** in both the SDEIS and the FEIS (numbering consistent between documents) is a good illustration of the continued failure to be rigorous in reporting of these critical data. For mercury, the SDEIS reported detection of mercury in 25 of 26 samples. In the FEIS, 41 of 41 samples detected mercury. Unless some data was removed form the more recent summary, which would be an improper practice, this report of no "non detect" samples is erroneous. Moreover, in this Table, the lowest concentration for mercury in the SDEIS was <0.25 ng/L. In the FEIS the lowest concentration reported was 0.81 ng/L (no non-detects). No explanation is provided why the lower concentration sample(s) reported in the SDEIS are no longer included in the FEIS. In the same Table of the SDEIS 4 of 24 samples reported detection of methylmercury, while 16 of 39 samples reported methylmercury detection in the FEIS. That means that of 15 additional samples, there were 12 with detected methylmercury. This remarkable increase in the detection of methylmercury (from 17% to 80%) could result from the lowering of detection limits for the newest 15 samples. (now reported as 0.015 ng/L as opposed to 0.05 ng/L in the SDEIS). If so, applying the 0.015 ng/L detection limit to all data reported in the FEIS is inaccurate and misleading.

If we accept that the SDEIS data is reported with a detection limit of 0.05 ng/L (a reasonable detection limit for methylmercury) and the new data was done with a lower detection limit, then it is impossible for a merged dataset with different detection limits to be reported as having the lower limit as 0.015 ng/L. The merged data set can only be as good as the least precise data that is part of the merged dataset, particularly if the "half detection limit" approach for handling non-detects is used (which it continues to be here). The inclusion of new data and 'corrections of inconsistencies', while having the appearance of improvement to the FEIS, in fact seems to be a somewhat arbitrary exercise, with surprising new inconsistences introduced by the addition of new data.

2.1.4 Failure to conform to standard approaches for Data Collection and Presentation

The incorrect manner with which mercury summary data is calculated, interpreted and then subsequently presented has not been addressed. The FEIS presentation of arithmetic means and ranges precludes any assessment of explanatory power in the data set, biases the interpretation of changes in loads, and cannot be used to satisfy any analyses of appropriate sample size. The data continues to be internally inconsistent and fails to demonstrate effective quality assurance.

A statement in the SDEIS concerning USEPA's request for an uncertainty range concerning groundwater quality has been revised. The information in italics was added:

> (FEIS 4-43) *In total, 24 monitoring wells were installed in surficial aquifer and 9 in bedrock (see Figure 4.2.2-8). Six or more groundwater samples have been collected for chemical analysis from each of those wells, except one surficial aquifer well that was dry after the first sampling (so it only provided a single sample) and three bedrock wells that were also sampled once only.* A statistical analysis indicated that the total number of groundwater quality samples was sufficient to satisfy the USEPA's request that an uncertainty range around the estimate of average concentration for each solute could be identified such that there was a less than 5 percent probability that the actual average would be outside of this range (Barr 2012p).

In the FEIS, **Table 4.2.2-6** now provides information about sampling locations. However, review of the underlying data in Barr 2012p shows that uncertainty analyses to address USEPA's request was only undertaken for selected elements and **did not** include mercury or methylmercury in the uncertainty analyses. As stated in Barr 2012p, because "only solutes included in the water quality modeling for the SDEIS are assessed."

An uncertainty analysis for reactive elements, such as mercury and methylmercury would be different than analysis for a geogenic element like calcium, or a conservative ion like chloride, since mercury concentrations would be expected to be more variable. Moreover, Barr (2012p) indicates that:

> For antimony, cadmium, selenium, silver and thallium there were not enough detected concentrations to be able to calculate meaningful mean and standard deviation values (it is not recommended to calculate statistics on datasets with less than 4-6 detected concentrations [EPA, 2010]); as a result the sample size calculation was not performed for these solutes. (Barr 2012p)

Review of Barr 2012p suggests that statistical interpretation of PolyMet data for even geogenic elements is problematic. For many elements reported in FEIS data, even with total sample numbers in excess of 150, the standard deviations (variation) are greater than the means, and in some cases are much more variable than plus or minus 100%. For example, the variability in iron concentrations is plus or minus 250% around the average, despite the number of samples taken. Arsenic and chromium, metals of obvious concern from an environmental perspective report variability of approximately plus or minus ~100% of the average concentration. Copper, Nickel and Cobalt have variabilities of plus or minus ~150%. The Barr analysis (2012p) is used by PolyMet to assert that sufficient samples were taken for groundwater, and to report mean concentrations in Table 4.2.2-6 even where uncertainty in the data was ***plus or minus 100% or more of the mean value for metals of concern***. Of course, as with other data tables in the FEIS, there is no way to assess the true variability and confidence in the reported mean concentrations when only the mean and range are reported, obfuscating the real uncertainty surrounding most of the mean concentrations reported. It is incomprehensible to me how an analysis of uncertainty where the measure of variability is plus or minus 100% could allow one to make any statements of confidence concerning the reported data. It does however explain why even widely variable concentration data for some elements was deemed acceptable in the FEIS.

No statistical analysis at all was done for either mercury or methylmercury to assess variability in the data. Neither the Barr analysis of mercury and methylmercury nor its reporting in the FEIS satisfies the USEPA's request for certainty in the reporting of mean concentrations of solutes.

Given the above-described data concerns, and given that no statistical analyses were performed for mercury or methylmercury in waters associated with the proposed development, I remain concerned that incomplete and insufficiently reliable sampling was done to adequately characterize any of the surface waters or groundwater chemistries reported in the FEIS, at least for mercury and methylmercury.

2.1.5 Inappropriate Handling of Non-Detect Samples

In my previous opinion I made a clear argument against the use of a value half of the detection limit for the purposes of calculating simple statistics (section 4.1.4 of my previous opinion). The FEIS was not modified in any way to reflect this more appropriate and up to date handling of non-detect sampling. FEIS A-408 states the following:

> Based on professional judgment, half of the detection limit was utilized in presenting data throughout the FEIS. Although contemporary science has refrained from utilizing half the detection limit, per the USEPA Region II Technical Guidance Document Chemical Concentration Data Near the Detection Limit (USEPA 1991) the method is valid. Additionally, the evaluation of the data provides a reasonable estimate of potential environmental effects for purposes of environmental review.

There are numerous troubling aspects in this argument against using a numerically more rigorous approach to this problem. First, the authors of this response to the comment acknowledge that "contemporary science" deals with non-detects in a more sophisticated way. This indicates that the data presentation and analysis is not in accordance with a currently accepted scientific approach, but an arbitrary "professional judgment". Secondly, I find it problematic that the authors turn to a nearly 25-year-old document as an authority on this issue, and indicate that this renders the approach "valid". There is much published work that was once considered valid, but is no longer. This is a case in point. The final sentence is the most problematic. In the absence of appropriately calculated simple statistics, and the failure to present other statistics like medians, measures of variance, we actually *cannot* evaluate the data to assess environmental effects, despite the authors' claim to be able to do so.

As a scientist, I would welcome a quantification of "reasonable estimate". This would require understanding of the margin of error. My professional judgment would suggest that a margin of error of plus or minus 20% would allow a reasonable estimate. If we were to impose a margin of error of 20% on all of the mass balance calculations used to estimate environmental effects as part of this Final EIS, then the firm conclusions of no effects would be most certainly discounted.

I do not believe that a "reasonable estimate of potential environmental effects" that fails to identify statistical uncertainty and the margin of error in the data would in any circumstance be considered acceptable when assessing the potential for downstream water quality impairments that could impact aquatic life and human activities. Yet, that is what Barr and the PolyMet FEIS propose in reaching judgments denying the potential adverse effects of mercury and methylmercury on downstream water quality.

My previous opinion elaborated more technically on this problem, so I will simply restate the title of Helsel's published paper on this matter: "*Fabricating data: how substituting values for nondetects can ruin results, and what can be done about it"*. The USGS has required that all of its data be handled in accordance with Helsel's approach for handling non-detects for many years.

2.2 Previous Opinion 2 (SDEIS)

The SDEIS fails to consider scientifically documented factors beyond simple changes in mercury in the environment that govern mercury methylation and uptake when evaluating the potential impacts of mercury release as a result of the proposed development.

The FEIS revisions disregard most of the comments made in my previous opinion (section 4.2) on this matter, however revisions do include additional literature concerning mercury methylation and its environmental controls.

The section beginning on FEIS 5-231 (Enhanced Mercury Methylation) speaks to several of the general points that were raised in my previous opinion, including the positive relationship between sulfate availability and methylation, the process of sulfate regeneration through wetting and drying, and the influence of changes in hydrology and water level fluctuations on enhancing mercury methylation.

> Many studies have shown that wetlands can be sinks for mercury and sources of methylmercury to surrounding watersheds (St. Louis et al. 1996). Galloway and Branfireun (2004) found that wetlands were an important site of sulfate reduction and methylmercury production. Balogh et al. (2004) and Balogh et al. (2006) concluded that increases in methylmercury in several Minnesota rivers during high-flow events was likely the result of methylmercury transport from surrounding wetlands to the main river channel. A recent study by the MDNR found little, if any, correlation between total mercury or methylmercury and sulfate concentrations in northeastern Minnesota streams (Berndt and Bavin 2012a; Berndt and Bavin 2012b; Berndt et al. 2014). Instead, the study found strong correlations between mercury and dissolved organic carbon concentrations and total wetland area. Overall, these studies suggest that most mercury methylation, at least in the St. Louis River Basin, primarily occurs within wetlands rather than in stream channels and the methylmercury is flushed to rivers from wetlands during storm events. (FEIS 5-231-232).

Despite the additional citations, like the SDEIS before it, the FEIS implies that there is a lack of consensus among researchers working on this topic, justifying its failure to analyze the factors that increase methylation. The first part of the above paragraph is accurate. However, following the reference to the three publications led by Berndt, the text implies that there is no relationship between methylmercury and sulfate, but only between mercury and dissolved organic carbon. This implication is misleading. Direct correlations between sulfate and methylmercury are unlikely not because there is no clear relationship, but because it is a well-established fact that sulfate is consumed as methylmercury is produced in a reduction reaction (one might expect a correlation between sulfide and methylmercury). It is also well-established fact that both mercury and methylmercury can be strongly associated with dissolved organic carbon as a vector of export from watersheds, especially wetlands and that mercury methylation occurs within wetlands and can be flushed to rivers and streams with hydrological events. There is nothing contradictory presented here – in fact it is all completely consistent with wetlands being sources of methylmercury in this landscape.

I would agree with the implication in the FEIS (5-232) that potential methylation of mercury would support mine and tailings facility design elements to reduce sulfate losses to surface waters and to groundwater seepage. It is beyond the scope of my opinion to comment on whether the proposed designs for the project are the best suited to reduce sulfate. However, the FEIS proposal continues to assume nearly 100% capture of runoff and seepage from unlined facilities and has not demonstrated that subsequent treatment of collected seepage would be effective for mercury (Barr 2013f).

