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Expert Review of the Minnesota Pollution Control Agency Clean Water Act Section 401 Certification for the NorthMet Project

Prepared for:

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Brian Branfireun at London Ontario Canada, January 20, 2019

1 Introduction 1
1.1 Qualifications 1
2 Summary Concerning 401 Certification, Mercury & Methylmercury 2
2.1 Limitations and Factors Omitted from the Cross-Media Analysis and Rationale for 401 Certification 4
2.1.1 Limiting sulfur loading to dust deposition in a single wetland fails to account for environmental risks 4
2.1.2 Sulfate and mercury loading from direct discharge and seepage to wetlands has not been evaluated 4
2.1.3 Mine Site Water Table Drawdown and Wetland Impacts 6
2.2 Monitoring required by the 401 Certification and NPDES/SDS permit is insufficient to detect irreparable harm resulting from mercury release and methylation 9
3 Concluding Remarks 12
4 Referenced Materials 15
5 Curriculum Vitae - Branfireun 17

1 Introduction

My name is Brian A. Branfireun, and I am a full-time Professor in the Department of Biology and Centre for 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. I was first 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. I also 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. I provided my opinion on the FEIS in final form on December 12, 2015.

Since submitting my opinion on the FEIS, I reviewed the Minnesota Pollution Control Agency (henceforth MPCA) draft NPDES/SDS permit and draft Clean Water Act Section 401 certification for the NorthMet project in 2018 and consulted informally with counsel, since my schedule did not permit preparation of an opinion. I have recently reviewed the Final MPCA NPDES/SDS permit and Section 401 certification for the NorthMet project, along with Findings of Fact, Conclusions of Law and Orders supporting their issuance, the Cross-Media analysis and various technical documents. I was asked to evaluate whether or not the MPCA Clean Water Act 401 certification for the NorthMet project, along with the NPDES/SDS permit and PolyMet's Cross-Media Analysis on which it relied, reasonably ensured that the NorthMet project would comply with water quality standards pertaining to mercury and methylmercury and would not endanger human health or the environment as a result of mercury or methylmercury. Materials referred to in this document are included either in whole, or in part. Some relevant documents (e.g. the FEIS) are extensive and are excerpted for convenience.

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 On-

tario 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).

I have authored or co-authored 70 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). Most recently research in my group has broadened to include the impacts of mercury on biota, including birds (e.g. Ma et al., 2018a,b). Details of my publications and other scholarly activities are outlined in my Curriculum Vitae (Section 5 of this document).

2 Summary Concerning 401 Certification, Mercury & Methylmercury

As summarized in MPCA's Fact Sheet provided in support of the 401 Certification, the FEIS for the PolyMet NorthMet project was deemed adequate by the Minnesota DNR (March 3, 2016). After this adequacy decision, the MPCA requested that PolyMet conduct a further "cross-media analysis to address potential water quality concerns from dust deposition from the Project." (401 Fact Sheet, p. 14). PolyMet submitted its Cross-Media Analysis to Assess Potential Effects on Water Quality from Project-Related Deposition of Sulfur and Metal Air Emissions on October 31, 2017, with supplemental information submitted November 29, 2017. The analysis was reviewed by the MPCA's technical experts and the resulting conclusions were considered in developing the Section 401 Certification.

Although a superficial reading would suggest that PolyMet's Cross-Media Analysis provides a rigorous, more in-depth analysis of the Project's potential environmental impacts, this is not the case. By virtue of its extraordinarily restricted scope (focusing only on dust deposition), its selective choice of a single wetland of interest, and subtle caveats in the analysis, PolyMet's analysis predictably led the MPCA to draw a conclusion that the project would result in "no measurable changes in mercury in water or fish" (*Id.*, p. 14). In my opinion, PolyMet's Cross-Media Analysis is a straw man that enabled MPCA to limit its assessment of the issues concerning mercury

and methylmercury to matters arising from the cross-media analysis only (i.e. dust deposition). The MPCA could then avoid addressing critical aspects of the problem of locating a copper-nickel sulfide ore mine in a landscape with high mercury methylation potential, including the effects of sulfate loading from direct discharge and seepage and the effects of changes in hydrology on mercury and methylmercury release from sediments, mercury methylation, bioaccumulation and transport.

MPCA's overreliance on a narrowly drawn study by the project proponent allowed much more profound mechanisms by which mercury and methylmercury in waters downstream of the NorthMet project to be disregarded, despite their identification in previous reviews and opinions. These mechanisms should have been examined and MPCA should have made an independent effort to model likely impacts, rather than simply dismissing their technical feasibility. The limitations of the Cross-Media Analysis and some of the critical mechanisms by which the NorthMet project would affect mercury and methylmercury that MPCA should have examined are elaborated upon in section 2.1 of this document.

In addition, although the MPCA concludes in its 401 Certification letter that there is "sufficient uncertainty that additional monitoring is necessary", the surface discharge, wetland and stream monitoring of mercury and methylmercury is inadequate. By virtue of location, scope and design, the MPCA's proposed monitoring would not capture changes in wetland biogeochemical function or degradation of water quality in headwater streams in the vicinity of the project. This monitoring could not even *detect* irreparable harm to the environment as a result of the project development and operations, let alone provide sufficient *early warning* to support an adaptive management approach. Again, while MPCA's statements give the impression of due diligence, upon close examination these additional monitoring requirements are wholly inadequate to protect human health or the environment. These concerns are discussed in section 2.2 below.

