Expert Opinion of

Brian A. Branfireun, PhD

Concerning the NorthMet Mining Project and Land Exchange Supplemental Draft Environmental Impact Statement

Prepared for:

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Brian Branfireun at London Ontario Canada, March 10, 2014

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.

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). I am considered an international 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).

2. Peer-Reviewed Publications

I have authored or co-authored 42 published 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).

3. Summary of Opinions

In forming this opinion, I have reviewed in full, the document entitled NorthMet Mining Project and Land Exchange Supplemental Draft Environmental Impact Statement, November 2013. I have reviewed this document with the understanding that it is expected to contain all information, or summaries thereof, pertaining to the proposed project, and the environmental conditions that are pre-development, as well those that are anticipated during mine commissioning, operations, and closure. I have also referred to reports and published literature to substantiate my opinions. These documents are included in the folder entitled "Branfireun_Opinion_Materials_Referred".

Opinion 1: It is my opinion that the background site-specific analyses provided in the SDEIS concerning total mercury and methylmercury in surface and groundwaters 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.

Opinion 2: It is my opinion that the SDEIS fails to consider scientifically documented factors beyond simple changes in total mercury in the environment that govern mercury speciation and uptake when evaluating the potential impacts of mercury release as a result of the proposed development.

Opinion 3: In my opinion, 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. Models currently exist which could be implemented.

Opinion 4: 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.

Opinion 5: 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.

Opinion 6: 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.

4. Discussion of Opinions and Evidence

4.1 Opinion 1: The background site-specific analyses and data provided in the SDEIS concerning total mercury and methylmercury in surface and groundwaters 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.

As part of the evaluation of the potential impacts of the Northmet Mining Project on mercury methylation, it is necessary to reasonably establish the distribution of total mercury (THg) and methylmercury (MeHg), in potentially impacted waters (streams, rivers, lakes, groundwaters), wetlands (including peatlands), and soils and sediments prior to any proposed development. In my opinion the SDEIS has developed insufficient site-specific data to adequately inform an evaluation of the projected or actual impacts of the Northmet Mining Project on mercury methylation in the adjacent watersheds. My opinion to this effect is based on: **the lack of data** on background methylmercury in the SDEIS (4.1.1); **inconsistencies** in minimum detection limits for total mercury in data presented in the SDEIS (4.1.2), and; **failure to conform to standard approaches** with respect the manner with which Hg data is calculated, interpreted and then subsequently presented (4.1.3).

4.1.1. The SDEIS fails to make reference to methylmercury (the Hg species of concern) in the Predicted Environmental Consequences Of The Proposed Connected Actions section of the Executive Summary (ES-34-37) and this oversight is carried throughout most of the the document when actual data are being presented and discussed. SDEIS Section 4.2.2.1.4 Mercury (4-37) provides an overview of Hg in the Embarrass and Partridge

Rivers, where, in addition to total Mercury, it states 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 is the only reference to methylmercury in natural surface waters that I noted, and Table 4.2.2-4 (4-41) that is referred to in this section does not present MeHg data (only THg). The two values for MeHg stated in the text are thus relatively meaningless, given the lack of context and numerical basis. Given other issues with inconsistencies with the calculation and presentation of Hg data (see 4.1.3), this is a significant oversight. It is apparent that based on the overview statement quoted above, that MeHg data exists from sampling of the Partridge and Embarrass Rivers, yet is not included in the SDEIS data tables. Although some MeHg data is presented for the tailings pond and seeps (see 4.1.2) these data cannot reasonably compared to background data that is not presented. The absence of robust reporting of MeHg concentrations in surface waters that are potentially affected by the proposed development is contrary to the general understanding of Hg bioavailability, risk of exposure to fish and consumers, and best practices associated with changes in land-use and hydrology in Hg sensitive landscapes. It is in sharp contrast with my experiences in Canada, where northern mineral resource development permits are held to a strict standard for reporting of USEPA compliant Total Hg ***and*** MeHg data in water, sediment and biota.

Moreover, the SDEIS does not provide any THg or MeHg for sediments in lakes, rivers and streams, or wetlands, despite the importance of the solid phase in supplying both species to downstream waters either through *in situ* methylation or solid-liquid phase partitioning.

4.1.2. Mercury data presented throughout the SDEIS reflect (presumably) non-standardized analytical approaches and reporting which challenge data comparison. Background Hg data for the Partridge and Embarrass Rivers and associated waters in Table 4.2.2-4 (4-41) are reported with internally inconsistent detection limits. Although the method, and method detection limits (MDL) are never explicitly indicated (doing so is standard practice), one can infer the MDLs from the range data where "less than" (<) is the MDL. Data in Table 4.2.2-4 (4-41) may then be inferred to have been produced via a minimum of three different laboratories/methods with MDLs ranging from 0.1 ng/L to 2 ng/L. It is important to note that some of these inferred MDLs are above the USEPA's required MDL of 0.5 ng/L method for the detection of Total Mercury in Water (EPA Method 1631 rev. E). In this document, the US EPA states:

> **12.5 Reporting**
>
> 12.5.1 Report results for Hg at or above the ML, in ng/L, to three significant figures. Report results for Hg in samples below the ML as <0.5 ng/L, or as required by the regulatory authority or in the permit. Report results for Hg in reagent blanks and field blanks at or above the ML, in ng/L, to three significant figures. Report results for Hg in reagent blanks, method blanks, or field blanks below the ML but at or above the MDL to two significant figures. Report results for Hg not detected in reagent blanks, method blanks, or field blanks as <0.2 ng/L, or as required by the regulatory authority or in the permit.
>
> (USEPA, Method 1631 rev. E, 2002).

Given, this, some data is reported at MDLs > 4x the EPA requirement, and others are apparently more than 5x more sensitive. The acheivement of the lowest MDL of 0.1 ng/L is one that is be technically challenging to routinely achieve based on my own experience and laboratory, so in the absence of appropriate quality assurance data, I have difficulty accepting this detection limit. A lack of documentation in the SDEIS concerning this range of reported MDLs precludes data comparison, as it suggests that different analytical methods were employed and no cross-validation provided.