Although the surface water guidance for sulfate concentrations to protect wild rice (10 mg/L) is an important consideration (and not considered in the scope of this opinion), these concentrations of sulfate (and lower) can stimulate methylation. For example Mitchell et al. (2009) found that delivery of runoff with sulfate concentrations ~5 mg/L from the catchment to peatlands in Minnesota produced very high pore water methylmercury concentrations between 2 and 4 ng/L. In constrast, locations with little mass of sulfate delivered showed low to non-detectable methylmercury concentrations. The small tributaries that are more proximal to the proposed NorthMet mine site location clearly have sulfate-limited conditions. The mean sulfate concentrations in Longnose Creek. West Pit Outlet Creek and Wetlegs Creek are 0.91, 2.6 and 3.9 mg/L, respectively. Despite sulfate concentrations that are well below 10 mg/L, methylmercury concentrations in these tributaries are high relative to total mercury (see my Table 4.1 above). The fraction of all mercury that is methylmercury ranges between 5.9 and 9.6 percent , indicating that even these relatively sulfate-poor, and relatively undisturbed tributaries have high potential for mercury methylation.

Wyman Creek presents an even more interesting case. Although its absolute methylmercury concentrations are the lowest of the upper Partridge River tributaries, the percentage of methylmercury is the highest (12.5%) because total mercury concentrations are also lower. This very high percentage of methylmercury is accompanied by elevated sulfate concentrations (67.1 mg/L at PM-5). Wyman Creek, unlike the other, relatively unimpacted tributaries at the proposed NorthMet mine site drains a previously mined area, including the Area 3 and 5S pits.

If the Longnose, West Pit Outlet and Wetlegs tributaries receive increases in sulfate loading to sites of methylation in tributary catchments, either through direct discharges greater than the highest concentration in that tributary (in each case < 4 mg/L) or through additional atmospheric loading, net methylmercury production in these tributaries proximal to the proposed NorthMet mine development is highly likely to increase.

FEIS statements about certainty (or lack thereof) in knowledge regarding methylmercury also seem to lack a scientific basis. The FEIS states that "there is a relationship, only partially understood, between sulfate concentration and the conversion of inorganic mercury by sulfate-reducing bacteria into methylmercury" (FEIS 5-21). This statement seems to be somewhat at odds with another statement, later in the FEIS that:

> [S]mall sulfate increases in sulfate-poor wetlands may increase methylmercury production in wetlands (Jeremiason et al. 2006). However, methylmercury produced in wetlands is not necessarily incorporated into food chains and concentrated to levels of concern (FEIS 5-313)

The above statement is an acknowledgement that even small additions of sulfate to sulfate-poor wetlands can increase methylmercury production. Naturally, not all of the methylmercury produced in wetlands is translated directly into biota, however there is clear evidence in the literature that aquatic life in waters receiving runoff from wetland-dominated catchments have higher methylmercury concentrations in tissues than elsewhere. For example, in a broad study conducted in the Voyageurs National Park area in Minnesota, Wiener et al. (2006) identified "pH, dissolved sulfate, and total organic carbon (an indicator of wetland influence) as factors influencing methylmercury concentrations in lake water and fish", indicating not only a connection between sulfate and methylmercury in fish, but also the degree of wetland influence.

Further contradicting the stated lack of certainty with respect to processes controlling methylmercury formation, the FEIS quite confidently states that predicts that after 55 years of operation, when the west pit floods, there will by an "oxygenated hydrologic environment" and it "would not be expected to promote mercury methylation". (FEIS 5-232). As a scientist who has spent my career studying methylmercury, I am troubled that the FEIS argues that there is insufficient scientific knowledge to develop a mechanistic model to evaluate the risk to surface waters from enhanced methylation in the impacted watersheds, yet is comfortable speculating about the future geochemical environment in a flooded pit 55 years from now in order to dismiss the potential for enhanced methylation. It is possible that the "hydrologic environment" (which presumably means the waters in the flooded west pit) may be well oxygenated, but it is actually more likely that the flooded pit will thermally stratify like most lakes over 20 feet deep in the geographic region would, and as such would promote anaerobic bottom waters during the summer and anaerobic bottom sediments that would *both* support methylmercury production (see Eckley et al., 2005, who definitively reports on these processes in a Wisconsin lake).

Further, despite the brief literature discussion about hydrological fluctuations potentially enhancing methylation, the FEIS analyzes a very limited scope of the impacts the proposed NorthMet development would have due to changes in hydrology. The FEIS focuses on the level of hydrological flows in streams and rivers, arguing that the magnitude of the fluctuation (expressed as a percentage in flow variation) will have no downstream impact and no impact on mercury methylation. Augmenting stream flow to stay within a specified percentage of variation will not prevent increased methylation in soils and sediments adjacent to or coupled to the streams. In fact, this matter is recognized elsewhere in the FEIS where it is acknowledged that sediments and anoxic waters are potential methylating environments:

> Bacteria that cause mercury methylation require an anoxic environment, and consequently methylation occurs in sediments or in anoxic waters rather than in the turbulent well-oxygenated water of a river. Therefore, methylation is unlikely to occur in the Partridge River or Embarrass River water column; however, it may occur in sediments or possibly in anoxic environments downstream. (FEIS 5-231).

In Section 2.5.2, I also discuss further the evidence from rigorous peer-reviewed science that demonstrates the role of drying and rewetting of peat soils on sulfate regeneration and mercury methylation. In light of this and the contradictory mention and dimissal of the state-of-the-science on mercury methylation, the FEIS analysis simplistic if not misleading.

2.3 Previous Opinion 3 (SDEIS)

The SDEIS does not make a reasonable attempt to model the potential aquatic ecosystem impacts of changes in water chemistry (primarily mercury and sulfate) due to the NorthMet Mining Project.

2.3.1 The Mass-Balance Model Approach

No additional effort to better understand or model the biogeochemical cycling of mercury and methylmercury in the watersheds of interest has been undertaken in the FEIS. This deficiency was discussed at length in my previous opinion, in which I outlined several alternative modeling strategies. They do not need to be repeated here.

Instead of acknowledging these alternative approaches, the FEIS reiterates the "benefit" of using a mass balance approach:

> Therefore, a simple mass balance model estimation method was used. This simple estimation method was preferred over a detailed mechanistic model because it incorporated the important input and removal processes for mercury, was very transparent with regard to data inputs, and allowed for easy assessment of the effects of changing parameter values on mercury concentrations. (FEIS 5-223).

The entire basis of my previous opinion concerning the modelling of mercury cycling was that a mass balance model *cannot* by definition incorporate mechanistically the input and removal processes for mercury, and *cannot* address the biogeochemical aspects of mercury methylation across the landscape which are at the root of the potential impacts associated with the PolyMet proposal. The reason why simple mass balance models are used is because they are simple to apply quickly and require little parameterization (i.e. are inexpensive). Being cheaper and easier to use is not sufficient justification for taking a naïve approach to evaluating possible environmental risks in a region of mercury sensitivity, when much more defensible approaches exist (see previous opinion), including models for watershed-steam mercury dynamics.

Moreover, although the statement that the mass balance model is transparent with respect to data inputs is true at face value, it seems to me that *any* model is transparent with respect to data inputs. The definition of input parameters and stated variables is always required in any model. I assume that what is meant is that mass balance model inputs are highly simplified, and as such are readily defined, and can be presented as definitive to a non-expert.

2.3.2 Error and Uncertainty Analyses

All modeled outcomes are only of utility when accompanied by an appropriate error analysis that addresses cumulative uncertainties throughout the model. No estimates of uncertainty accompany any of the modelling associated with mercury, except for the presentation of two different scenarios that are based on assumptions concerning the speciation of air emissions (FEIS 6-85). This does not constitute an error analysis, merely a testing of assumptions. If an analysis of the margin of error in projections of sulfate and mercury releases had been performed, it is my opinion that that the FEIS statements of certainty based on grams of sulfate or mercury released could not be supported. Thus, conclusions from this asserted mass balance that the proposed development will not have appreciable impacts on water quality would be similarly unsupported, simply because of uncertainty that would bracket the model output.

2.3.3 The Assumption of Proportionality between Mercury in Deposition and Fish

The FEIS maintains that “methylmercury content in fish are roughly proportional within individual watersheds” and cites the MPCA’s Mercury Risk Estimation Method (MMREM) principle of proportionality between mercury in fish and atmospheric deposition (FEIS 5-22). Although the MMREM identifies the need to control atmospheric mercury inputs, the model is fundamentally flawed in that it relies on the assumption of proportionality between total mercury in water and methylmercury in fish. This is an archaic approach to this problem, and does not reflect current scientific thought or the best available tools.

The fundamental flaw in the assumption of proportionality has been demonstrated clearly in a recent publication in the same geographical region as the proposed development. Brigham et al. (2014) show compellingly that atmospheric deposition of mercury in the Voyageurs National Park area of Minnesota significantly decreased (32%) between 1998 and 2012, yet the responses of mercury in fish in four case study lakes was highly variable. Two lakes showed decreases nearly proportional to the decrease in atmospheric deposition. However fish methylmercury in another lake increased by 80%, and a fourth lake that was subject to disturbance (fire; beavers) in the watershed showed no change. They conclude that:

> Understanding changes in MeHg contamination of aquatic food webs, in response to changes in key factors of methylmercury production, is critical to assess the efficacy and benefits of emissions reductions. This case study - the first we are aware of to report a >10-year trend in $MeHg_{aq}$ and THg_{aq} - shows diverging responses among the study lakes and exemplifies the complexity of ecosystem responses to decreased loads of atmospheric pollutants. Although we cannot establish causation, the downward trends in $MeHg_{aq}$ and Hg_{fish} in two of our four study lakes are consistent with decreases in atmospheric loading of mercury, as well as SO_4^{-2} and H^+, which indirectly affect the mercury speciation and bioavailability. However, the mixed results from the remaining two lakes exemplify that recovery will vary among ecosystems, and may be affected by watershed-specific hydrologic conditions and disturbances. (Brigham et al., 2014).

This finding is consistent with my own scientific knowledge of watershed mercury biogeochemistry – the relationship between mercury deposition, transport, transformation, speciation, and ultimately biological uptake is variable among catchments, and that without knowledge concerning the hydrological interactions between surface waters and the watershed, predictions about the dominant source(s) of mercury to biota are not possible.

The findings and subsequent discussion concerning the application of the MMREM model obfuscate the fact that the real concern with the NorthMet development, in my opinion, is not an appreciable increase in local atmospheric deposition of mercury to lakes, but its changes to the hydrology of watersheds, subwatersheds and their surface streams and rivers that are proximal to the proposed mine and tailings site. These hydrological changes will increase the methylmercury production potential of the landscape, and ultimately engender downstream impacts on the St. Louis River. I further substantiate this conclusion my discussion of my previous opinions 5 and 6 below.

2.4 Previous Opinion 4 (SDEIS)

It is my opinion that ombrotrophic bogs (peat-dominated, rain-fed, acidic wetlands) play important roles in catchment methylmercury supply, and the SDEIS incorrectly considers them decoupled from the environmental impact considerations with respect to sulfur and mercury impacts on receiving waters.