These serious weaknesses are not new issues, and comprise a significant part of my previous opinion on the project FEIS (December, 2015) that identified: incomplete or missing mercury and methylmercury data from tributaries (Section 2.1.1); the failure to document mercury and methylmercury in sediments, soils, and biological media (section 2.1.2); the likely impacts of additional sulfate loading to tributaries that are proximal to the proposed development (Sections 2.2, 2.6); the importance of sensitive headwater wetlands in regulating methylmercury loading to the Partridge and Embarrass Rivers (Section 2.4.1); and the significance of hydrological impacts on wetlands impacted by the proposed mine pit dewatering (Sections 2.5.1, 2.5.2, 2.5.3).

2.1 Limitations and Factors Omitted from the Cross-Media Analysis and Rationale for 401 Certification

2.1.1 Limiting sulfur loading to dust deposition in a single wetland fails to account for environmental risks

The MPCA requested that PolyMet conduct a cross-media analysis to assess the impact of particulate emissions of sulfur compounds on mercury methylation and to assess the impacts of mercury air deposition. The restriction of the analyses to atmospheric dry deposition allows for a scientifically defensible consideration of potential impacts on water quality. I have no criticism of the factors reflected in the analysis as far as it went. The analyses included in Appendix F of the 2017 Cross-Media Analysis is thorough in its consideration of the literature highlighted in my previous opinions and other works that speak to wetland cycling of sulfur, mercury, and methylmercury.

The conclusions concerning the relative loads of sulfur to wetlands in proximity to the project are conceptually sound, although only with respect to atmospheric loading. The "Wetland of Interest" (WOI) located in proximity to the mine site is likely to receive the highest loading of fugitive dust, and its use to model the impacts of sulfur dry deposition *only* is appropriate. The analysis concludes that this loading is estimated at 1.55 kg/ha/yr; a 32% increase above the estimated background sulfate deposition stated in the analysis (4.8 kg/ha/yr). This is a higher level of change from background sulfate air deposition than in wetlands to the north of the tailings basin at the plant site Embarrass River headwaters, which are predicted to receive sulfur air deposition (~0.3 kg/ha/yr) that represents a 6% increase in loading.

However, by design, PolyMet's Cross-Media Analysis failed to account for hydrologic changes that will affect other mine site wetlands, aqueous sulfate releases, and mercury air deposition to wetlands. It is, thus, a useful analysis of *one* of the factors by which the NorthMet project activities could contribute to mercury methylation, but a wholly inappropriate basis from which to draw overall conclusions as to the NorthMet project's impacts on mercury and methylmercury in the Partridge, Embarrass, and St. Louis River watersheds.

2.1.2 Sulfate and mercury loading from direct discharge and seepage to wetlands has not been evaluated

The Cross-Media Analysis described the wetlands north of the tailings basin in the Embarrass River watershed as "unimpacted", which is only slightly misleading when considering sulfur loading from air deposition. However, for the purposes of assessing the impacts of *total* sulfate loading on mercury methylation and subsequent surface water quality degradation, it is my opinion that the wetlands north of the tailings basin are of far greater relevance than the WOI because of spatial extent, direct hydrologic connectivity to headwater streams, and most importantly, direct loading of both sulfate and mercury in wastewater discharges. In this document, I will refer to this site as the Embarrass River wetlands and focus on the wetlands at the headwater of the Trimble Creek tributary to the Embarrass River.

The NPDES/SDS documents state that rainwater coming in contact with tailings and plant site materials, Colby Lake water used for processing, and water from the pit dewatering process and mine site construction activities will be captured (to some unspecified degree) in a seepage containment system. Some of that seepage will be returned to the tailings basin and some will be treated in a Wastewater Treatment System (WWTS) and subsequently discharged from the site.

Although there are no effluent limits in the NPDES/SDS permit for any surface discharge outfalls, internal waste stream operating limits (WS074) propose that mercury concentrations will be set at 1.3 ng/L for total mercury, and 10 mg/L for sulfate. As I previously stated in my comments on the inadequacy of the FEIS, it is my opinion that PolyMet has not convincingly established that taconite tailings adsorption or the wastewater treatment methods proposed will effectively remove mercury to comply with the 1.3 ng/L limit, but for the purposes of this example, I will accept this assertion.

As approved in the NPDES/SDS permit, the internal treated waste stream from WS074 will be sent to SD001 and then divided into multiple discharge outfalls (SD002 to SD011), each of which will discharge into wetlands in the headwaters of the Embarrass River. The MPCA NPDES/SDS permit (Table 2.1, p. 10, attached) identifies estimated average discharges of 0.24 million gallons per day (MGD) in mine year 1, increasing to 0.39 MGD in mine year 10 and maximum discharges of 0.29 MGD in mine year 1, increasing to 0.57 MGD in mine year 10 from each of the 10 outfalls northwest and north of the tailings basin in the Embarrass River watershed.