Other THg data presented have similar inconsistencies, including:

Table 4.2.2-6 (Summary of Existing Groundwater Quality Monitoring Data for the NorthMet Mine Site). Apparent MDL for Hg 0.25 ng/L.

Table 4.2.2-13 (Baseline Water Quality from the South Branch of the Partridge River). Apparent MDL of 500 ng/L where data are being reported from the 1970s – reliable trace mercury data in water were not reported until the mid-1980s so this data has no utility, and the absence of any more recent data is questionable.

Table 4.2.2-14 (Average Existing Water Quality Concentrations in the Partridge River). Apparent THg MDL of 0.0025 ng/L is analytically impossible using current technologies. I suspect that this is an error in reporting and highly problematic given that this is taken from the range of THg concentrations reported, which must also be in error.

Table 4.2.2-15 (Mean Water Quality Data for Longnose Creek, Wetlegs Creek, Wyman Creek, and West Pit Outlet Creek). Apparent THg MDL of 0.25 ng/L.

Table 4.2.2-23 (Existing Pond Water and Groundwater Quality at the Tailings Basin). Apparent THg MDL of 0.25 ng/L. Methylmercury also reported here with apparent MDL of 0.03 ng/L.

Table 4.2.2-24 (Summary of Existing Groundwater Quality Monitoring Data Downgradient from the Existing LTVSMC Tailings Basin). Apparent THg MDL of 0.25 ng/L. Methylmercury also reported here with apparent MDL of 0.05 ng/L.

Table 4.2.2-34 (Summary of Surface Water Quality Monitoring Data for the Tailings Basin Surface Seeps). Apparent THg MDLs range from 0.25 to 2 ng/L depending on sampling location. MeHg reported for one location with all samples detected (lowest is 0.15 ng/L) so no estimate of MDL is possible.

Table 4.2.2-6 (Summary of Existing Groundwater Quality Monitoring Data for the NorthMet Mine Site). Mercury data is presented under the "Total metals" part of the table as opposed to the "filtered" section. Unfiltered groundwater samples are unrepresentative of the mobile phase and should be discounted.

The presentation of Hg concentration data that is biased by insensitive analytical methods and subsequently high MDLs precludes a reasonable assessment of potential impact of the proposed development.

4.1.3. The manner in which background mercury data is calculated, interpreted and subsequently presented is inappropriate in all data tables and related analyses. The presentation of THg (and limited MeHg data) in all of the aforementioned tables are as arithmetic means and ranges. For data that is strongly skewed toward low values (in this case, many values <MDL), this is an inappropriate and misleading presentation of data. The central tendency of skewed data must be presented as the median value not the mean, and for data such as those in the SDEIS, the median will be (much) lower than the mean. As such, **representative background Hg concentrations will be lower than those reported in the SDEIS, and the relative magnitude of changes to those background Hg concentrations discussed in the SDEIS analyses as a result of changes in Hg load due to the Northmet development will be greater.**

The presentation of means and ranges precludes an assessment of the contention of the successful adherence to the following USEPA requirement:

> A statistical analysis indicated that total number of groundwater quality samples was sufficient, where "sufficient" was based on the USEPA 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 2012y).
> (SDEIS, p. 4-58)

This sort of analyses requires sufficient data to calculate a reliable mean and a measure of variance about that mean (see Ulanowski and Branfireun, 2013 and citations therein). Although there are different approaches to this problem, it is my opinion that this metric has not been applied appropriately or uniformly across the groundwater and surface water sampling program reported in the SDEIS, as ranges in data and sample numbers, at least qualitatively, fall well outside of this confidence statement, in my opinion. Most importantly, this standard is untestable since no measure of variance is presented with the summary statistics of any of the data. Ranges of concentrations are meaningless as a measure of variance. **This observation affects all reported water chemistry data in the SDEIS, including mercury and sulfate.**

4.1.4. The SDEIS does not use currently accepted methods for interpreting non-detect samples in the background data presented. In all data tables where non-detect samples are reported, the tables are footnoted with the following statement:

> Where non-detects occur, the mean was calculated using half the detection limit.

The contemporary state of the science does not accept this simplistic handling of non-detect samples. This matter is critical when MDLs are relatively high, and there is a significant proportion of reported data as non-detects, as is the case in many instances here. The appropriate handling of non-detect values when calculating descriptive statistics or loads is well described in Helsel's seminal paper, "Fabricating data: how substituting values for nondetects can ruin results, and what can be done about it" (Chemosphere, 65, 2006: 2434-2439). The application of techiques such as Maximum Likelihood Estimation for predicting the distribution of non-detect values are expected of those of us attempting to publish in the scientific literature; the SDEIS should be held to this standard. **This observation affects all reported water chemistry data in the SDEIS, SDEIS, including mercury and sulfate.**

All of the concerns expressed associated with this Opinion call into question the assessments of relative impact of the proposed project on mercury presented within the SDEIS. For example, the NorthMet Project Proposed Action is predicted to increase mercury loadings in the Embarrass River, but decrease mercury loadings in the Partridge River. The net effect of these changes would be an overall reduction in mercury loadings to the downstream St. Louis River. (5-8; 5-210). These assertions may be inaccurate and/or incorrect if the background Hg concentration data were re-evaluated in a more technically appropriate manner. **It is likely that the loadings to the Embarrass River may increase concentrations to a much greater degree than predicted, and it is also possible that loadings to the Partridge River will not decrease if the estimated background concentrations are in fact lower than those presented in the SDEIS, and appropriate uncertainties are considered in the analyses.**

4.2. Opinion 2: 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 SDEIS contends that:

> "Research suggests that total mercury concentrations in streams and methylmercury content in fish are roughly proportional within individual watersheds (USGS 2010), such that, for example, a 5 percent increase in total mercury in water would be expected to result in about a 5 percent increase in mercury content in fish within that watershed." (SDEIS, p. 5-21).

The citation points to a USGS information website: (http://toxics.usgs.gov/highlights/mercury_response.html), that is in fact, an overview of a project on which I was a co-investigator (see Branfireun et al., 2005; Harris et al., 2007). I can say uneqivocally that the above statement from the SDEIS that is attributed to the USGS is not a statement which is derived from either the website referred do, nor the research discussed therein.