2.4.1 Evidence of Peatland Influence on Current Surface Waters

The FEIS does not make connections between existing wetland types and current or projected water quality in the area of influence of the proposed development. In particular, the FEIS does not make the connection between the dominant wetland type and landcover class (bog wetland, ombrotrophic or otherwise) in the area of impact around the proposed NorthMet mine site and methylmercury production in the landscape. This remains a critical oversight because of the potential impacts on hydrology and atmospheric deposition of mercury, but in particular sulfate, as a result of the proposed project (see comments on previous Opinion 5, below). Literature cited in the FEIS draws a clear connection between bog-type peatlands and methylmercury production and export, with some of the most relevant work done in the state of Minnesota, yet the FEIS does not discuss the impact of this source of methylation.

There is clear evidence from the stream water quality data presented in the FEIS that the surface waters in the small tributaries at the proposed mine site, the Partridge, and the Embarrass Rivers are all strongly influenced by the presence of wetlands in their watersheds. Surface runoff from these wetlands are clearly sources of methylmercury to surface waters in this area. In no other surface waters that I am professionally aware of are the fractions of total mercury as methylmercury as high as are reported in the FEIS (see previous sections).

Based on previous work that I have undertaken with colleagues in the St. Louis River watershed, there are no other wetland types other than moss-dominated (bog) wetlands that are characterized by a percentage of methylmercury in soils or porewaters that is consistently above 5% (see Figure 6.4.1 of previous opinion). Since there is clear evidence that the watersheds in which the NorthMet development is proposed should be considered 'sensitive' with respect to the production of methylmercury (see Munthe et al., 2007), it logically follows that impacts on these watersheds and wetlands that could influence the methylating environment should have be considered in the EIS. Even small changes that increase methylation could have marked detrimental and cumulative effects downstream.

2.5 Previous Opinion 5 (SDEIS)

In my opinion, the SDEIS presents the shallow groundwater hydrogeology, bog hydrology, and the nature of connectivity between these landscape components in a purely conceptual fashion, or with limited data from an unproven analog system. In doing so, hydrological impacts of the proposed development on surrounding wetlands and subsequent changes in methylmercury production and release are not adequately evaluated.

2.5.1 Impact Considerations of the Proposed Development on Peatlands

Based in part on the valid arguments of my previous opinion, the FEIS acknowledges that the SDEIS consideration of ombrotrophic bogs as "no effect" with respect to impacts of the proposed development was incorrect, although this is not explicitly stated. In the FEIS:

> Open and coniferous bog wetlands within and surrounding the Mine Site were subcategorized as either ombrotrophic (hydrology and mineral inputs solely from direct precipitation) or minerotrophic (some degree of mineral inputs from groundwater and/or surface water runoff) to determine if the bogs would be affected by groundwater drawdown. Due to the potential connection to groundwater flowpaths, ombrotrophic bogs would have a low likelihood of being affected by groundwater drawdowns associated with proposed mining operations. Similarly, more minerotrophic bogs would have also had a low likelihood of being affected (Eggers 2015a). Using a conservative approach for the analysis (i.e., one that errs on the side of estimating greater wetland impacts), all bog communities within 0-1,000 ft from the edge of the mine pits were categorized as Low Likelihood of wetland hydrology impact (PolyMet 2015b). (FEIS 5-273).

This is a curious statement in that it implies that (Eggers, 2015) makes statements concerning ombrotrophic versus minerotrophic 'bogs'. In fact, Eggers, in his well considered and reasoned memo of January 15, 2015 indicates that:

> It was recognized that the September 2010 field work was not ideal for distinguishing ombrotrophic versus somewhat minerotrophic bog communities. Subsequent to that field work, discussions occurred regarding whether more expansive and intensive field work using releves, precise measurements of pH and Ca concentrations, etc., for differentiating ombrotrophic versus somewhat minerotrophic bog communities should be accomplished. This was not implemented, however, due to a determination that more detailed vegetation/pH/Ca/landform data would still not provide a definitive answer regarding potential indirect impacts. (Eggers, 2015).

Therefore no such distinction can reasonably be made given that other diagnostic data was not collected and as a consequence, no "definitive answer regarding potential indirect impacts" (Eggers, 2015) could be provided. Eggers further recognizes the potential for hydrological impacts of bogs that were previously assumed to be 'perched' and decoupled from groundwater, and found that the argument made in my previous opinion, and the literature provided to this effect (e.g. Siegel and Glaser, 1987) were "convincing" (Eggers, 2015). Eggers does not, however, reflect on the other important literature that I discussed that demonstrate the direct effects of under-drainage from dewatering on peatland hydrology, nor does this enter into the analyses included in the FEIS (see my previous opinion Section 4.5, discussion focusing on Whittington and Price, 2013). In light of this potential groundwater connection, and as a consequence, the potential for effect of under-drainage as a consequence of pit dewatering, Eggers states:

> Therefore, it would be reasonable to assume that **all wetland types within this zone would experience some degree of hydrology effects due to groundwater drawdown**. Some reviewers may be concerned that "low likelihood" for hydrology impacts due to groundwater drawdown is not accurate and instead should be "moderate likelihood" or "high likelihood." The bottom line is that the potential for indirect impacts to **all bog communities within the 0-1,000 foot analog zone** is acknowledged. In the event that the NorthMet Project is permitted and constructed, monitoring would be required to verify whether indirect impacts occur and, if so, the magnitude of those impacts. (Eggers, 2015). (Emphasis in **bold** is mine).

This statement stands in sharp contrast with what appears to be a misstatement of Eggers' conclusions that is found in the FEIS:

> "…ombrotrophic bogs would be less likely to be affected by groundwater drawdowns associated with proposed mining operations, whereas more minerotrophic bogs would have a higher likelihood of being affected (Eggers 2011a, 2015). (FEIS 5-263)

This language in the FEIS clearly does not reflect Eggers' revised professional opinion in his 2015 memo.

It is therefore clear that, based the FEIS, in its shift in categorization from no-effect to low likelihood, is “acknowledging” the potential for ‘impacts’ on bog wetlands, which are sources of methylmercury in these watersheds. This shift in categorization would suggest that, in keeping with the recommendations of Eggers, at the very least potential mitigative measures and/or additional monitoring would be undertaken if the NorthMet Project were to be permitted and constructed. However, this is not the case. The FEIS not only minimizes the risk of drawdown effects on ombrotrophic bogs, but proposes no method to prevent or detect these impacts.

> **If** the NorthMet Project Proposed Action were to be permitted **and** it was determined that the NorthMet Project Proposed Action would cause future wetland effects, wetland monitoring would be conducted. (FEIS 5-355).

This sentence absolves the NorthMet project proponents from taking even the proactive action of monitoring. It is completely unclear how it can be determined if the project would cause wetland effects without performing hydrological monitoring first. This and other similar text in the FEIS suggests that there is, in fact, no plan for proactive monitoring to address incremental direct or indirect impacts of the proposed project on wetlands in the area of impact.

In fact, to the extent that monitoring is planned for indirect wetland impacts, it is proposed that this monitoring will exclude the ombrotrophic bogs at the NorthMet mine site.

> Wetland hydrology and vegetation **would be** monitored, and additional monitoring locations **may be considered** during permitting. A component of the monitoring plan would be based on those wetlands that would have a **high likelihood** of indirect effects as a result of groundwater drawdown. (FEIS 5-361).
>
> The monitoring plan, developed as part of the federal and state permitting process, would be based on those wetlands that have a **high likelihood** of indirect effects as a result of groundwater drawdown. (FEIS 5-303).

Despite the FEIS’ discussion of its “conservative approach” (FEIS 5-279) of considering bogs to be low likelihood of impact rather than no-effect, there are *no implications of this change in language from the SDEIS to the FEIS*. The FEIS retains the unproven analog model to assess indirect wetlands impacts at the NorthMet mine site. Then, when Eggers (2015) indicates that it's a matter of professional opinion whether or not impacts on ombrotrophic or minerotrophic bogs are of low, moderate or high likelihood, particularly within 1,000 feet of the proposed mine, the FEIS requires no mitigation measures or monitoring of impacts by placing them in a “low likelihood” impact category.

To place ombrotrophic wetlands that are potentially the greatest source of methylmercury to receiving waters in this landscape in a low likelihood of impact category that excludes these wetlands from further consideration and even from monitoring, renders meaningless the shift from a “no-effect” classification. This exclusion also disregards the recommendation by Eggers

(2015), that, “Monitoring would include a network of monitoring wells/dataloggers and permanent vegetation plots established in representative wetlands (including communities mapped as ombrotrophic bogs) to quantitatively measure any indirect impacts.”

It is critical to emphasize that neither the FEIS nor the Eggers memo recognize the distinct indirect effects of mine drawdown at the project site on mercury methylation. Even if monitoring were done in ombrotrophic wetlands to evaluate the effects of hydrology on changes in vegetation, that monitoring would not detect changes in mercury methylation impacts. The indirect effects of changes in hydrology on vegetation community is perhaps the least significant consideration in terms of water quality impacts and cumulative effects on aquatic and human health in receiving waters of small tributaries, the Partridge and Embarrass Rivers, and the St. Louis River. Even relatively small changes in water table position and wetting and drying frequency in the ombrotrophic wetlands at the NorthMet mine site have the potential to impact sulfate and methylmercury concentrations of receiving waters. Both baseline and future monitoring of outflow waters from these wetland types for flow volumes and water chemistry, including methylmercury and sulfate, would be necessary to truly monitor and evaluate the impacts of the proposed development. Perhaps more important, considering the potential for mercury methylation, bog wetlands around the proposed mine site must be considered to have a very high likelihood of indirect impacts from the proposed NorthMet development.

2.5.2 Impact of Hydrological Impacts on Sulfate and Methylmercury in Peatlands

In my previous opinion, I highlighted that the SDEIS does not make the connection between the dominant wetland type and landcover class (bog wetland, ombrotrophic or otherwise) in the area of impact around the proposed NorthMet project and methylmercury production in the landscape. The SDEIS completely failed to consider the impacts that additional sulfate from seepage to surface water and atmospheric deposition, and changes in hydrology may have on the biogeochemical function of wetlands. Superficially, the FEIS has modified some sections to add language on the scientific basis of these relationships. However it is not carried the science forward in any formal consideration of potential impairments of downstream water quality.

In a review of the FEIS there are statements that clearly link wetlands to methylmercury export to surface waters in the area of proposed development.

> Overall, these studies suggest that most mercury methylation, at least in the St. Louis River Basin, primarily occurs within wetlands rather than in stream channels and the methylmercury is flushed to rivers from wetlands during storm events. (FEIS 5-232).