Seven of these outfalls (SD004-SD010) discharge directly into the wetlands at the headwater of a single tributary of the Embarrass River, Trimble Creek. Under average conditions, these seven outfalls would discharge at total of 1.68 to 2.73 MGD (1,166 to 1,896 gallons per minute (gpm)) to this headwater wetland. Even if, as the MPCA has assumed, PolyMet is able to reduce effluent concentrations of mercury and sulfate to the permissible levels using its WWTS, this additional water input will deliver 64 to 103 kg of sulfate per year to the headwater wetland of Trimble Creek - a significant sulfate loading. Although wetlands are not generally considered limited with respect to the amount of inorganic mercury available for methylation, these outfalls will also discharge up to 5 grams of mercury per year to this same wetland that would then be available for methylation.

The MPCA did not consider nor analyze the effects of this sulfate loading through direct discharge to wetlands. Although seepage is released from the existing taconite tailings facility under current conditions, the FEIS estimated that if existing conditions continue maximum surface seepage along the entire perimeter of the tailings basin would be 2,390 gpm. (FEIS Table 5.2.2-37 attached) As stated in the NPDES/SDS permit, maximum direct surface wastewater discharge outfalls to the Embarrass River wetlands on the north side of the tailings basin in mine year 10 would be 5.72 MGD or 3,972 gpm. This is in addition to any seepage that is not contained by PolyMet's proposed capture system, for which projected capture efficiencies are scientifically unproven.

In my opinion, there is a very high likelihood that these direct surface discharges to the Embarrass River wetlands and, in particular, the wetlands at the headwaters of Trimble Creek, would result in an increase in methylmercury production precisely at a location in the watershed that would result in the greatest environmental harm – a headwater wetland that then supplies water and solutes to downstream.

The literature underscores the importance of this consideration. McCarter et al. (2017) found that an addition of simulated mine wastewater containing 30 mg/L sulfate into a northern wetland with no additional mercury input resulted in an 40x increase in methylmercury concentrations (from 0.13 to over 4 ng/L) over an experimental discharge period of only approximately 45 days. A stimulation of mercury methylation in the Embarrass River wetlands, particularly those in the headwaters of Trimble Creek, of even a fraction of this magnitude would result in increased loading of methylmercury to the Embarrass River ecosystem and environmental damages, particularly when combined with hydrological loading from the outfalls that will decrease water residence time in the Embarrass River wetlands and increase hydrological and chemical connectivity.

Throughout the environmental review process, I have been concerned about the lack of background data on mercury, methylmercury or sulfate in wetlands northwest and north of the tailings basin. The lack of data, particularly data pertaining to the wetlands that form the headwaters of Trimble Creek, is highly problematic. Despite the MPCA's statement that there is "sufficient uncertainty" to warrant additional monitoring as part of the 401 Certification, this additional monitoring is strictly bounded by PolyMet's self-declared areas of concern, its Mine Site wetland of interest, which will neither be impacted by direct discharge nor by uncaptured tailings seepage and has no direct surface connection to downstream tributaries.

The inadequacy of monitoring, particularly of wetlands affected by significant volumes of direct aqueous discharge as well as tailings wastewater seepage will be discussed further in Section 2.2. It is my opinion that it was unreasonable for the MPCA to rely on a Cross-Media Analysis to address uncertainty concerning potential impacts to water quality due to sulfur air emissions inputs when that analysis failed to consider the impacts of aqueous sulfate loading to highly sensitive parts of the watershed that are many times the level of sulfate loading resulting from dust deposition. Failure to analyze the effects of high volumes of aqueous sulfate loading in the wetlands forming the headwaters of Trimble Creek and other Embarrass River wetlands disregards one of the most significant risks the NorthMet project poses to mercury methylation and its downstream effects on health and the environment. The MPCA's sole focus on a wetland impacted only by sulfur dust deposition, and its failure to analyze risks to the environment posed by aqueous sulfate additions to wetlands makes the MPCA's 401 Certification of the NorthMet project unreasonable.

2.1.3 Mine Site Water Table Drawdown and Wetland Impacts

The MPCA, through statements in its 401 Certification Fact Sheet, appears to accept the PolyMet contention that "Site conditions at the Mine Site preclude the use of computer modeling to

predict the groundwater cone of depression and resultant impacts around the mine pit," and that "the probability of accurately specifying the location, extent, or degree of wetland impacts from the drawdown effect of the proposed mine pit prior to construction is very low." (401 Fact Sheet, p.10).

In my opinion, these statements are at odds with the evidence that is presented in the FEIS, documents supporting the NPDES/SDS, and other PolyMet permitting documents. Modeled estimates of pit dewatering volumes are an essential aspect of open mine pit planning, and modeled groundwater inflows are included in the project FEIS (Table 5.2.2-19 attached) and the project Permit to Mine Application (Appx.11.2 -Water Mgt. Plan- Mine, Dec. 2017, pp. 11-13, attached). Since the FEIS, average maximum total mine inflow estimates have increased from a total of 870 gpm (FEIS Table 5.2.2-19) to between 1203 and 1510 gpm (Water Mgt. Plan – Mine, p. 12), which is equivalent to 1.7 to 2.2 MGD. As stated in the Permit to Mine Application (p. 11), these projections are based on probabilistic modeling.