The Mercury Experiment to Assess Atmospheric Loadings in Canada and the United States (METALLICUS) has indeed, found that changes in fish tissue mercury concentration is positively related to changes in simulated atmospheric inputs of mercury directly to a lake surface. However, these changes were not proportional, are lagged temporally, and are very dependent on lake and watershed characteristics. In particular, the direct response of fish to changes in mercury loading from precipitation speaks only to one component of the project results and does not go on to consider the longer term role of mercury in runoff from the watershed in delaying the decline of mercury in fish.

The SDEIS oversimplifies or fails to address other factors that affect Hg fate and transport in its assessment of potential impacts of the proposed Project on downstream water quality. For example:

> "*All samples [from monitoring locations at or near the tailings basin] were well below average concentrations in precipitation (approximately 9.8 ng/L).*" (SDEIS 5-21)

This statement implies that precipitation-derived Hg is a larger and more important source than runoff from tailings, but is misleading since a) the data is from a 2003 source which cannot account for a trend in decreasing Hg in precipitation in Minnesota; b) fails to recognize that precipitation-derived Hg is primarily delivered to the watershed, and is not a significant direct input to surface waters; c) 75-80% of Hg loading to most aquatic ecosystems is from runoff (Harris et al., 2007) with small seepage lakes and the Laurentian Great Lakes being exceptions.

> **5.2.2.3.4 Mercury** (SDEIS 5-201). "*Current scientific understanding of the factors and mechanisms affecting mercury methylation and bioaccumulation is limited.*"

Based on the burden of evidence in the scientific literature, this is an inaccurate statement. A thorough discussion of the response of fish tissue Hg concentrations to changes in Hg loading is easily found in Munthe et al. (2007), where a multitude of factors, based on a significant body of other literature, are described in governing the response of fish tissue Hg in response to changes in Hg loading. This scientific review identifies: **Sulfur**, particularly the balance between available sulfate and sulfide in the methylating environment; **pH**, where acidic environments tend to enhance Hg methylation and uptake by biota; **Organic matter**, which affects the complexation, bioavailability and methylation of Hg; **Iron**, through complexation with sulfur and organic matter, as well as now the *known role of some iron-reducing bacteria in Hg methylation*; **Hg "aging"**, where "newer" Hg has been shown to have a different reactivity and potentially greater methylation potential than older Hg that is stored in the watershed, and;

Type and activity of bacteria, where biogeochemical conditions such as redox state of the sediments, organic matter quality and temperature will directly affect the processes of methylation and demethylation. This review makes it clear that many factors ultimately govern the transformation of inorganic Hg to MeHg, in addition to the absolute amount of inorganic Hg in the environment.

In a contradictory statement several pages later, The SDEIS goes on to acknowledge these factors, indicating that:

> *"There are several factors that appear to influence mercury methylation, including total available mercury, organic carbon, temperature, micronutrients required by sulfate-reducing bacteria, sulfate loadings ... but the effect on two of these, sulfate concentrations and hydrologic conditions, warrants further discussion ... Recent research in northern Minnesota suggests that increased atmospheric sulfate loading to a peatland can result in increased mercury methylation and export (Jeremiason et al. 2006) ... However, the relationship between sulfate concentration and methylmercury production is complicated. ... Branfireun and Roulet (2002) found a negative relationship between sulfate and methylmercury in a wetland, which they interpreted as showing that methylmercury production at that site was caused by the reduction of sulfate."* (SDEIS 5-207, 5-208).

This section clearly identifies increased sulfate loading as implicated in enhancing Hg methylation, yet by its wording, suggests that the scientific literature is conflicted in its findings. Upon close reading of the cited material, it is clear that there is no disagreement in the scientific literature on this issue. Jeremiason et al. (2006) found that increased sulfate loading to a peatland in north-central Minnesota increases mercury methylation and export. The SDEIS fails to go further and state that these authors also found that sulfate concentrations in the peat and waters quickly decreased to below detection level after sulfate addition because of the process of sulfate reduction (and mercury methylation). This is precisely the conclusion of Branfireun and Roulet (2002) (sulfate concentrations decrease as methylmercury concentrations increase), yet the citations are presented as conflicting results in the SDEIS with the inclusion of the word, "However". The scientific literature, including those cited in the SDEIS, is uneqivocal on this issue: increased sulfate loading to freshwater systems increases MeHg production.

4.3. Opinion 3: 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.

As above in section 6.2, the SDEIS presents blanket statements concerning the lack of scientific knowledge concerning the cycling of mercury, and as a consequence, an inability to effectively model its dynamics in receiving waters.

5.2.2.3.4 Mercury (SDEIS 5-201). *"Mercury was not included in the GoldSim model, as insufficient data and a general lack of definitive understanding of mercury dynamics prevented modeling mercury like the other solutes."*

This is an inaccurate and misleading statement, and implies that Hg does not conform to basic chemical laws, and is unmodellable given current knowledge. A more accurate statement would be that, "The model that was employed as part of this assessment does not include Hg dynamics. This is a deficiency of the model.". Other models that focus on mercury dynamics address these processes, including the well-established D-MCM (see http://www.reed-harris.com/modeling-mercury-cycling-and-bioaccumulation-in-lakes/ for overview) or work by USEPA scientists Knightes et al. (2009) for a review of a number of ecosystem models for mercury cycling and bioaccumulation and their application to a range of case studies. It is my opinion that appropriate models are available and should have been employed to determine project impacts.

4.4. Opinion 4: Ombrotrophic bogs 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.

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 project and methylmercury production in the landscape. This is a critical oversight because of the potential impacts on hydrology and atmospheric deposition as a result of the proposed project (see 6.5 Opinion 5). The literature, including some of that cited in the SDEIS, 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.