This statement is true with respect to the location of methylation in the watersheds. However, it is overly simplified in that is focuses on export during storm events. It is true that mercury, methylmercury and other solutes are flushed during storms, but they also are continuously exported under baseflows, and during other high flow events, such as the spring snow melt. See Mitchell et al. (2008b) for an elaboration on the timing and sources of methylmercury export from a peatland catchment in north central Minnesota. Despite the tendency of the language used in the FEIS to imply that the ombrotrophic, or rain-fed bogs are "perched" in the landscape and only connected hydrologically to the atmosphere (and are therefore neutral with respect to their impact on water chemistry and sensitivity to impact from changes in hydrology), the reality is that all bogs shed water via outflows to downstream systems, and as such strongly influence the chemistry of receiving waters.

Despite the apparent awareness in the PolyMet FEIS of the role of wetlands as sources of methylmercury in this sensitive landscape, the potential impacts of the proposed NorthMet development on the mercury biogeochemistry of wetlands are not considered in any of the EIS assessments, including the FEIS. There is clear published evidence (almost all from Minnesota) that the addition of sulfate, either from runoff to the edges of bogs (Mitchell et al. (2008a), or from direct atmospheric deposition to bogs (Jeremiason et al., 2006; Coleman-Wasik et al., 2012) increases mercury methylation in wetlands.

2.5.3 Drying and Wetting Effects on Methylmercury in Peatlands

In their most recent work, Coleman-Wasik et al. (2015) show that water level draw down in a bog due to a summer drought resulted in the oxidation of sulfide back to sulfate, which, upon rewetting significantly stimulated the production of methylmercury. This important new research concluded that:

> "Because the sulfate that reappeared in pore waters during rewetting events likely came from the large pool of organic sulfur in the peatland, prolonged water table drawdowns lead to greater sulfate release in all treatments"

and

> "Although there was evidence of increased MeHg production as the drought-induced sulfate was consumed, our results also demonstrate the potential for drought to further elevate MeHg flux from peatlands because of oxidation and desorption of MeHg from the solid phase."

Moreover,

> "Not only was that sulfate then available to drive SRB activity and Hg methylation but it was also available for export to downstream aquatic systems (e.g., lakes and other wetlands) that could be equally susceptible to i*n situ* net methylation."
>
> (Coleman-Wasik et al., 2015)

The sulfate regeneration phenomenon is well-documented in wetlands and in particular, Minnesota peatlands (see Coleman-Wasik et al., 2015). Given the recent findings of Coleman-Wasik et al., and the consistency of these findings with prior research and biogeochemical understandings, the most reasonable scientific conclusion is that stimulation of methylmercury production by the rewetting process is a ubiquitous process in peatlands such as those studied, which are typical of Minnesota bog-type wetlands. As such we must expect that a significant proportion of bog wetlands that are within the zone of drawdown from the proposed mine proposed development will also exhibit sulfate regeneration and increased export of methylmercury, under natural rewetting cycles as well as storm events.

It follows logically that wetlands proximal to the proposed development will be hydrologically influenced by the open pit dewatering, particularly in the 0-1000 foot analog zone. As such, bog underdrainage could increase the amplitude of water table fluctuation, and enhance drought-induced peat drying, sulfate regeneration, and mercury methylation. It is clear that the pattern of methylmercury concentrations observed in the Partridge and Embarrass tributaries of the St. Louis River is strongly indicative of a peatland influence (see comments above pertaining to prior Opinion 1). In fact, from my own research and familiarity with the literature, it is only in bog-type peatlands that the percentage of methylmercury in any waters (mainly porewaters) is persistently 10% or greater, indicating that the chemistries of both these rivers and their headwaters are dominated by runoff from their peatland-dominated catchments.

The findings of Coleman-Wasik et al. (2015) also call elevate concerns about other impacts of the NorthMet development on mercury methylation. Storage of peat overburden in the unlined laydown area for 11 years would result in repeated flushes of methylmercury as well as inorganic mercury. Although the FEIS suggests (FEIS 5-227) that the impact of stored mercury on loading of inorganic mercury has been considered as part of its mercury mass balance, no data is provided from which it can be determined if the FEIS assumptions are reasonable. In addition, the FEIS does not consider the effect of the peat overburden storage on methylmercury formation and export. The continuous process of drying and rewetting of overburden peat stockpiled in laydown areas may not only continue to release inorganic mercury, but may also continuously regenerate sulfate, and in anaerobic locations, promote methylmercury formation.

If natural drought-rewetting cycles contribute to net methylmercury production in wetland types that are already sensitive with respect to mercury methylation, then we must expect that any development-induced change in hydrology, such as those proposed at both the NorthMet mine site and tailings basin, could amplify those drought-rewetting cycles (in terms of magnitude, frequency, or both). These implications should not be understated. Independent of any additional releases of uncaptured sulfate or mercury from the proposed NorthMet development, dewatering of wetlands surrounding the tailings basin through seepage collection and even modest impacts on water table position by underdrainage of mine site peatlands through open pit dewatering could increase total mercury, methylmercury and sulfate in the Partridge, Embarrass, and ultimately the St. Louis River.

2.5.4 Effects of Atmospheric Deposition of Sulfate on Methylmercury in Peatlands

The principal atmospheric impact on methylmercury production in nutrient-poor wetlands is through the deposition of sulfate. Jeremiason et al. (2006) found that there was a strong correlation between increase in sulfate loading and increase in methylmercury in peatland pore waters. However with a ~4x increase in sulfate loading, the magnitude of the increase in methylmercury export (i.e. the direct effect on downstream systems) from the peatland was ~2x.

The FEIS projects a potential incremental increase in surface waters of 4.2 mg/L in wetlands (FEIS 5-339). I reviewed Barr (2015f) that is the source of this information, and found that the data reflects a more substantial sulfate loading than that characterized in the FEIS. On p. 42, Barr (2015f), 1.26 grams of sulfate per square meter per year (g/sq.m/yr) is presumed to mix "with the surface 12 inches of water (30 cm = 0.3 meters; average depth of water in a typical 'wetland' as defined by the MDNR (2014))".

This is an invalid assumption. Nutrient-poor wetlands like ombrotrophic bogs do not have a foot of standing water at their surface – in fact they rarely have any standing water. Therefore, sulfate deposition should be assessed as a true load to the surface, not as a diluted concentration (2015f). If 1.26 g/sq.m/yr of sulfate deposition is reconciled against the reported background deposition of sulfate for the region, the FEIS conclusion that there would be an "incremental change" or "small increases" in sulfate-poor wetlands (FEIS 5-339) cannot be sustained.

As reported in Coleman-Wasik et al. (2012), sulfate deposition in north-central Minnesota in the 2000s averaged ~ 5.5 kilograms per hectare per year (kg/ha/yr). Coleman-Wasik notes that this is a decline of about 50% from the much higher deposition rates of the mid-1980s. PolyMet (2015b, p. 40) reports an average wet deposition of sulfate used in their calculations as 3.75 kg/ha/yr from a local deposition monitoring station, with an assumption of an additional 22% of total deposition as dry deposition (dust). Therefore total sulfate background deposition in the project area would be 4.58 kg/ha/yr using PolyMet's own numbers, which are in line with the average presented in Coleman-Wasik et al.

If we express the maximum estimated sulfate deposition rate of 1.26 g/sq.m/yr from the Barr (2015f, p. 42) reference used in the FEIS analysis in units equivalent to those for background sulfate deposition then (since there are 1,000 g/kg, and 10,000 sq.m/ha):

1.26 g/sq.m/yr = 12.6 kg/ha/yr

Therefore, the increase in sulfate loading calculated for the proposed development is not inconsequential. The new total sulfate load of 17.2 kg/ha/yr is, in fact, 3.76 times the background sulfate deposition rate of 4.58 kg/ha/yr.

This total load is more than half of the experimental increase in sulfate applied to the experimental wetland first reported in Jeremiason et al. (2006), and subsequently described in Coleman-Wasik et al. (2012; 2015). It is also approaching the enrichment above estimated background (4x) that these researchers applied experimentally, resulting in significant increases in pore water methylmercury, methylmercury export, and sulfate regeneration as discussed above.

Jeremiason and colleagues found that the increase in peatland export of methylmercury in runoff was approximately 2x with a 4x increase in sulfate deposition (based on 1990s sulfate deposition values of approximately 8 kg/ha/yr). If we accept that the 4.58 kg/ha/yr background level in PolyMet's calculations is a reasonable value for contemporary total sulfate deposition for the region, then methylmercury export from sensitive peatlands may increase by up to 1.88x if the relationship presented by Jeremiason holds true. Barr (2015f) states that the deposition values are conservative and assume that all sulfur in dust is converted to sulfate. However given the magnitude of the potential impact described above, if less than the total sulfur deposited is liberated to the environment as sulfate, there will still be a substantial stimulatory effect on peatland methylmercury production.

The potential near-doubling of methylmercury export from methylating peatlands receiving an additional sulfate load from the proposed PolyMet development would be reflected in methylmercury concentrations in the upper tributaries, and the Embarrass and Partridge Rivers, given the role these wetlands play in supplying water to these streams and rivers. Increased methylmercury would also be expected to impact the upper St Louis River, given the direct hydrological connection and known methods of methylmercury transport. In addition. Coleman-Wasik et al. (2015) found that the portion of the experimental wetland recovering from high sulfate loading had methylmercury levels intermediate between those of unimpacted and current experimental treatments. It can be expected that effects of elevated sulfate deposition on peatlands will persist to some degree even after additional sulfate loading has ceased.

2.6 Previous Opinion 6 (SDEIS)

It is my opinion that the potential for the discharges of mercury and sulfur from the tailings stockpiles/ponds are inadequately addressed in the SDEIS, and the potential for both direct and indirect downstream water quality impairments are understated.

In the FEIS, there is considerable uncertainty in the data on mercury in both natural surface waters and groundwaters. This uncertainty stems from concentration data that continues to be fraught with errors, fails to apply an uncertainty analysis to mercury or methylmercury, and fails to report chemical data in a consistent and scientifically standard way. Moreover, the FEIS' continues to rely on a mass balance model that, even if its underlying discharge assumptions were reasonable (which they do not seem to be) in the absence of a modeled cumulative error, presents us with mass loadings of sulfate, mercury and methylmercury to the Partridge and Embarrass Rivers that are unusable. Cumulative errors embedded within the estimates cast serious doubt on the extremely small net gains or losses used in the FEIS to claim that the NorthMet impact would have no net impact on downstream loading of inorganic mercury.

The FEIS continues to rely on several insufficiently substantiated assumptions regarding collection of seepage from both the mine site and tailings basin to assert that surficial groundwater won't be impacted by release of sulfates to methylating environments. In my opinion, the data presented in the FEIS is insufficient to discount the potential for seepage of sulfates and associated impacts to wetlands in the vicinity of both the project mine site and tailings basin. Such seepage would enhance methylmercury production in the project area and could also contribute directly to water quality impairments in sulfate-poor sediments downstream of the project site.