The claim that the site conditions at the Mine Site preclude the use of computer modeling to predict the groundwater cone of depression suggests that the determination of pit dewatering volumes and the accurate modelling of the groundwater flow field and surface recharge in three-dimensions are separate and decoupled activities. This is factually untrue. The continued refinement of the project MODFLOW simulations to improve estimates of pit dewatering volumes means that computer modeling *has already* been used to predict the groundwater cone of depression, as the volume of water influent to the pit is by definition, defined by this piezometric surface. A prior expert opinion on this very matter supports this assertion:

> While a numerical model (MODFLOW) was used extensively to determine pumping rates, etc., the proponents incongruently argue that it cannot be used to predict a cone of depression that would identify wetlands potentially susceptible to impact. While it is acknowledged that identification of individual wetlands' susceptibility cannot be predicted without a detailed characterization of overburden thicknesses, a sensitivity analysis using the same model setup as that used to predict pumping rates, would constitute an appropriate scientific investigation that can identify the potential cone of depression that affect wetland function. (J. Price, Expert Opinion, 2017)

Dr. Price's opinion was supported with an illustration of just such an analysis undertaken prior to, and during the development and operations of an open pit mine in northern Ontario, Canada. Using the very models that have already been employed and refined for the proposed NorthMet site, the risk of water level impacts in wetlands and streams can be technically assessed to predict probabilistic outcomes. It is undisputed that hydrological changes underlie potential wetland impacts of great concern related to this project, affecting vegetation community composition and water quality as well as stream flows. It is also undisputed that water table fluctuation is an important factor in wetland geochemistry.

Appendix F of the Cross-Media Analysis explains how water table drawdown may impact the oxidation of reduced sulfur species, replenishing sulfate that can contribute to surface water acidification and stimulate the methylation of mercury. However, the entire analysis is solely focused on natural droughts, and is further undermined by the assertion that droughts are "not a common occurrence" in mid-latitude climates, and are a "special case" (Appendix F, p. 3). There are two critical oversights in this assertion and subsequent analyses:

1) Climate-change induced drought frequency and magnitude will both increase over the period of mine operation. Sheffield and Wood (2008) used a range of model ensembles to predict the duration, magnitude and spatial extent of droughts around the world to the year 2100. For central North America, they concluded that by 2050 the frequency of 4-6 month droughts would increase by approximately 50%, 12-month droughts by approximately 300%, and the spatial extent of those droughts would approximately double. Northern Minnesota will be subjected to more frequent, and more severe droughts over the period of mine operations.
2) More importantly and superimposed on the occurrence of natural and climate-change induced drought, is mine induced "drought" in the form of water table drawdown due to pit dewatering. It is undisputed that mine operations will affect water levels in proximate wetlands, even though there is a dispute between the agencies and the independent experts over the likely extent of this impact, and whether or not it can be modeled and assessed prior to mine development. In fact, many of the monitoring measures incorporates in the MPCA's 401 Certification (based on PolyMet's 2017 Wetland Impact Monitoring Plan, 2017) reflect the high likelihood of this occurring.

The Cross-Media Analysis does not consider climate change impacts on drought frequency and magnitude and most critically, ignores mine dewatering and underdrainage effects on wetland water levels. As a consequence, it concludes that in wetlands other than the selected Wetland of Interest which has a culvert leading to it that prevents drawdown at the particular location (Appendix C, Figure C-3), "the potential export of SO_4 [sulfate] and MeHg [methylmercury] is expected to be the same as background wetlands and likely no different with the Project in operations as occurs now in existing conditions" (Appx. F, p. 12). This claim, upon which the MPCA apparently relies in issuing the 401 Certification for the NorthMet project, is unreasonable and scientifically unsupportable.

Even if the designed surface inflows for PolyMet's Wetland of Interest exclude this singular wetland from water level drawdown from mine dewatering, other NorthMet mine site wetlands will not be similarly protected. Failure to consider mine dewatering hydrologic impacts on wetland biogeochemistry and mercury methylation on and proximate to the proposed NorthMet mine site (as discussed in detail in my 2015 opinion Sections 2.5.2 and 2.5.3) and the resulting export of sulfate and methylmercury is a fatal omission, rendering the predictive power of the

Cross-Media Analysis inadequate and the subsequent 401 Certification minimizing mercury methylation impacts compromised and defective.

Given the fundamental role that hydrologic impacts play in mercury methylation, MPCA should have required PolyMet to release all the data used to model pit inflow models (which must be accurate to ensure safety of operations), so that this data could be used to model the indirect impacts of mine pit dewatering on wetlands. It is inexplicable and unreasonable for MPCA to request a detailed analysis of sulfur air deposition to address concerns about compliance with State water quality regulations without requiring disclosure and modeling to refine the understanding of NorthMet mine site hydrology prior to 401 Certification, particularly since this hydrological model is already well-developed.

2.2 Monitoring required by the 401 Certification and NPDES/SDS permit is insufficient to detect irreparable harm resulting from mercury release and methylation

Although the MPCA issued its Section 401 Certification for the NorthMet project subject to monitoring conditions, these conditions are insufficient to detect, let alone prevent impacts related to mercury in the environment caused by the project.