The SDEIS indicates in numerous locations that, "*Most of the wetland vegetation present at the Mine Site (69 percent) is indicative of acid peatland systems (i.e., open and coniferous bogs) that are dependent on precipitation rather than groundwater for hydrologic inputs and reflect a perched water table*." (SDEIS 4-150). The focus on the lack of groundwater inputs to bogs downplays the role that the internal biogeochemistry of bogs has on downstream water quality. Peatlands, in particular bogs, are among the most potent Hg methylating environments in the temperate/boreal landscape. Grigal et al. (2000) highlighted the importance of peatlands in the overall mercury budget in north-central Minnesota. Work in Minnesota and NW Ontario by Mitchell et al. (2008a, Env. Sci. & Technol.) showed that the edge pools of bogs are 'hot spots' for MeHg production. Mitchell et al. (2008b, Appl. Geochem.) also showed that methylation in these 'hot spots' was stimulated by the addition of sulfate in runoff. Jeremiason et al. (2006), cited in the SDEIS, showed that the addition of sulfate significantly enhanced MeHg production and export in a small bog in north-central Minnesota. Coleman-Wasik et al. (2012) showed a direct link between the decline in sulfate loading and methylmercury production in the same system. In a report to EPRI and Minnesota Power – Allete and undertaken in partnership with the MPCA and the Fond du Lac First Nation, Branfireun, Fowle and Krabbenhoft (2009) clearly showed that, from a survey of wetland types in the St. Louis River Watershed, that Moss-Lichen dominated wetlands (the term used for bogs in the US National Wetlands Inventory), had the highest median fraction of THg that is MeHg - ~7% in solid peats, with a maximum of >20%.

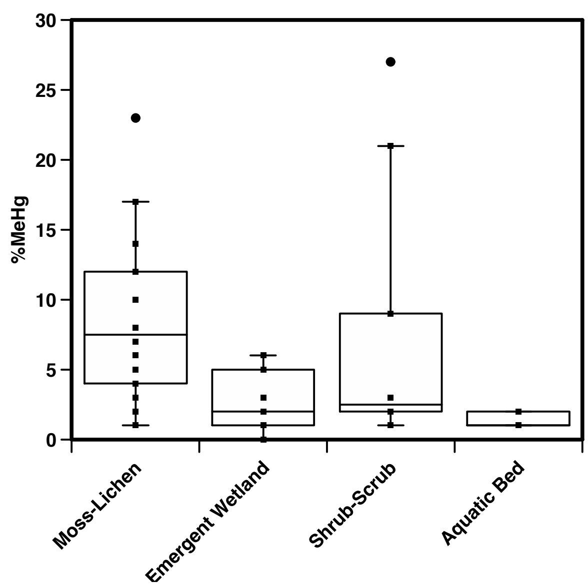

Figure 6.4.1: %MeHg in wetland soils (0-10 cm) by wetland type. Moss-Lichen wetlands are The horizontal line is the median of the data. Lower and upper whiskers are the 10th and 90th percentile respectively. All data for each category are displayed as points to illustrate sample size and range differences (Figure 6.8. from Branfireun, Fowle and Krabbenhoft, 2009).

In all of the above cited literature, ombrotrophic bogs are considered sources of MeHg to downstream systems. Changes to their hydrology, biogeochemistry or both, as a result of the proposed project are particularly salient for MeHg production, MeHg export, or both.

4.5. Opinion 5: 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.

The SDEIS identifies bogs as "*wetlands in which hydrology and mineral inputs are almost entirely from direct precipitation, and that have little hydraulic connection to underlying groundwater [Eggers 2011a]).*" (4-46). This general appraisal of bogs as 'disconnected' or perched hydrological units on the landscape, implies throughout the SDEIS that they are somehow shielded from the effects of changes in hydrology as a result of the proposed project. The SDEIS fails to identify that the basis of this statement is that ombrotrophic bogs generally have little interaction with groundwater under **natural vertical hydraulic gradients,** which would be expected to be very small. It should be noted that even this supposition is not universally generalizable. In the Red Lake peatlands of Minnesota, seminal work by Siegel and Glaser (1987) showed that the 'ombrotrophic character' of bogs in this area was maintained by a fine balance between downward flow of groundwater recharge driven by precipitation that counteracted the upward flow of groundwater from the regional aquifer. In drought years when precipitation was low, mineral-rich groundwater reached the surface layers of the 'bog', indicating the requirement for empirical data concerning groundwater hydraulic gradients and peat/mineral hydraulic conductivity.

Enhanced vertical hydraulic gradients imposed by open pit mine dewatering may drive considerable bog-groundwater interaction with downward vertical flows, potentially dewatering surface peat deposits. This has been documented for the first time in the peatlands in the Hudson Bay Lowlands of northern Ontario, Canada where open pit mining requires dewatering due to a water table at the ground surface and a conductive limestone geology. Whittington and Price (2013) documented the dramatically enhanced downward hydraulic gradients driven by the development of the cone of depression from the open pit depressurization of the underlying bedrock. The degree of impact on the water table in the overlying peatlands was a function of the thickness of the intermediate low hydraulic conductivity marine sediments that lay between the peat and the bedrock unit that was previously thought to function as an effective aquitard, regardless of thickness.

In the case of the sites investigated by Whittington and Price, the overburden marine silt layer between the highly heterogeneous bedrock aquifer and the ~2m thick peat layer was relatively 'impermeable' based on conventional tests of hydraulic conductivity and were assumed to function as a perfect aquitard in modelling scenarios. These authors noted that,

> under normal field conditions (i.e. no depressurization of the regional aquifer), the properties of the [marine silt] are rarely tested; in fact, high water tables can be maintained [even if] no [marine silt] are present. In the post-glacial landscape, the [marine silt] likely played a critical role in reducing recharge to more permeable deposits (like sand) and thus allowing for the establishment of the wetlands; **however, this also would have occurred with a minimal vertical gradient** [emphasis mine] (Whittington and Price, 2013).

These authors concluded that the physical properties of the marine silt layer only partially controlled the degree of hydrological isolation of the surface peats under a depressurization scenario such as that imposed by a cone of depression imposed by open pit mine dewatering - the thickness of the overburden layer was equally important. Areas of thinner deposits led to significant bedrock groundwater – ombrotrophic bog peat interactions. It is therefore unacceptable that, "No data were available regarding the [water] storage parameters for the surficial deposits." (SDEIS 4-53) which current science would indicate is possibly the most important parameter for evaluating potential hydrological impacts to wetlands due to the proposed project.