Unchanged from the SDEIS, the FEIS continues to rely heavily on the implementation of a Waste Water Treatment Plant (WWTP) with Reverse Osmosis (RO) at the tailings basin and the addition of further Reverse Osmosis (RO) water treatment facility at the mine site Waste Water Treatment Facility (WWTF) upon closure, to reduce sulfate and mercury concentrations in captured seepage from wastes, and tailings seepage water prior to discharge to surface waters. Additional flaws in the logic of this approach were revealed to me after reviewing additional documents that arose from the SDEIS review. The comment by Daniel Pauly (see materials referred) was helpful in directing me to review project pilot test information about treatment technologies, which, like many other aspects of the FEIS, turn out to be deficient with respect to mercury.

In fact, the pilot test cited in the FEIS (Barr 2013f) includes no testing and provides no certainty concerning the removal of mercury or methylmercury from tailings basin seepage or other recovered waters as part of the proposed NorthMet development. When combined with the uncertainty of other FEIS estimates concerning mercury inputs to treatment plant influent, I have no confidence that these proposed strategies will succeed in meeting water quality guidelines. Pauly rightly identifies that the project's proposed "adaptive engineering" approach will lead to decades of reactive actions to impaired water quality triggers. Moreover, the release of sulfate and mercury (particularly that which has been atmospherically deposited) from watersheds may occur after a significant lag time associated with sequestration, biogeochemical processing and subsequent release to the downstream environment. This lag time may be at least a decade (and likely multiple decades) in time scale (see Harris et al., 2005; Munthe et al., 2007) indicating that potential impacts may not be revealed in a way that adaptive engineering can manage, resulting in what will effectively be a permanent downstream impairment.

3 Conclusions Concerning the FEIS

There are no modifications to the FEIS from the SDEIS that change my opinion that the likelihood of downstream water quality impairments from mercury and methylmercury as a result of the proposed NorthMet development is not scientifically or rigorously evaluated in the EIS. The mass balance model used by the FEIS to deny the potential impact of inorganic mercury loading to downstream waters is neither reasonable nor based on reliable data. The FEIS' misleading precision regarding inorganic mercury releases serves as a distraction from the far more significant impacts of the NorthMet project on increased production and export of methylmercury, the form of mercury that bioaccumulates and poses risks both to aquatic life and wildlife and to human health.

As I stated in my opinion on the SDEIS, the NorthMet project would result in the potential for downstream impacts to ecosystems, and potentially to human health, through the exposure to increased methylmercury concentrations in surface waters and the aquatic food chain.

In fact, since my prior opinion, additional methylmercury data included in the FEIS and supporting references and newly-published peer-reviewed literature reinforces and strengthens the conclusion from my previous opinion. The methylmercury data from the mine site tributaries and Partridge and Embarrass Rivers, in particular, reveal a landscape that is sensitive to mercury contamination, and already has high potential to convert inorganic mercury to methylmercury (i.e. many potential sites of methylation that are hydrologically connected to receiving waters). Moreover, recent credible scientific findings about sulfate regeneration and enhanced methylation in bogs that are subjected to wetting and drying cycles leads me to a justifiable concern that increased drying from dewatering near the proposed NorthMet mine site and tailings site would further the increase the potential of these watersheds to produce and export methylmercury. These potential drying and wetting impacts will be superimposed onto a changing climate over the next century that will further enhance drought and rewetting effects on methylmercury production in wetlands.

Increased mercury methylation in wetlands at the NorthMet mine and tailings basin site as well as potential direct releases of mercury, sulfate and methylmercury from the project create a substantial risk of increased methylmercury in project site tributary streams, in the Partridge and Embarrass Rivers and downstream in the St. Louis River. My conclusion is based on the preceding opinion, the opinion I submitted commenting on the SDEIS and the accepted conceptual understanding of wetland methylation and downstream impact summarized below:

1. Methylmercury is produced in the methylation "hot spots" in the landscape (wetlands). This methylation may be enhanced by direct and indirect impacts of the proposed

development that include hydrological impacts, the atmospheric deposition of sulfate, and to a lesser degree, the atmospheric deposition of mercury.

2. Wetlands (including true ombrotrophic bogs) are the water supply for the headwater tributaries of the Partridge and Embarrass Rivers.

3. Methylmercury is exported in both baseflow (continuous supply to streams) and stormflow (during snowmelt and rainstorms) runoff from these wetland sites of production to headwater tributaries of the Partridge and Embarrass Rivers.

4. As wetlands are the source of much of this methylmercury, most will be bound to dissolved organic matter (derived from the decomposition of wetland organic soils) in water, which stabilizes methylmercury in solution, even under oxygenated conditions.

5. Methylmercury is transported in the Partridge and Embarrass Rivers. Along the flowpath, some methylmercury will be sorbed to particles, bound to plant matter and algae, and bioaccumulated into aquatic organisms including fish. Binding to dissolved organic matter will reduce photodemethylation rates due to both the molecular binding, as well as light attenuation from the water color associated with organic matter (and iron, as may be the case).

6. Methylmercury dissolved in water, suspended organic and inorganic particles, and biological media will continue downstream in the Partridge and Embarrass Rivers and flow into the St. Louis River. This methylmercury will continue to cycle as described in the above paragraph 5. By rough approximation, the distance between headwater tributaries proximal to the Plant Site (Embarrass River Watershed) and the Mine Site (Partridge River Watershed) are roughly 12-15 miles from the St. Louis River. There are numerous lakes, reservoirs, and other sources and sinks of methylmercury along these flowpaths, however there is no physical or chemical basis to discount contributions of methylmercury from the upper tributaries of the Partridge and Embarrass Rivers to the St. Louis River.

7. There are no barriers to fish movement among the tributaries and the St. Louis River, so entry of methylmercury into higher organisms and fish could occur at upstream in the Partridge and Embarrass Rivers and fish could migrate downstream to the St. Louis River.

In conclusion, I reject as unsupported and without scientific justification, any statement or implication in the FEIS that the proposed NorthMet development would not increase risks of methylmercury production and transport in the Partridge and Embarrass River watersheds, particularly in ombrotrophic wetlands near the mine site and wetlands affecting by tailings site seepage collection, changes to hydrology or atmospheric deposition. Based on the relatively high concentrations of methylmercury, and more importantly the high percentage of total mercury that is methylmercury in mine tributary streams and in the Partridge and Embarrass Rivers as well as the scientifically accepted mechanisms of methylmercury production and transport, it is clear that the watersheds impacted by the proposed development contain significant sites of methylmercury production, and therefore are sensitive to changes presented above that would result in enhanced methylmercury production.

It is my opinion that the NorthMet development could create a substantial risk of ecologically significant increases in water column and fish methylmercury concentrations in downstream waters, including the St. Louis River. Finally, even if appropriate monitoring for biogeochemical changes in wetlands and sediments near the development were to be designed and implemented (a difficult and complex undertaking requiring collection of baseline data not supplied in the FEIS), it is highly likely that lag times for expression of methylmercury increases, multiple mechanisms of transport, and the likelihood of legacy regeneration of sulfate stored in the watershed would preclude effective adaptive management prior to irreversible impairment of downstream waters.

4 Materials Referred

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2. BARR, Final Pilot Testing Report: Plant Site Wastewater Treatment Plant Pilot Testing Program 2013f
3. BARR, Technical Memorandum: Ongoing groundwater and surface water data collection for NorthMet water quality modeling - Version 5, 2014d
4. BARR, Mercury Overview: A summary of potential mercury releases from the NorthMet Project and potential effects on the environment, 2015f
5. Branfireun, BA, Expert Opinion concerning the NorthMet Mining Project and Land Exchange Supplemental Draft Environmental Impact Statement, 2014.
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20. Whittington and Price (2013) Effect of mine dewatering on the peatlands of the James Bay Lowland: the role of marine sediments on mitigating peatland drainage, HYDROLOGICAL PROCESSES, 27, 1845–1853. 2013.

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5 Curriculum Vitae - Branfireun

PERSONAL INFORMATION

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APPOINTMENTS AND POSITIONS HELD

CURRENT

- **Associate Professor** with Tenure Department of Biology, Western University (2013-current)
- **Canada Research Chair** (Tier 2: renewed July 2015. Term: 2015-2020).
- **Adjunct Professor (Graduate Supervision)**, Department of Biology, University of Waterloo (2015-2020)
- **Adjunct Professor (Graduate Supervision)**, Department of Geography, University of Waterloo (2013-2018)
- **Adjunct Professor (Graduate Supervision)**, Department of Geography, Nipissing University (2015-2020)
- **Adjunct Professor (Graduate Supervision)**, Queen Mary University of London, UK (2011-2015)
- **Adjunct Professor (Graduate Supervision)**, Swedish Agricultural University, Uppsala, Sweden (2014-2018)
- **Director**, Biotron Centre for Experimental Climate Change Research (2012-2017).

PREVIOUS ACADEMIC APPOINTMENTS

- **Associate Professor** (probationary) Department of Biology, Western University (2010-2013)
- **Associate Professor** (with tenure) University of Toronto Mississauga Department of Geography (2005-2010)
- **Assistant Professor** (probationary) University of Toronto Mississauga Department of Geography (1999-2004)

PREVIOUS ADMINISTRATIVE APPOINTMENTS

- **Director**, Faculty of Science Integrated Materials Analysis and Characterization Network (2011-2012).
- **Acting Chair**, UTM Department of Geography (March/05 to June/05)

- **Interim Chair**, UTM Department of Geography (July/05 to June/06)
- **Director**, UTM Programs in Environment (July 2004 – June 2009)

6 3. EDUCATION AND QUALIFICATIONS

PhD	1999	McGill University, Montreal, Canada. Dissertation: Catchment-scale hydrology and methylmercury biogeochemistry in the low boreal forest zone of the Precambrian Shield. Supervisor: N. T. Roulet
MSc	1994	Geography, York University, North York, Ontario, Canada. Thesis: The hydrology of a precambrian shield peatland: controls on methylmercury formation and flux. Supervisor: N. T. Roulet
HBA	1992	Geography, University of Western Ontario, London, Ontario, Canada. Thesis: Patterns of flow in a gravel-bed river bend. Supervisor: P. Ashmore

AWARDS and RECOGNITIONS

2008 Canadian Geophysical Union Young Scientist Award. Award made at the 2008 Canadian Geophysical Union Annual General Meeting, Banff, AB.

SERVICE AND ADMINISTRATION

SOCIETY MEMBERSHIP

- Soil Science Society of America (since 2014)
- Canadian Geophysical Union (since 1993)
- American Geophysical Union (since 1993)
- International Association of Great Lakes Research (2011-13)

INTERNATIONAL SERVICE (Last 5 Years)

1. **Co-organizer,** Canadian bid to host 2019 Quadrennial Assembly of the International Union of Geodesy and Geophysics in Montreal, QC.

   Myself as President of the CNC-IUGG (see 2.) along with Dr. G. Young (past president of the International Assoc. of Hydrological Sciences) were behind a national bid to host an important meeting of >6000 international delegates. This bid was successful at the Quadrennial meeting in Prague in June 2015, and I will be co-hosting this meeting in 2019 in Montreal.

2. **President**, Canadian National Commission – International Union of Geodesy and Geophysics (2013-2015) (iugg.org). Associated with national service items 11-13.