The MPCA 401 Certification requires PolyMet to provide data to assess potential effects on water quality resulting from *air deposition* of sulfur and metal air emissions associated with the project, and data from monitoring of methylmercury (401 Certification, pp. 2-3). However, as with the Cross-Media Analysis, a closer look demonstrates that the monitoring of methylmercury is inadequate and that the data provided are improperly restricted in ways that will fail to detect, let alone prevent, harm to the environment and risks to human health from methylmercury production and transport.

Although the MPCA requires surficial groundwater monitoring for sulfate, mercury and methylmercury among other parameters in 22 wetland locations, this monitoring is only required *"until the commencement of* project *mining operations*." (Final PolyMet 401 Certification, 2018). Although this recommendation seems to reflect the language used by mercury expert Dr. Monson in the MPCA analysis of the Cross-Media Report, it is my opinion that his comment was taken too literally; continued monitoring after the beginning of operations was implicit given the context of the statement in Dr. Monson's analysis. His sentence preceding the comment concerning wetland water quality monitoring reads, "Given the complexity and uncertainty of the biogeochemical processes governing the transport, methylation, and bioavailability of mercury in any particular water body, it is necessary to monitor water quality to **confirm the expected outcomes**. To this end…" (emphasis mine). The clear meaning of this phrase is that monitoring must continue to confirm the predicted outcomes during operations.

Despite this recommendation from its own scientist, MPCA's Section 401 Certification requires no ongoing wetland water quality monitoring over the duration of mine operation. Therefore, no "expected outcomes" could possibly be detected and no reasonable assurance afforded that the

activities proposed for the NorthMet project will be conducted in a manner that will not violate water quality standards or harm the environment. (401 Certification, p. 2).

Given the explicit inclusion of stream monitoring both prior to, and during mine operations in the 401 Certification, the MPCA's explicit exclusion of wetland monitoring during project mining and processing is at best capricious, and at worst deliberately designed to prevent discovery of any impacts on wetland biogeochemistry - particularly methylmercury production - during NorthMet project mine and processing operations.

Monitoring of wetland biogeochemistry proximate to the NorthMet mine and tailings basin is essential to detect and prevent mercury methylation increases and environmental harm. These wetlands are the sites where methylmercury would be produced in both the Partridge River and Embarrass River watershed as a result of NorthMet project activities. Even if subsequent stream monitoring were provided, increases in methylmercury in streams could only be detected after irreparable harm had already occurred. The requirement to monitor wetland vegetation for change cannot serve as an indicator of biogeochemical function, and moreover would be extremely lagged (years to decades) behind the onset of changes in hydrology (with the obvious exception of overt flooding). By the time that methylmercury showed up in downstream tributaries, increases in methylmercury would already be incorporated into the aquatic foodweb in upstream locations. In addition, this enhanced methylmercury production in wetlands would have had other significant direct ecological impacts.

It is now well established that birds and bats suffer from elevated levels of methylmercury in locations where methylmercury is elevated due to industrial activity (Kopec et al. 2018; Sullivan et al. 2018) or in locations where methylation is naturally enhanced such as wetlands (Ackerman et al., 2016). Many species of birds and bats have elevated methylmercury levels because of their insectivorous diet. In addition to the direct grazing of invertebrates in wetland environments, numerous flying insect species spend their larval stages in wetland and aquatic environments where they accumulate methylmercury. When they emerge, they transfer this methylmercury to the terrestrial food chain.

The direct impacts of elevated methylmercury on birds include reproductive failure and neurocognitive impacts that compromise rearing, foraging, and migration fitness. Ma et al. (2018a) found that elevated methylmercury severely compromised flight performance under simulated migratory flight. It has been posited that elevated methylmercury across entire species (dominantly insectivorous long distance migrants like the Black Poll Warbler) is at least in part responsible for their precipitous population declines in North America in the last two decades (Ma et al., 2018b).

There are fewer published studies on bats. However Chetelat et al. (2018) found that brain mercury levels in some bats were above sub-lethal effect levels, suggesting some level of impairment of neurocognitive functioning. As with migratory impairment with birds, methylmercury likely has similar impacts on bat navigation and foraging. Further, Chetelat et al. (2018) found a striking geographical overlap between environmental mercury levels and the presence of bat species in decline or at risk, particularly from diseases like white-nose syndrome. Yates et al.

(2014) concluded that high levels of mercury in female bats would be readily transferred to pups through breast milk resulting in potential population-level effects. The project FEIS identifies listed species at risk that may be affected by the development, but only do so in the context of habitat disruption (FEIS p. ES-39). The northern long-eared bat (federally-listed), little brown bat, eastern brown bat, and yellow rail (state-listed) are all species that are identified in the FEIS would be directly impacted by increased in methylmercury in wetlands impacted by the proposed project. Monitoring of mercury and methylmercury downstream will not detect nor prevent these ecological impacts.