The SDEIS is entirely deficient in documenting the effect of depressurization of the underlying aquifer due to open pit dewatering. There is no geophysical data concerning the extent and thickness of the surficial aquifers. There is no modelling presented that simulates the development of the cone of depression associated with pit development over time. The reliance on the analog case to evaluate the potential extent and magnitude of the cone of depression and dewatering impact of surface wetlands and streams is completely unsatisfactory, in my opinion, given the availability of robust hydrogeological models that could reasonably evaluate potential impact scenarios. The SDEIS in numerous sections indicates that the underlying bedrock formation is relatively well connected to the surficial unconsolidated materials, even under natural hydraulic gradients. For example:

> Near the ground surface, groundwater in the bedrock is thought to be hydraulically connected with the overlying surficial aquifers, resulting in similar flow directions (Barr 2007d).
>
> (SDEIS, 4-44)

> The overlying surficial sediments at the Mine Site are poorly sorted and range from very dense clay to well-sorted sand with boulders and cobbles (Barr 2006b; Golder Associates 2007). Hydraulic testing of the surficial sediments indicates that these sediments may contain layers of relatively low hydraulic conductivity (e.g., comparable to the Duluth Complex). Tests using wells that penetrate through the surficial zone, however, ***found much higher average hydraulic conductivity*** (emphasis mine), with values similar to the Biwabik Formation aquifer (see Table 4.2.2-5).
>
> (SDEIS, 4-45)

These statements must be considered in the context of numerous references in the SDEIS that indicate that the ombrotrophic bog wetland classes have little to no hydrological connection to underlying groundwater/hydrogeological units. The disclosure concerning the coupling of the bedrock groundwater with the surficial groundwater indicates leads naturally to the conclusion that if depressurization of the bedrock groundwater were to occur due to open pit dewatering, then one would expect a depressurization of the surficial groundwater, given the statements of connectivity in the SDEIS. From Whittington and Price (2013) we may then extend that connectivity to the overlying "disconnected" ombrotrophic bog peatlands, which may become increasingly "connected" under a depressurized scenario, leading to a potential dewatering of the overlying peatlands due to an enhanced downward vertical hydraulic gradient. As there is no modelled or empirical evidence contained within the SDEIS concerning the actual effects of depressurization of the bedrock aquifer associated with the proposed project, this is as reasonable and likely a scenario as that presented in the SDEIS such as that in Table 5.2.3-3 (Wetlands Crossing Analog Impact Zones Resulting from Potential Changes) (SDEIS p. 5-247). In this table, the SDEIS **speculates** that "Ombrotrophic coniferous bog and open bog" would be completely unaffected by hydrological changes under the analog impact scenario, while more hydrologically connected wetlands would be affected more significantly. This conjecture is **contradicted** by the empirical (measured) data in Whittington and Price (2013), who note that:

> "When determining the effects of (vertical) dewatering in peatlands, the lateral transmission of surface waters must also be considered, as the fens in this study area appear to be less impacted due to their hydrogeomorphic setting (i.e. non-ombrogenous)."

Given that the SDEIS relies upon analogs that are not based on data, it is my opinon that the observations of Whittington and Price (2013) must be brought to bear with greater weight on this consideration than a speculative assessment based on the analog scenario. As such, the classification of degree of potential wetland impacts due to the proposed project in Table 5.2.3-3 is unsubstantiated, not based on sufficient empirical evidence, not based on the best available science, and may in fact be opposite to the real outcomes. This conclusion undermines the efficacy of the proposed wetland impact monitoring strategy outlined in the SDEIS, which would be "based on those wetlands that would have a high likelihood of indirect effects as a result of groundwater drawdown." (p. 5-310).

The implications on mercury cycling are not to be underestimated. Dewatering of surficial groundwater and peats may lead to more amplified water table fluctuations in impacted wetlands than may occur under naturally conditions (Whittington and Price, 2006). This in turn may lead to enhanced oxidation of reduced sulfur and sulfate production in surficial peats (e.g. Devito and Hill, 1999), increased activity of sulfate reducing bacteria and increased mercury methylation upon rewetting (see Sorenson et al., 2005). In some wetland types in the St. Louis River watershed in Minnesota, more prolonged drying and rewetting of organic-rich soils has been shown to increase MeHg content under experimental conditions by Branfireun, Fowle and Krabbenhoft (2009); see Figure 6.5.2).

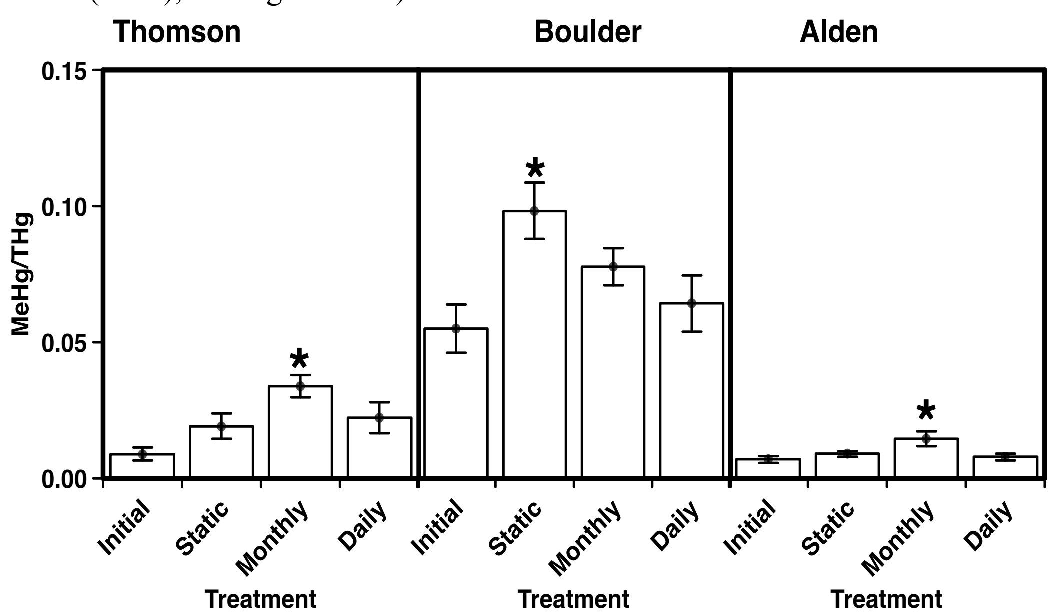

Figure 6.5.2: PROPORTION OF TOTAL MERCURY AS METHYLMERCURY: Bars are the mean for each treatment. Error bars are one Standard Error about the mean. An asterisk (*) above the bar indicates that the mean of the experimental treatment is statistically significantly different from the Initial mean value at the 95% confidence interval. (Figure 8.7. from Branfireun, Fowle and Krabbenhoft, 2009).