3. **Technical Review Committee Member**, US Department of Energy Oak Ridge National Laboratory (ORNL) Mercury Science Focus Area (SFA) Review, Washington, DC (2012; 2015)

   My involvement in federal and state review programs pertaining to mercury in the environment has been ongoing since the early 2000s. My invitations to serve on this US DOE review committee is evidence of my continued credibility in the most up to date areas of mercury research.

4. **Science Advisory Panel Member** for Sensing the Americas' Freshwater Ecosystem Risk (SAFER) from Climate Change, Instituto Argentino de Oceanografía, Argentina. (2013-).

   I was asked to serve on this Panel as a result of my internationally recognized expertise in wetlands, aquatic systems and environmental change and oversee the scientific direction of a lake monitoring network that spans all of the Americas from Argentina to northern Canada.

5. **Technical Advisory Committee Member:** California Central Valley Regional Water Quality Control Board Technical Advisory Committee (Mercury Control Projects) Member (2012-2018)

6. **Scientific Advisory Panel Member:** CALFED Yolo Bypass Mercury Project, Sacramento California (2012-2014)

   Pertaining to 5) and 6), The research and regulatory community in the State of California has recognized my expertise in mercury and wetland ecosystems. I have served on numerous advisory and grant review panels for California since the mid-2000s and have had decision-making influence over the trajectory of funding programs valued in excess of $25M.

7. **Host Scientist and Convener:** 10th International Conference on Mercury as a Global Pollutant, Halifax, Nova Scotia. July, 2011.

   This biannual international conference was secured by a bid by a team of Canadian scientists at the 2006 meeting and was 6 years in planning and execution. The meeting attracted over 1000 international scientists to Canada.

8. **National Correspondent on Water Quality**: Canadian National Commission of the International Association for Hydrological Sciences (2007-2011).

NATIONAL SERVICE (Last 5 Years)

9. **Group Co-Chair** NSERC Discovery Grant Evaluation Group 1506 Geosciences (2015-16)

10. **Committee Member** of NSERC Discovery Grant Evaluation Group 1506 Geosciences (2013-16)

    As part of the NSERC DG review process, committee members are provided access to ~250 proposals and CCVs in the fall, review for comfort level, are assigned ~60 as a first to fifth level reviewer, provides full reviews and rankings of these, along with any from other cognate committees (in my case additional ~5 per year from Engineering, Chemistry and Ecology & Evolution). The review process is ~300 hours of effort from Sept – February. Additionally, a full week is committed to the review panel meeting in Ottawa in February. For the 2016 competition I have been asked by NSERC to serve as a Group Co-Chair which means that in addition to my reviews I will assist the Program Officer with decisions concerning group membership, cross-committee review files, and will co-ordinate and oversee approximately 1/3 of the review process in Ottawa.

11. **President**, Canadian Geophysical Union (2013-2015) (www.cgu-ugc.ca)

12. **Vice-President** of the Canadian Geophysical Union (2011-2013)

13. **President** of the Canadian Geophysical Union – Hydrology Section (2009-2011)

Applies to previous 3 entries. The CGU is the national scientific society representing the geophysical sciences in Canada and is the representative of Canada at the International Union of Geodesy and Geophysics (IUGG).

14. **Co-Organizer**: Joint Congress of the Canadian Water Resources Association and the Canadian Geophysical Union, Banff, AB. May 2010.

UNIVERSITY SERVICE (Last 5 Years – Western University Only)

15. Co-Chair, Northern Scientific Training Program Committee (2015-16)

16. Chair, Search Committee for Tier 1 CRC in Complex Systems Modelling (2014-2015)

17. Member, Search Committee for Senior Hire in Adaptation to a Changing Environment (2014-2015)

18. Internal Research Tools and Instruments Screening Review Panel (Western – 2014)

19. Member, Faculty of Science Environment & Sustainability Focus Area Executive Committee (2013-)

20. Director, Biotron Centre for Experimental Climate Change Research (2012-2017).

21. Director, Faculty of Science Network for Materials Analysis and Characterization Facilities (2011-2012)

22. Member, Department of Biology Research Committee (2013-).

23. Member, Environmental Science Undergraduate Program Advisory Committee (2011-).

24. Co-Chair, Northern Scientific Training Program Committee (2011-12)

OTHER SERVICE (Last 5 Years)

25. Member, City of London Advisory Committee on the Environment (2015-)

26. Engagement with provincial ministries (Environment, Natural Resources) on matters concerning provincial planning and priorities e.g. meeting with MOECC Regional Managers in Thunder Bay for discussion about hydrological and biogeochemical implications of road construction across peatlands for Ring of Fire mineral development. (on-going; generally 3-5 presentations and/or teleconferences per year)

27. Engagement with non-for-profit sector through lecture and scientific advising (on-going; generally 3-5 presentations and/or teleconferences per year)

28. Engagement in legal matters (e.g. expert opinion) on mercury related cases (Canada and United States) (on-going; involved in 1-2 cases per year through provision of expert opinions and consultations [e.g. http://justchangelaw.com/2015/04/detailed-comments-submitted-on-minnesotas-first-proposed-sulfide-mine/]). This work is undertaken in the interest of the public good and environmental protection, and is done on my personal time. I do not seek out such activities but am contacted directly by stakeholders and interested parties.

29. Reviewer of manuscripts for peer-reviewed journals (*personal quota of 20 per year*): Analytica Chemica Acta, Arctic, Hydrological Processes, Water Air and Soil Pollution, Wetlands, The Science of the Total Environment, Ecosystems, Biogeochemistry, Global Biogeochemical Cycles, Canadian Journal of Fisheries and Aquatic Sciences, Environmental Toxicology and Chemistry, Journal of Geophysical Research - Biogeosciences; Water Resources Research, Water Research, Environmental Science & Technology, Science, Nature Geoscience.

30. Reviewer of research grant proposals (*personal quota of 10-12 per year; in 2013-16 much more because of NSERC Discovery Grant committee service*): Natural Science and Engineering Research Council (NSERC - Canada); Canada Research Chair Program; Canada Excellence Research Chair Program; Canada Foundation for Innovation; Natural Environment Research Council (NERC - Great Britain); CALFED (California Bay Area Restoration Project); US Geological Survey - National Institutes for Water Resources Competitive Grants Program, US National Science Foundation.

RESEARCH GRANTS (last 5 Years)

APPLIED FOR

Title	Dates	Total Amount	Agency	Co-Investigators	% of Award to BB
A portable ultra-trace mercury analysis system	2016-2017	$92,000	NSERC Research Tools and Instruments	Swanson, H, Laird B, Power, M (UWaterloo)	25%

AWARDED

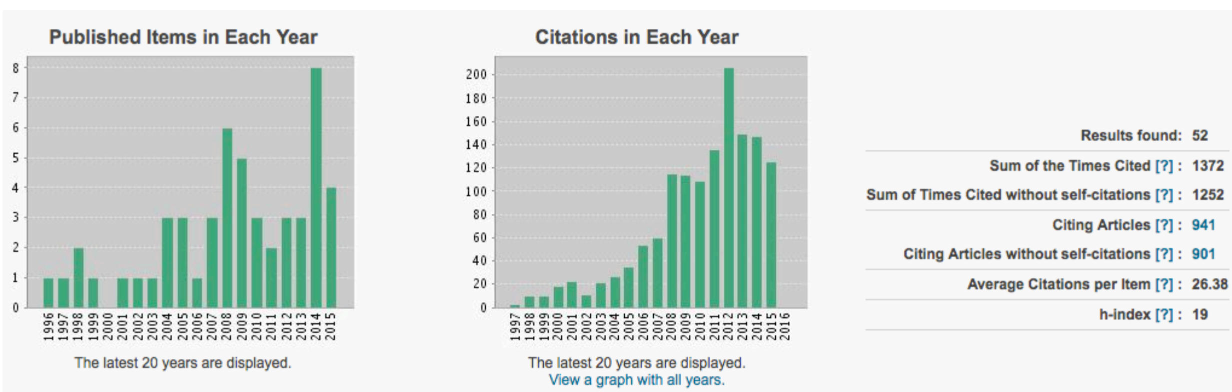
Title	Dates	Total Amount	Agency	Co-Investigators	% of Award to BB
Northern Peatland Ecosystem Responses to Climate Change	2015-2018	$516,281	NSERC Strategic Partnership Grants	Branfireun, Petrone R (UWaterloo) and 3 others	33%
Biological (biofilm and zooplankton) indicators to monitor aquatic ecosystem health with communities across the NWT	2015-2018	$60,650	Canadian High Arctic Research Station Science and Technology Program	Dr. E Kelly, Associate Deputy Minister, NWT, 28 First Nations Communities	~33%
Understanding contaminant levels in commonly consumed fish of Kluane Lake, Yukon	2015-2016	$22,425	AANDC: Northern Contaminants Program	Chief Mathieya Alatini, H. Swanson, R. Hall (UWaterloo) and 9 others.	15%
Mercury cycling and bioaccumulation in fluctuating hydroelectric reservoirs	2015-2016	$60,000	Ontario Ministry of the Environment and Climate Change		100%

A field-based experimental system for the evaluation of the effects of elevated temperature and CO2 on peatlands	2014-2015	$148,612	NSERC Research Tools and Instruments	Z. Lindo (PI), B. Branfireun, R. Petrone (UWaterloo) and 3 others	50%
Bioavailability of mercury in aquatic food webs	2014-2015	275 000 DKK	Nordic Cooperation Committee	K. Bishop (Uppsala University)	50%
NSERC Canadian Network for Aquatic Ecosystem Services	2012-2016	$4,416,625	NSERC Strategic Networks	D. Jackson (UofT lead); and 22 others, including H. Swanson, J.S. Price (UWaterloo).	~5%
In situ optical sensors for the characterization of dissolved organic matter and other solute fluxes in remote rivers and ocean waters	2012	$53,000	Western Academic Development Fund	C. Trick	50%
Cluster for Subarctic Ecosystems in Transition, C-SET.	2012-2014	$451,545	Canadian Space Agency	B. Quinton (Laurier – lead), Branfireun (co-lead), R. Petrone, M. Macrae (UWaterloo)	15%
Water Resource Management in Dry Subtropical Mexico	2011	$5500	UWO		100%
An Inductively Coupled plasma mass spectrometer and other isotopic tools to study the interactions of carbon and trace metal biogeochemistry in the environment	2010-2011	$210,483	Canada Foundation for Innovation		100%
An Inductively Coupled plasma mass spectrometer and other isotopic tools to study the interactions of carbon and trace metal biogeochemistry in the environment	2010-2011	$210,483	Ontario Research Fund		100%
Hydrology and mercury biogeochemistry of the Hudson Bay lowland	2009-2016	$240 000	NSERC (Discovery Grant – 3 year extension for NSERC Committee Service)		100%