In addition, MPCA's proposed monitoring of mercury and methylmercury in five stream locations is inadequate. Again, Dr. Monson in his section of the MPCA analysis of Cross-Media Report (Attachment 3) states that, "I recommend adding methylmercury, along with total mercury, to the stream water quality monitoring specified in the NPDES/SDS permit", with no direct reference to a subset of sampling locations, as he did for wetland monitoring. I believe that his recommendation was for the addition of total mercury and methylmercury to *all* stream monitoring locations specified in the NPDES/SDS permit. In the final 401 Certification, the MPCA ultimately requires only two monitoring locations upstream of the proposed development, and only three downstream (potentially impacted) sites where change might be detected. Downstream monitoring sites are only on larger channels and considerable distance from potential locations of direct operational impact such as the Embarrass River wetlands discussed previously. Sampling is inexplicably restricted to filtered total mercury and methylmercury, which will by definition not capture any inorganic mercury and methylmercury associated with organic or inorganic particles. Finally, the specification for sampling the streams only four times annually is scientifically indefensible – detection and confirmation of systematic change above natural variability will be nearly impossible over any reasonable time period. All of these details actually minimize the likelihood of change detection despite their appearances and stated intent, and even if change were detected it would only be at some time after the environmental impact was already manifest and irreversible.

As previously discussed, PolyMet's selected Wetland of Interest is of marginal relevance to determine the production and transport of methylmercury from the NorthMet project, due to the planned supplementation of water to this location to offset potential hydrologic effects. But, even at the WOI, neither mercury nor methylmercury will be sampled. As a result, the MPCA conditions included in the Section 401 Certification ensure that *no data* will be provided on mercury or methylmercury at any headwater wetland or tributary location during the course of project mining and processing operations.

In my experience working with both regulators and the mining sector in Canada, biological monitoring of large and small bodied fish, young of year fish, and/or invertebrate biosentinels is considered a more reliable indicator of ecosystem level increases in methylmercury than periodic water sampling in open waters, where hydrological variability can strongly influence concentrations, and biological exposure can be highly spatially variable in wetlands, streams and rivers. This biological monitoring is standard practice and is customarily required to detect

environmental impacts from methylmercury to the aquatic food web and allow intervention to protect the health of species, including humans, consuming methylmercury impacted aquatic life.

For example, at the DeBeer's Victor Mine which is located in a wetland-rich region of northern Ontario, 500-700 small-bodied fish (young of year) are collected each year late in the open water season and analysed for methylmercury content as biosentinels under provincial regulation; the mercury in these biota reflect mercury exposure conditions *in that year only*, permitting annual assessments of change both prior to, and during mine operations. This is in addition to a large food fish monitoring program, and an extensive open water and groundwater sampling program, for which *every surface water sample* is analysed for filtered and unfiltered total mercury and methylmercury. These data are reported to the provincial regulator annually, and are in the public record. The MPCA's failure to require biological monitoring of methylmercury in the Section 401 Certification of the NorthMet project is an additional omission that prevents detection of, or protection from, methylmercury impacts of the project on the environment or on human health.

3 Concluding Remarks

The Cross-Media Analysis and MPCA's discussions in its Section 401 Certification Fact Sheet and Findings of Fact derived from this analysis do not resolve the concerns that I have raised in opinions on the NorthMet Supplemental Draft Environmental Impact Statement (SDEIS) and Final Environmental Impact Statement (FEIS). To recapitulate the most salient of these:

1. Background site-specific analyses 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.

This concern not only persists, but has been reinforced by the MPCAs 401 Certification conditions and requirements, which cannot in any way capture potential Project impacts with respect to mercury and methylmercury in surface waters or biota, nor provide any transparent strategies for the adaptive management of impacts, should they be detected. As such, these conditions cannot afford any protection of the environment, nor can they protect human health due to the consumption of mercury-contaminated fish.

2. The failure 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.

Although there has been extensive subsequent consideration on the controls on mercury methylation in the FEIS, the Cross-Media Analysis, and subsequent review of that Analysis by MPCA scientists, the 401 Certification either completely disregards these factors, or considers them in a tangential way by only addressing dust deposition from the Project, and thus fails to

address the much more serious impacts that the Project may have on water quality. All of this taken together provides the appearances of a scientifically considered environmental assessment and monitoring plan, however nothing could be further from the truth.

3. No reasonable attempt to model the potential aquatic ecosystem impacts of changes in water chemistry (primarily mercury and sulfate) due to the NorthMet Mining Project, nor was there any reasonable attempt to model the hydrological impacts of the Project on shallow groundwater hydrogeology, bog hydrology and hydrological connectivity.

The Cross-Media analysis gives the appearance of an attempt to address the serious deficiency in the FEIS related to water quality, however it focuses only on dust emissions that, in my opinion, would have been known, *a priori,* to be neither the sole nor the most significant factor contributing to methylmercury increases. This analysis merely serves to divert attention away from the much more environmentally impactful changes in hydrology and surface water discharges. By dismissing the site hydrology as 'too complicated to model' the MPCA has granted license to PolyMet to conduct an experiment on the headwaters of the Embarrass and Partridge Rivers without any boundary conditions or expected outcomes. Unfortunately, water quality parameters will be so inadequately monitored that we won't even know what the results of this 'experiment' are until serious consequences have occurred. The failure to require a rigorous analysis of the impacts of mine development on site and regional hydrology results in nearly complete uncertainty concerning the cascading effects of hydrological changes on wetland biogeochemistry, presenting an unreasonable risk to the environment, including downstream methylmercury contamination of fish.