From their laboratory experiment on the effects of drying and wetting on MeHg production in wetland soils, Branfireun, Fowle and Krabbenhoft conclude:

> Methylating bacterial communities require a supply of a) bioavailable inorganic Hg; b) nutrients (e.g. sulfate), and; c) labile substrate. The periodic oxidation of wetland soils will provide for the enhanced release of inorganic Hg, sulfate and DOC into pore waters, promoting MeHg production upon rewetting. The period of air-entry must be sufficiently long to allow for the oxidation of organic matter and reduced-S. Equally importantly, in order for Hg methylation to be significantly promoted the period of rewetting must be sufficient to allow for the maintenance of a viable microbial community that can utilize the metabolize the available nutrients and substrate.

Underdrainage due to changes in hydrology in wetlands surrounding the proposed project has the potential to enhance summer drying of surface peats which, upon rewetting in the typically wetter fall, release of inorganic Hg, sulfate and DOC and promote MeHg production. The SDEIS discusses how enhanced wetting and drying may enhance MeHg production but concludes that the effect would be "negligible" because of the limited effect of the proposed project on water levels in the Embarrass and Partridge Rivers (SDEIS 5-210). The SDEIS errs in not accounting for the hydrologically-impacted wetlands as a potentially enhanced source of Total Hg and MeHg during mine operations and open pit dewatering.

4.6. Opinion 6: 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.

My Opinion 1 (Section 4.1) expresses concern about the adequacy of the background data presentation and subsequent analyses in estimating the relative potential impacts of changes in loading of solutes to the Embarrass and Partridge Rivers. The deficiencies in the approach taken in the SDEIS preclude a confident assessment of the potential impacts, and in my opinion do not support the SDEIS contention that, on the whole, loadings of sulfate and Hg will be decreased to the St. Louis River system (ES-36). In fact, the percentage increases and decreases are well within the margin of error of any reasonable water quality monitoring program. In this case, *we are unable to assess the margins of error because the required data are not provided in the SDEIS*.

Further, the SDEIS (5-208) rightly indicates that Hg methylation is likely not an in-channel process but is more likely occurring in the watershed (such as in wetlands – see Opinion 4, Section 4.4). As such, if our concern is with respect to MeHg production, then attention should be directed toward the delivery of Hg and sulfate to sites of methylation in the watershed (i.e. wetlands), not to statements of inconsequential and speculative changes in concentrations in surface waters.

My Opinion 5 (Section 4.5) addresses the inadequate characterization of the current, and future surficial groundwater – wetland iteractions. This deficiency is critical since sulfate delivered to surficial groundwater discharges to wetlands may be very important to Hg methylation, and has been shown to be so in analagous hydrogeological situations (Branfireun et al., 1996; Branfireun and Roulet, 2002). Therefore changes in sulfate in surficial groundwater are more likely to result in downstream water quality impairments from MeHg than even incremental increases in total Hg in direct surface water discharges.

The SDEIS relies 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 SDEIS 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 MeHg production in the project area and could also contribute directly to water quality impairments in sulfate-poor sediments downstream of the project site.

The SDEIS proposal also relies 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 pond water prior to discharge to surface waters.

In my opinion, these strategies are poorly documented. Neither the current WWTP(RO) nor the future WWTF+RO are detailed technically in any way pertaining to the influent levels of sulfates and mercury and the technology that would be employed to remove these parameters. In the absence of technical data, the burden of proof concerning technical feasibility and efficacy has not been met by the SDEIS.

In summary, it is my opinion that the potential for cumulative downstream impacts both from mercury and mercury methylation at the project site are understated in the SDEIS. Based on the literature (much of which is from Minnesota) and my experience in other wetland ecosystems, it is my opinion that discharges of sulfate and total mercury and hydrologic changes to peatlands at the project site have the potential to significantly increase methylmercury in downstream wetlands and surface waters. There are models available that would allow assessment of this potential. There is also no reason to assume that effects on mercury and methylmercury would be limited to the smaller streams, or the main channels in the Partridge or Embarrass River watersheds. Both direct and indirect water quality impairments would have the potential to affect the St. Louis River.

5. Materials Referred to (References used in the SDEIS are not included in this list).

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Mitchell, CPJ, BA Branfireun, and RK Kolka, Spatial characteristics of net methylmercury production hot spots in peatlands, Environmental Science and Technology., 42, 1010-1016. 2008.

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Appendix 1 – Curriculum Vitae of Brian A. Branfireun

A. BIOGRAPHICAL INFORMATION

1. PERSONAL

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Room 2064 Biology and Geological Sciences Building
University of Western Ontario
London, Ontario, Canada N6A 5B7
Phone: 519-661-2111 ext 89221
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2. DEGREES

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

3. EMPLOYMENT

Unit: Department of Biology (50%) and Centre for Environment and Sustainability (50%)

Present Appointments:

Associate Professor with Tenure Department of Biology, Western University
Canada Research Chair (Tier 2: 2010-2015)
Associate Professor (Status only), Department of Geography, University of Toronto Mississauga.
Director, Biotron Centre for Experimental Climate Change Research (2012-14).
Director, Faculty of Science Integrated Materials Analysis and Characterization Network (2011-2012).
Acting Director, Biotron Centre for Experimental Climate Change Research (2011-12).