Implications of Climate Change on Ontario Far North Peatlands and peatland carbon dynamics	2009-2012	$250 000	Ontario Ministry of Natural Resources	N. Basiliko, S. Finkelstein (UToronto)	33%
The Impact of Mine Dewatering on the Hydrology and Mercury Biogeochemistry of Peatlands in the Hudson/James Bay Lowland: The De Beers Victor Diamond Mine	2008-2013	$1 452 708 (NSERC+Industry)	NSERC and De Beers Canada (NSERC-CRD)	J.S. Price (Waterloo) V. Remenda (Queens)	33%
Synthesizing watershed mercury dynamics using a fish sentinel monitoring program	2009-2011	$150 000	Ontario Ministry of the Environment		100%
Mechanistic coupling of atmosphere-vegetation-surface transfers of mercury along an urban-rural gradient.	2008-2010	$68 100	Great Lakes Air Deposition Program	G. Mierle (MOE) E. Prestbo (Tekran Inc). (BB Lead PI, other collaborators non-funded)	100%

PUBLICATIONS (all time)

7



ISI Web of Science Citation Report: October 14, 2015

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1. Dieleman, CM*, Branfireun BA, McLaughlin, JW, and Lindo, Z. 2015. Enhanced carbon release from a northern poor fen under future climate conditions: Role of phenolic compounds, Plants and Soil, in press.
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3. Coleman Wasik, J.K., D.R. Engstrom, C.P.J. Mitchell, E.B. Swain, B. A. Monson, S.J. Balogh, J.D. Jeremiason, B. A. Branfireun, R.K. Kolka, J.E. Almendinger (2015) Hydrologic fluctuations and sulfate

regeneration increase methylmercury in an experimental peatland, Journal of Geophysical Research – Biogeosciences, 120: 10.1002/2015JG00299

4. Li, J, Drouillard, K, Branfireun, B, Haffner, G. D, A Comparison of the Toxicokinetics and Bioaccumulation Potential of Mercury and Polychlorinated Biphenyls in Goldfish (Carassius auratus), Environmental Science & Technology, 49(18), 11019-11027.

5. Malczyk, E.*, Branfireun, BA. 2015. Wetlands reduce mercury exposure risk in a tropical lake ecosystem. SCIENCE OF THE TOTAL ENVIRONMENT Science of the Total Environment DOI: 10.1016/j.scitotenv.2015.04.015. pp. 260-268

6. Bond, A., K. Hobson and BA Branfireun, 2015. Rapidly increasing methyl mercury in endangered Ivory Gull (Pagophila eburnea) feathers over a 130-year record, PROCEEDINGS OF THE ROYAL SOCIETY B, 282(1805), 20150032.

7. Dieleman, CM*, Branfireun BA, McLaughlin, JW, and Lindo, Z. 2014. Climate change drives a shift in peatland ecosystem plant community: Implications for ecosystem function and stability. GLOBAL CHANGE BIOLOGY (21)1, 388-395, 2015.
8. Morris, MA*, Spencer, KL, Belyea, LR, Branfireun BA, Temporal and spatial distributions of sediment mercury in restored coastal saltmarshes. MARINE CHEMISTRY, (167),150-159, 2014.
9. Cole, AS, Steffen, A, Eckley CS, Narayan J, Pilote M, Tordon R, Graydon JA, St. Louis, Branfireun BA, A survey of mercury in air and precipitation across Canada: patterns and trends, ATMOSPHERE, 5(3), 635-668, 2014.
10. Farrick, KK*, Branfireun, BA. Soil water storage, rainfall, and runoff relationships in a tropical dry forest catchment, WATER RESOURCES RESEARCH, (50)12, 9236-9250, 2014.
11. Oswald, CJ*, Branfireun BA, Antecedent moisture conditions control mercury and dissolved organic carbon 1 concentration dynamics in a boreal headwater catchment, WATER RESOURCES RESEARCH, 50(8), 6610–6627, 2014
12. Denkenberger, J, Driscoll, C, Branfireun, B Warnock, A; Mason, E, A Fluvial Mercury Budget for Lake Ontario, ENV SCI TECHNOL., 48 (11), 6107–6114, 2014.
13. Farrick, KK* and Branfireun, BA. Infiltration and soil water dynamics in a tropical dry forest: it may be dry but definitely not arid. HYDROLOGICAL PROCESSES doi: 10.1002/hyp.10177, 2014
14. Orlova Y*, Branfireun BA, Surface water and groundwater contributions to streamflow in the James Bay Lowland, Canada, ARCTIC, ANTARCTIC AND ALPINE RESEARCH, 46(1), 2014.
15. Oswald, C J.*, Heyes, A; Branfireun, BA. Fate and Transport of Ambient Mercury and Applied Mercury Isotope in Terrestrial Upland Soils: Insights from the METAALICUS Watershed, ENVIRONMENTAL SCIENCE & TECHNOLOGY, 48(2), 1023-1031, 2014
16. Farrick, KK*, and Branfireun BA, Left high and dry: a call to action for increased hydrological research in tropical dry forests, HYDROLOGICAL PROCESSES, doi: 10.1002/hyp.9935, 2013.
17. Gupta V, Smemo, KA, Yavitt JB, Fowle D, Branfireun B, Basiliko N. Stable isotopes reveal widespread anaerobic methane oxidation across latitude and peatland type, ENVIRONMENTAL SCIENCE & TECHNOLOGY, 47 (15), 8273–8279, 2013
18. Ulanowski, T*, Branfireun BA, Small-scale variability in peatland pore-water biogeochemistry, Hudson Bay Lowlands, Canada, SCIENCE OF THE TOTAL ENVIRONMENT. 454–45.5, 211-218, 2013.
19. Coleman Wasik, JK, Mitchell, CPJ, Engstrom DR, Swain EB, Monson BA, Balogh SJ, Jeremiason JD, Branfireun BA, Eggert SL, Kolka RK, Almendinger, JE. Methylmercury declines in a boreal peatland when experimental sulfate deposition decreases, ENVIRONMENTAL SCIENCE & TECHNOLOGY, *46* (12), pp 6663–6671 **DOI:** 10.1021/es300865f, 2012.
20. Denkenberger.J.S. , C.T. Driscoll, B. A. Branfireun, C.S. Eckley, M. Cohen, P. Selvendiran, A synthesis of rates and controls on elemental mercury evasion in the Great Lakes Basin, ENVIRONMENTAL

POLLUTION, DOI: 10.1016/j.envpol.2011.06.007, 2011.

21. Oswald CJ*, Richardson MC, Branfireun BA, Water storage dynamics and runoff response of a boreal Shield headwater catchment, HYDROLOGICAL PROCESSES: DOI: 10.1002/hyp.8036, 2011.
22. Duval TP, Waddington, JM, Branfireun, BA, Hydrological and biogeochemical controls on plant species distribution within calcareous fens, ECOHYDROLOGY: DOI: 10.1002/eco.202, 2011.
23. Richardson, MC*, Mitchell CPJ, Branfireun BA, Kolka, RK, Analysis of airborne LiDAR surveys to quantify the characteristic morphologies of northern forested wetlands, Journal of Geophysical Research – Biogeosciences, 2010.
24. Duval, TP; Waddington, JM; Branfireun, BA Towards calcareous wetland creation in flooded abandoned aggregate quarries: A 3-year field mesocosm study, ECOLOGICAL ENGINEERING, 36(4), 586-595, 2010.
25. Sunderland, EM; Dalziel, J; Heyes, A, Branfireun, BA, Krabbenhoft, DP and FAPC Gobas Response of a Macrotidal Estuary to Changes in Anthropogenic Mercury Loading between 1850 and 2000, ENVIRONMENTAL SCIENCE & TECHNOLOGY, 44(5), 1698-1704, 2010
26. Richardson, MC*; Fortin, MJ; Branfireun, BA Hydrogeomorphic edge detection and delineation of landscape functional units from lidar digital elevation models, WATER RESOURCES RESEARCH 45, W10441. 2009.
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28. Branfireun, B.A. and M.L. Macrae. Advances in Canadian research coupling hydrology and water quality: 2003-2007. Canadian Water Resources Journal. 34(2), 187-194, 2009.
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30. Mitchell, CPJ*, BA Branfireun, and RK Kolka. Total mercury and methylmercury dynamics in upland-peatland watersheds during snowmelt, Biogeochemistry, 90:225–241, DOI 10.1007/s10533-008-9246-z. 2008.
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32. Eckley, CS*, Branfireun, B. Mercury mobilization in urban stormwater runoff. Science of the Total Environment, 403, 164-177. 2008.
33. Mitchell, CPJ*, BA Branfireun, and RK Kolka, Assessing sulfate and carbon controls on net methylmercury production in peatlands: An in situ mesocosm approach, Applied Geochemistry, 23, 503-518. 2008.
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BOOKS AND/OR CHAPTERS (Peer-Reviewed)

55. Krabbenhoft, D.P., B. A. Branfireun and A. Heyes, Biogeochemical cycles affecting the speciation, fate and transport of mercury in the environment, In Mercury: Sources, Measurements, Cycles, and Effects, M. B. Parsons and J. B. Percival (eds.), Mineralogical Assoc. of Canada. 2005.

MANUSCRIPTS SUBMITTED (Students under direct supervision are *)

56. Dieleman, CM*, Lindo, Z, McLaughlin, JW, Craig, A. and Branfireun BA. Climate change effects on peatland decomposition and porewater dissolved organic carbon biogeochemistry. Biogeochemistry. Submitted.

57. Gordon, J, Quinton, W., Branfireun, BA and D. Olefeldt, Methylmercury and dissolved organic matter along a wetland cascade within a thawing permafrost plateau, Northwest Territories, Canada, Arctic, Antarctic and Alpine Research, in review.

PRESENTATIONS (last 5 years)

SELECTED PAPERS PRESENTED AT SCIENTIFIC MEETINGS & SYMPOSIA (Last 5 Years. HQP are *, presenter is underlined if not BAB). Presentations at research network workshops (e.g. national NSERC strategic network), project working groups or other more local venues are **not** listed (between HQP and PI ~10 per year).

May 2015	Joint Assembly of the American Geophysical Union, Canadian Geophysical Union, Geological Association of Canada - Mineralogical Association of Canada, Montreal, QC. Branfireun, BA, Lindo ZL and McLaughlin, J. Lower water tables, not increased temperature, increase methylmercury production in northern peatlands under climate change. POSTER.
May 2015	Joint Assembly of the American Geophysical Union, Canadian Geophysical Union, Geological Association of Canada - Mineralogical Association of Canada, Montreal, QC. Branfireun, BA. Natural and anthropogenically-induced hydrological connectivity produces methylmercury hotspots in the Hudson Bay Lowlands, Canada. ORAL (invited).
Nov 2014	Soil Science Society of America Annual Meeting, Long Beach CA. Branfireun, BA, Lindo ZL and McLaughlin, J. Lower water tables, not increased temperature, increase methylmercury production in northern peatlands under climate change. ORAL (invited).
May 2014	Joint Assembly of the Canadian Geophysical Union and the Canadian Society of Soil Science, Banff AB. Despault T*, Branfireun BA, Fluorescence fingerprinting of dissolved organic matter in the Attawapiskat River Watershed – Towards the development of *in situ* proxies for mercury in northern waters POSTER. (Award Winner)
May 2014	Joint Assembly of the Canadian Geophysical Union and the Canadian Society of Soil Science, Banff AB. Farrick KK*, Branfireun BA, Wetting the sponge: Storage, rainfall and runoff relationships in a Mexican tropical dry forest ORAL. (Award Winner)

Aug 2013 11th International Conference on Mercury as a Global Pollutant, Edinburgh Scotland. Goacher, J.* and Branfireun BA, Evidence of millennial trends in mercury deposition in pristine peat geochronologies. ORAL.