The MPCA has continued to accept PolyMet's assertions regarding the efficacy of mercury adsorption and treatment and the efficacy of seepage containment in the face of independent expert opinion that PolyMet's assumptions are unreasonable and unsupportable. Although the MPCA required PolyMet to provide an analysis of sulfur deposition from mine site dust, this analysis at best explores only one of many factors that may increase mercury methylation in proximate wetlands and tributaries and result in biomagnification of this methylmercury increase in both aquatic and terrestrial ecosystems. At worst, this singular focus of the Cross-Media Analysis may serve to divert attention from the other critical problems posed by the NorthMet project. Critical factors that should have been analyzed before a conclusion could be reached that the NorthMet project will not degrade water quality, violate water quality standards, and pose a threat to the environment and human health include the following:

1. The probable impact of the mine development and operations on surface water and groundwater hydrology and hydrogeology
2. The potential for enhanced mercury methylation due to sulfate and mercury loading from direct surface water discharges and seepage through aquifer connections to surface water.

3. The distribution of total mercury and methylmercury, in water, sediment, and biota across the entire region of potential impact from mine activities.

In summary, based on my review of the project SDEIS, FEIS, numerous technical documents, the subsequent Cross-Media Analysis and the MPCA's explanations in connection with issuing a Section 401 Certification for the NorthMet project, I maintain my professional opinion that the weight of the scientific evidence indicates that the NorthMet project is would create a substantial risk of ecologically significant increases in water column and fish methylmercury concentrations in downstream waters, including the St. Louis River due to changes in wetland biogeochemical processes (primarily mercury methylation) driven by hydrological impacts of pit dewatering, subsequent changes to wetland biogeochemistry as a function of these changes, and aqueous sulfate discharges to headwaters.

The Section 401 Certification documents fail to address aspects of the proposed development that present an unreasonable risk to downstream water quality and human health due to increases in methylmercury in the environment. As a consequence, it is my opinion the MPCA has failed to ensure that the project will not result in water quality impairments that violate State standards. In addition, the MPCA has failed to require adequate or appropriate monitoring prior to, and during mine operations to detect environmental impact as part of its Section 401 Certification conditions for the proposed project.

4 Referenced Materials

Branfireun, B.A. Final Expert Review of the NorthMet Mining Project and Land Exchange Final Environmental Impact Statement, Dec. 12, 2015 and Referenced Materials

Barr, Cross-Media Analysis to Assess Potential Effects on Water Quality from Project-Related Deposition of Sulfur and Metal Air Emissions, Prepared for Poly Met Mining, Inc., October 31, 2017.

Chetelat, J. et al. Spatial variation of mercury bioaccumulation in bats of Canada linked to atmospheric mercury deposition, SCIENCE OF THE TOTAL ENVIRONMENT 626, 668–677. 2018.

Ma Y, Branfireun B, Perez C, Guglielmo, C. Dietary Exposure to Methylmercury Affects Flight Endurance in a Migratory Songbird. Environmental Pollution. 234: 894-901. 2018

Ma Y, Branfireun B, Hobson K, Guglielmo, C. Evidence of negative seasonal carry-over effects of breeding ground mercury exposure on survival of migratory songbirds. Journal of Avian Biology. 49(3), UNSP e01656. 2018.

McCarter, C.P.R. B.A. Branfireun, J.S. Price, Nutrient and mercury transport in a sub-arctic ladder fen peatland subjected to simulated wastewater discharges, SCIENCE OF THE TOTAL ENVIRONMENT, 609, 1349-1360, 2017.

MDNR et al., NorthMet Mining Project and Land Exchange Final Environmental Impact Statement, Nov. 2015.

MPCA, Clean Water Act Section 401 Water Quality Certification, NorthMet Project, Dec. 20, 2018.

MPCA, Clean Water Act Section 401 Water Quality Certification Program Fact Sheet, NorthMet Project, Dec. 20, 2018.

MPCA, Conclusions and Recommendations Related to Poly Met Mining, Inc.'s NorthMet Project "Cross-Media Analysis to Assess Potential Effects on Water Quality from Project-Related Deposition of Sulfur and Metal Air Emissions, Ann Foss, Jan. 5, 2018.

MPCA, Findings of Fact, Conclusions of Law and Order re Issuance of NPDES/SDS Permit No. MN0071013 for the Proposed NorthMet Project, Dec. 20, 2018.

MPCA, Findings of Fact, Conclusions of Law and Order re Issuance of MPCA Certification under Section 401 of the Clean Water Act for the Proposed NorthMet Project, Dec. 20, 2018.

MPCA, NPDES/SDS Permit Program Fact Sheet, Permit MN0071013, NorthMet Project

NPDES/SDS Permit MN007103, NorthMet Project, issued Dec. 20, 2019.

Price, J.S. Evaluation of the Impact of the Proposed NorthMet Mine on Local Wetlands, July 2017, with attached articles.

Yates et al., Mercury in bats from the northeastern United States, ECOTOXICOLOGY, 23:45-55 2014.