Previous Appointments:

Associate Professor Department of Biology, Western University (probationary)
Associate Professor with Tenure, University of Toronto Mississauga Dept. of Geography (2004-10)

Assistant Professor, University of Toronto Mississauga Department of Geography (1999-2004)
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)

4. HONOURS

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

5. PROFESSIONAL AFFILIATIONS AND ACTIVITIES

CURRENT

- President, Canadian Geophysical Union (2013-2015)
- Science Advisory Panel Member - Sensing the Americas' Freshwater Ecosystem Risk (SAFER) from Climate Change, Instituto Argentino de Oceanografía, Argentina. (2013-).
- California Central Valley Regional Water Quality Control Board Technical Advisory Committee (Mercury Control Projects) Member (2012-2018)
- Scientific Advisory Panel Member – CALFED Yolo Bypass Mercury Project, Sacremento California (2012-2014)
- Member of Canadian Geophysical Union, American Geophysical Union, International Association of Hydrological Sciences

PREVIOUS

- Technical Review Committee, US Department of Energy Oak Ridge National Laboratory (ORNL) Mercury Science Focus Area (SFA) Review (2012)
- Vice-President, Canadian Geophysical Union (2011-2013)
- Co-Chair, 2012 Joint Assembly of the Canadian Geophysical Union and Canadian Water Resources Association.
- President, Canadian Geophysical Union Hydrology Section (May 2009-May 2011)
- Vice-President, Canadian Geophysical Union Hydrology Section (May 2007-May 2009)
- Secretary, Canadian Geophysical Union - Hydrology Section (May 2005 - May 2007)

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

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

- Reviewer of manuscripts for peer-reviewed journals 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.

- Reviewer of research grant proposals for 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.

B. ACADEMIC HISTORY

6. RESEARCH AWARDS HELD/APPLIED (LAST 5 YEARS)

Title	Dates	Total Amount	Agency	Co-Investigators	% of Award to BAB
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	~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), and 7 others	15%

Water Resource Management in Dry Subtropical Mexico	2011	$5500	UWO	none	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	2009-2015	$240 000	NSERC (Discovery Grant)		100%
An ion chomatograph for the chemical characterization of natural waters and soils	2009-2009	$46 807	NSERC (Research Tools and Instruments)	N. Basiliko	50%
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%

Monitoring Mercury Species in Air and Precipitation in Ontario Watersheds: Phase II	2007-2009	$100 000	Ontario Ministry of the Environment		100%
Tributary Inputs of Mercury and Methylmercury to Lake Ontario	2008-2009	$50 000	Ontario Ministry of the Environment		100%
Air-Vegetation Transfers of Mercury	2008-2009	$50 000	Ontario Ministry of the Environment		100%
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%
Changes in Mercury Methylation in a Boreal Wetland Previously Enriched in Sulfate: Synergistic Effects of Atmospheric Deposition and Water-level Fluctuations	2007-2009	$110 000	Great Lakes Air Deposition Program	D. Engstrom, J. (Lead PI) Jeremiason, R. Kolka, B. Monson.	20%

6.C. PATENTS

None to date

C. SCHOLARLY AND PROFESSIONAL WORK *indicates graduate student.

7. REFEREED PUBLICATIONS (complete list)

A. Articles

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14. 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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35. Branfireun, B. A., K. Bishop, N. T. Roulet, G. Granberg and M. Nilsson, Mercury cycling in boreal ecosystems: the long-term effect of acid rain constituents on peatland pore water methylmercury concentrations, Geophysical Research Letters, 28(7), 1227-1230, 2001.

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37. Branfireun, B. A., D. Hilbert and N. T. Roulet, Sinks and sources of methylmercury in a boreal catchment, Biogeochemistry, 41, 277-291, 1998.
38. Branfireun, B. A. and N. T. Roulet, The baseflow and stormflow hydrology of a Precambrian Shield headwater peatland, Hydrological Processes, 12, 57-72, 1998.
39. Devito, K. J., M. J. Waddington and B. A. Branfireun, Flow reversals in peatlands influenced by local groundwater systems, Hydrological Processes, 11, 103-110, 1997.
40. Branfireun, B. A., A. Heyes and N. T. Roulet, The hydrology and methylmercury dynamics of a Precambrian Shield peatland, Water Resources Research, 32(6), 1785-1974, 1996.

B. Books and/or Chapters

1. 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.

C. Books Edited

None to date

8. NON-REFEREED PUBLICATIONS

1. Branfireun, B.A. 2002. Mercury cycling in the boreal forest: Insights from models experiments and isotopes, In: Proceedings and Summary Report: Workshop on the Fate, Transport, and Transformation of Mercury in Aquatic and Terrestrial Environments, Cincinnati: US Environmental Protection Agency.

9. MANUSCRIPTS SUBMITTED * indicates student

SUBMITTED:

1. Oswald, C, Heyes, A. and Branfireun, BA. Ambient mercury and applied mercury isotope in soil and soil-water in a boreal upland catchment: identifying sources of Hg to catchment runoff. Submitted Environmental Science & Technology, Resubmitted, 2013.
2. Oswald, CJ* and Branfireun, BA. Antecedent moisture conditions control mercury and dissolved organic carbon concentration dynamics during summer storms in a boreal headwater catchment, Water Resources Research. in review.
3. Denkenberger, JS, Driscoll, CT, Branfireun, BA, Warnock, A, Mason, E. Watershed Influences on Mercury in Tributaries to Lake Ontario, Biogeochemistry, in review
4. 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, in review.

10. SELECTED PAPERS PRESENTED AT MEETINGS & SYMPOSIA (Last 5 Years)

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.

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.

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, K.*, 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.

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, Cynthia, REED, Harris, KELLY, Carol A.,HINTELMANN, Holger, KRABBENHOFT, David P., AMYOT,Marc, BLANCHFIELD, Paul, PATERSON, Michael, RUDD, John M.W., TATE, Michael, SANDILANDS, Ken, BEATY, Ken, LINDBERG, Steven, SOUTHWORTH, George, HEYES, Andrew, ST. LOUIS, Vince, GRAYDON, Jenny, BABIARZ, Chris,BRANFIREUN, Brian, HURLEY, James 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, Jill 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)
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).
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)
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
Dec 2010	Annual Meeting of the American Geophysical Union, San Franscisco, 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.

11. INVITED PRESENTATIONS

May 2013 Waterloo University, 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.