Aug 2013 11th International Conference on Mercury as a Global Pollutant, Edinburgh Scotland. Morris, M.* Spencer, K, Belyea, L and Branfireun BA, Patterns of total and methylmercury in natural and restored coastal wetlands in south-east England. ORAL.

Aug 2013 11th International Conference on Mercury as a Global Pollutant, Edinburgh Scotland. Branfireun BA, 150 years of mercury accumulation in bogs in Eastern Canada. ORAL.

Jun 2013 Joint Assembly of the Canadian Water Resources Association, Canadian Geophysical Union, and Canadian Meteorological and Oceanographic Society Saskatoon, Sk. Kline, MI*, Branfireun BA, Base and event-flow hydrologic and biogeochemical connectivity in a fen-stream transition in the central Hudson Bay Lowland, POSTER. (Award Winner)

Jun 2013 Joint Assembly of the Canadian Water Resources Association, Canadian Geophysical Union, and Canadian Meteorological and Oceanographic Society Saskatoon, Sk. Farrick, KK* and Branfireun BA , Iinfiltration and percolation in a Mexican tropical dry forest soil: controls on near-surface soil water storage dynamics, POSTER. (Award Winner)

Jun 2013 Joint Assembly of the Canadian Water Resources Association, Canadian Geophysical Union, and Canadian Meteorological and Oceanographic Society Saskatoon, Sk. Branfireun BA , TR Moore, NT Roulet and J Turunen, 150 years of mercury accumulation in bogs in Eastern Canada ORAL.

Dec 2012 Annual Meeting of the American Geophysical Union, San Franscisco, CA, ON. Branfireun BA , TR Moore, NT Roulet and J Turunen, 150 years of mercury accumulation in bogs in Eastern Canada ORAL.

Jun 2012 Joint Assembly of the Canadian Water Resources Association and Canadian Geophysical Union, Banff, AB. Farrick, KK*, Branfireun BA . Infiltration and percolation in a Mexican tropical dry forest soil: controls on near-surface soil water storage dynamics (Poster)

Dec 2011 Annual Meeting of the American Geophysical Union, San Franscisco, CA, ON. Oswald, CJ*, Branfireun BA, Hydrological Controls on mercury concentration – discharge dynamics in a boreal shield catchment. ORAL. (Award Winner)

July 2011 10th International Conference on Mercury as a Global Pollutant, Halifax, NS. Branfireun BA and JS Price., Total mercury and methylmercury fluxes from peatland-dominated catchments of the Hudson Bay Lowlands, ORAL.

July 2011 10th International Conference on Mercury as a Global Pollutant, Halifax, NS. METAALICUS: Mercury and MeHg budgets for seven years of hg loading to lake 658, ELA, Ontario. GILMOUR, C, Harris, R, KELLY, C A.,HINTELMANN, H, KRABBENHOFT, D P., AMYOT,M, BLANCHFIELD, P, PATERSON, M, RUDD, J M.W., TATE, M, SANDILANDS, K, BEATY, K, LINDBERG, S, SOUTHWORTH, G, HEYES, A, ST. LOUIS, V, GRAYDON, J, BABIARZ, C, BRANFIREUN, B, HURLEY, J P. (oral)

July 2011 10th International Conference on Mercury as a Global Pollutant, Halifax, NS. Rapid declines in methylmercury production from decreased sulfate deposition to a boreal peatland, COLEMAN WASIK, J K., ENGSTROM, Daniel R., MITCHELL, Carl P.J., SWAIN, Edward B., MONSON, Bruce A., BALOGH, Steven J., JEREMIASON, Jeff D., KOLKA, Randall K.7, BRANFIREUN, Brian A., ALMENDINGER, James E. (oral)

July 2011 10th International Conference on Mercury as a Global Pollutant, Halifax, NS. Mercury processes under elevated carbon dioxide and soil warming in a peatland: hypotheses for the SPRUCE experiment. KOLKA, Randy, SEBESTYEN, Stephen, MITCHELL, Carl, NATER, Ed, BRANFIREUN, Brian, HANSON, Paul. (poster)

July 2011 10th International Conference on Mercury as a Global Pollutant, Halifax, NS. A synthesis of rates and controls on elemental mercury evasion in the great lakes basin. DENKENBERGER, Joseph S., DRISCOLL, Charles T., BRANFIREUN, Brian, ECKLEY, Chris S., SELVENDIRAN,
Pranesh (oral).

July 2011 10th International Conference on Mercury as a Global Pollutant, Halifax, NS. Watershed responses to changes in mercury loading: results from the terrestrial aspects of the METAALICUS project. TATE, Michael, SABIN, Thomas, DEWILD, John, ST. LOUIS, Vince, GRAYDON, Jennifer, BRANFIREUN, Brian, HARRIS, Reed, HEYES, Andrew, LINDBERG, Steve, SOUTHWORTH, George (oral)

July 2011 10th International Conference on Mercury as a Global Pollutant, Halifax, NS. Changes in mercury methylation in a boreal wetland previously enriched in sulfate: synergistic effects of atmospheric deposition and water-level fluctuations. ENGSTROM, Daniel R., COLEMAN WASIK, Jill, SWAIN, Edward B, MONSON, Bruce A., MITCHELL, Carl P. J., ALMENDINGER, James E., BALOGH, Steven J., BRANFIREUN, Brian A., KOLKA,Randy K., JEREMIASON, Jeff D. (oral)

July 2011 10th International Conference on Mercury as a Global Pollutant, Halifax, NS. Decline of ecosystem hg levels during the initial recovery phase of METAALICUS. HARRIS, Reed C., RUDD, John W.M., KELLY, Carol A., KRABBENHOFT, David P., ST. LOUIS, Vince, HINTELMANN, Holger, GILMOUR, Cynthia C., HEYES, Andrew, AMYOT, Marc, BRANFIREUN, Brian, BLANCHFIELD, Paul, GRAYDON, Jennifer, PATERSON, Michael, SANDILANDS, Ken, TATE, Michael T, DIMOCK, Brian, BEATY, Ken, BABIARZ, Christopher (oral)

July 2011 10th International Conference on Mercury as a Global Pollutant, Halifax, NS. Controls on the spatial distribution of ambient mercury and applied mercury isotope in a boreal shield soil landscape. OSWALD, Claire J, BRANFIREUN, Brian A, HEYES, Andrew. (Poster)

July 2011 10th International Conference on Mercury as a Global Pollutant, Halifax, NS. Hydrological controls on mercury concentration-discharge dynamics in a boreal shield catchment. OSWALD, Claire J, BRANFIREUN, Brian A, (oral) (Award Winner)

July 2011 10th International Conference on Mercury as a Global Pollutant, Halifax, NS. Assessing the variability of peatland solute and mercury biogeochemistry in the Hudson Bay Lowlands, Canada. ULANOWSKI, Tom, BRANFIREUN, Brian A. (poster). (Award Winner)

July 2011 — 10th International Conference on Mercury as a Global Pollutant, Halifax, NS. An analysis of lake Ontario's mercury budget: is it balanced? DENKENBERGER, Joseph S., DRISCOLL, Charles T., BRANFIREUN, Brian (oral)

July 2011 — 10th International Conference on Mercury as a Global Pollutant, Halifax, NS. Small-bodied fish as indicators of aquatic mercury exposure in surface waters of the Hudson Bay Lowlands, WARNOCK, Ashley L., ORLOVA, Yulia, BRANFIREUN, Brian A. (poster)

July 2011 — A comparison of yearling perch mercury variability in two headwater lakes: watershed versus in-lake controls. RICHARDSON, Murray and BRANFIREUN, Brian. (poster).

May 2011 — Canadian Geophysical Union Annual Meeting, Banff, AB. Branfireun BA and JS Price, Total mercury and methylmercury fluxes from peatland-dominated catchments of the Hudson Bay Lowlands ORAL.

May 2011 — Canadian Geophysical Union Annual Meeting, Banff, AB Assessing the Variability of Peatland Solute and Mercury Biogeochemistry in the Hudson Bay Lowlands, Ulanowski T., BA Branfireun (Poster) (Award Winner)

May 2011 — Canadian Geophysical Union Annual Meeting, Banff, AB Groundwater – surface water interactions in Catchments of the Hudson Bay Lowlands, Orlova, Y, BA Branfireun.

May 2011 — Canadian Geophysical Union Annual Meeting, Banff, AB Water storage dynamics and runoff response of a boreal Shield headwater catchment, Oswald, CJ, Richardson, MC and BA Branfireun Oral. (Award Winner)

Dec 2010 — Annual Meeting of the American Geophysical Union, San Francisco, CA, ON. Oswald, CJ, Branfireun BA*, Mercury-DOC dynamics in runoff during storm events in a Boreal Shield catchment ORAL.

May 2009 — Joint Assembly of the Canadian Geophysical Union and American Geophysical Union, Toronto, ON. M.C. Richardson*, B.A. Branfireun, M-J. Fortin, Quantitative geomorphic analysis with LiDAR DEMs: Case-studies from Boreal landscapes. ORAL.

May 2009 — Joint Assembly of the Canadian Geophysical Union and American Geophysical Union, Toronto, ON. Oswald, CJ* and BA Branfireun, Hydrologic connectivity and runoff response in the METAALICUS experimental catchment, ORAL.

INVITED PRESENTATIONS

May 2013 — University of Waterloo, Mercury Biogeochemistry and Hydrology in the central Hudson Bay Lowlands. Invited by: P. Van Capellen (CERC), Ecohydrology Speaker Series.

Oct 2012 — Uppsala University, Mercury cycling in Ontario's northern peatlands. Invited by: K. Bishop as part of the first international Workshop on Catchment Mercury Cycling.

April 2012 — Queen Mary University of London Department of Geography Invited Presentation (invited by K. Spencer, Department of Geography). Title: Hydrology and mercury cycling in the Hudson Bay Lowlands, Ontario, Canada.

April 2012	First International Meeting of the Network for Business Sustainability Ivey School of Business. London ON. Opening Address to the Congress: Tipping points, vulnerable ecosystems, mitigation and adaptation. (invited by Dr. T. Bansal).
Jan 2012	2012 Woo Water Lecture, School of Geography and Earth Sciences, McMaster University (invited by Dr. JM Waddington). Title: Mercury in Ontario's Far Northern Rivers: Exploring the connections between water, land, and traditional foods.