April 2007 Lake Ontario Contaminant Monitoring, Modelling and Research Workshop, Grand Island, NY. "Cycling of Mercury in the Watershed and Waterbody". Invited Expert Panel Presentation (with C. Knightes, USEPA, R. Harris, Tetra Tech, Inc)

Jan 2006 US Environmental Protection Agency and Ontario Ministry of the Environment, Collaborative Workshop on developing a bi-national strategy for managing mercury in the Great Lakes, Niagara Falls, NY "Watershed controls on mercury load to surface waters" (Invited presenter and participant)

July 2005 International Joint Commission 2005 Biennial Forum – Mercury Multicompartment Modelling Workshop, Kingston, ON "Terrestrial Cycling and Watershed Modelling of Mercury" (Invited presenter and participant)

D. LIST OF COURSES TAUGHT (last 5 years)

12.A. UNDERGRADUATE COURSES

UNIVERSITY OF WESTERN ONTARIO

- ENVSCI 3350G Techniques in Environmental Science
- BIO 4243G: Poliical Biology (1 guest lecture; 2012/2013)
- BIO 4405G: Ecosystem Ecology (1 guest lecture; 2012/2013)

UNIVERSITY OF TORONTO

- GGR117Y: Where on Earth? (Introduction to Geography)
- GGR 217H: The Global Water Cycle

- ENV232H: Environmental Sustainability Practicum
- GGR 309H: Wetlands: Science, Management and Preservation
- GGR 315H: Physical Hydrology
- ENV331H: International Environmental Sustainability: Mexico
- GGR 407H: Ecohydrology

12.B. GRADUATE COURSES

UNIVERSITY OF WESTERN ONTARIO

- BIOL 9440: Special Topics in Ecology and Evolution- Wetland Ecosystems
- GEOG 9220: Hydrology (Smart, Creed, Branfireun) (2011)
- Multidisciplinary Sustainability Workshop, Ivey School of Business (1 lecture)

UNIVERSITY OF TORONTO

- GGR 1302: Advanced Hydrology and Water Quality

12.C. THESES SUPERVISED (Whole Career)

Students listed are primary supervision unless otherwise indicated.

Name	Yr	Degree	Thesis Topic	Current Position
Ma, Y. (with C. Guglielmo)	2013	PhD	Mercury in terrestrial migratory birds	In Progress
Smofsky, A. (with E. Webb)	2013	MSc	Soil biochemical indicators of early Mayan settlement, Central America.	In Progress
Dieleman, C. (with Z. Lindo)	2012	PhD	Tropical Wetland Ecology	In Progress
Krynak, E. (with A, Yates)	2012	PhD	Aquatic Ecosystem Bioindicators	In Progress
Goacher, J.	2012	MSc	Geochronology of Mercury in Far North	In Progress
Despault, T.	2012	MSc	Dissolved Organic Matter in Natural Waters	In progress
Resente, F.	2012	PhD	Hydrology of Northern Watersheds	In progress
Morris, M. (with K. Spencer, Queen Mary Univ, of London)	2011	PhD	Salt marsh mercury biogeochemistry	In progress
Liznick, K.	2011	MSc	Mercury in the L. Erie Foodweb	In progress
Nava-Garibaldi, C.	2011	MSc	Nutrient Cycling in tropical freshwater lakes	withdrawn
Kline, M.	2011	MSc	Hydrogeology of Hudson Bay Lowlands	In progress
Ulanowski, Thomas	2010	MSc	Hydrology of extensive bog/fen ecosystems	ABD
Warnock, Ashley	2010	MSc	Small-bodied fish as sentinels of ecosystem mercury sensitivity	In progress
Orlova, Yulia	2009-12	MSc	Hydrology of subarctic watersheds	Environmental Professional
Farrick, Kegan	2009	PhD	Subtropical forest hydrology	In progress
Abbasi, Golnoush	2008	PhD	Mercury cycling in extensive peatland ecosystems	Withdrawn
Oswald, Claire	2005-10	PhD	Controls on watershed mercury cycling	PDF – McMaster U.
Malczyk, Evan	2007-09	MSc	Mercury cycling in sub-tropical lakes	Environmental Pro-

				fessional
Stupple, Geoff	2007-09	MSc	Air-vegetation-surface transfers of mercury	Environment Canada
Richardson, Murray	2003-09	PhD	Landscape scale hydrologic controls on mercury fate and transport	Assistant Professor, Carleton University.
Eckley, Chris	2003-07	PhD	Mercury cycling in urban ecosystems	Research Scientist, USEPA
Mitchell, Carl	2002-06	PhD	Spatiotemporal dynamics of mercury bi-omethylation in peatland ecosystems	Associate Professor with tenure, Universi-ty of Toronto - Scar-borough
Biesiada, M. (with M-J Fortin)	2005-2007	MSc	Spatial Distribution of Mountain Pine Beetle in the Morice Timber Supply Area in Western Brit-ish Columbia Between 1995 and 2002	Research Associate, National University of Ireland
Bayer, A	2001 - 2003	MSc	Mercury distribution and speciation in a macro-tidal salt marsh	Environmental Consult-ing
Richardson, M. (with Robinson)	2001 - 2003	MSc	Landscape hydroecological modelling	Assistant Professor, Carleton University
Mitchell, C.	2000-2002	MSc	Redox chemistry of boreal upland-wetland inter-faces	Associate Professor with tenure, University of Toronto - Scar-borough
Morgan, A. (with Csil-lag)	2000-2002	MSc	Hydrological modelling the impacts of urbaniza-tion on large watersheds	Senior Manager, World Wildlife Fund
Galloway (Young), M.	1999-2001	MSc	Hydrology and mercury biogeochemistry in a temperate forested swamp	Environment Canada

13. Postdoctoral Fellows and Technical Supervision

Name	Yr	Position	Topic	Current Position
Columbus, M.	2013-14	PDF	Microbial community structure and function in disturbed northern peatlands	In Progress
Whittington, P.	2012-13	PDF	Evaluating Environmental Change in the Hudson Bay Lowlands	In Progress
Si, L.	2011-12	PDF	Mercury-Dissolved Organic Matter Interactions	Unknown
Craig, A.	2013-	Tech	Research Project Manager	In Progress
Rees-Tiller, R.	2011-	Tech	Laboratory Analyst	In Progress
Morris, M..	2008-11	Tech	Laboratory Analyst	PhD Candidate