5 Curriculum Vitae - Branfireun

PERSONAL INFORMATION

NAME: Brian A. Branfireun
CITIZENSHIP: Canadian

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APPOINTMENTS AND POSITIONS HELD
CURRENT

Full Professor with Tenure Department of Biology and Centre for Environment and Sustainability, Western University (2015-current)
Canada Research Chair in Environment & Sustainability (Tier II: 2015-2020).
Associate Chair – Research, Department of Biology, Western University (2016-2019)
Adjunct Professor (Graduate Supervision), Department of Biology, University of Waterloo (2015-current)
Adjunct Professor (Graduate Supervision), Department of Geography, University of Waterloo (2013-current)

PREVIOUS ACADEMIC APPOINTMENTS

Associate Professor (probationary) Department of Biology and Centre for Environment and Sustainability, Western University (2010-2013) **Adjunct Professor (Graduate Supervision)**, Department of Geography, Nipissing University (2015-2018)
Adjunct Professor (Graduate Supervision), Queen Mary University of London, UK (2011-2015)
Adjunct Professor (Graduate Supervision), Swedish Agricultural University, Uppsala, Sweden (2014-2018)
Associate Professor (with tenure) Univ. of Toronto Mississauga Department of Geography (2005-2010)
Assistant Professor (probationary) Univ. of Toronto Mississauga Department of Geography (1999-2004)

PREVIOUS ADMINISTRATIVE APPOINTMENTS

Director, Biotron Centre for Experimental Climate Change Research (2012-2018).

Director, Faculty of Science Integrated Materials Analysis and Characterization Network (2011-2012).
Director, Univ. of Toronto Mississauga Programs in Environment (July 2004 – June 2009)
Interim Chair, Univ. of Toronto Mississauga Department of Geography (July/05 to June/06)
Acting Chair, Univ. of Toronto Mississauga Department of Geography (March/05 to June/05)

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 methyl-mercury 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

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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)

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

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.

Technical Review Committee Member, US Department of Energy Oak Ridge National Laboratory (ORNL) Mercury Science Focus Area (SFA) Review, Washington, DC (2012; 2015; 2018)

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

Science Advisory Panel Member for Sensing the Americas' Freshwater Ecosystem Risk (SAFER) from Climate Change, Instituto Argentino de Oceanografía, Argentina. (2013-2017).

> 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.

Technical Advisory Committee Member: 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, 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.

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.

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

President, Canadian National Commission – International Union of Geodesy and Geophysics (2013-2015) (iugg.org). Associated with national service items 20-21.

NATIONAL SERVICE (Last 5 Years)

Committee Member – Interdisciplinary Adjudication Committee, Canada Research Chairs Program (Dec 2017-Aug 2018).

Committee responsible for addressing any new or renewing CRC applications which were considered problematic and requiring additional input. Reviewed approximately 40 CRC proposals. Declined invitation to return as permanent member of committee for three year term.

Member, Tribunal Hearing Committee – McMaster University, Secretariat (Jan-Mar 2018)

Served as university external member of a hearing committee on a University-level academic misconduct matter.

External Reviewer – Department of Earth Science, Simon Fraser University (March 2018)

Three day site visit to SFU and co-preparation of a full departmental review document (undergraduate, graduate, research) with 3 co-reviewers (16pp).

Expert Advisor – Grassy Narrows Mercury Contamination. Ontario Ministry of Environment and Climate Change (2017-18)

Serving as a member of an advisory team to the Provincial government to guide the development of an appropriate data collection and remediation plan to address the mercury contamination issues in the English-Wabigoon River. The development of the remediation plan is ongoing.

Science Advisor on Mercury – Grassy Narrows First Nation

I am working with a larger team of scientists on behalf of the community of Grassy Narrows to provide scientific advice on planned remediation activities to finally clean up a legacy of mercury contamination that has affected the community for over 50 years.

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

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.

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

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

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).

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

UNIVERSITY SERVICE (Western University Only)

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

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

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

Member, Faculty of Science Environment & Sustainability Focus Area Executive Committee (2013-2016)

Director, Biotron Centre for Experimental Climate Change Research (2012-2018).

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

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

Member, Environmental Science Undergraduate Program Advisory Committee (2011- 2014).

Co-Chair, Northern Scientific Training Program Committee (2011-current)

OTHER SERVICE (Last 5 Years)

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

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)

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

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.

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.

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

Project Title	Dates	Total Amount	Agency	Co-Investigators	% of Award to BB
Trackdown of fugitive mercury release in groundwater from the former Chlor-Alkali Mill in Dryden, Ontario.	2017-2022	178,042	Ontario Ministry of Environment and Parks Grassy Narrows Remediation Panel		100 %

AWARDED

Project Title	Dates	Total Amount	Agency	Co-Investigators	% of Award to BB
The role of peatlands in boreal forest land-use carbon management under climate change	2019-2021	111,000	NRCan/UWO	Branfireun B, Lindo Z, Emilson, E	33 %
Climate change and catchment controls on the mercury cycle of northern lakes	2018-2023	215,000	NSERC Discovery		100 %
Solid-phase CHNS analyser for plant, soil and sediments from aquatic and terrestrial ecosystems,	2018-2019	102,873	NSERC RTI	Lindo Z, Branfireun B, Henry H, Macfie S	0%
Wetland Ecosystem Terrain System Simulator (WETSyS),	2017-2022	1,083,524	Ontario Research Fund	Price J and 8 others	0%

Wetland Ecosystem Terrain System Simulator (WETSyS),	2017-2022	1,083,524	Canada Foundation for Innovation	Price J and 8 others	0%
Indigenous Mentorship Network Training Program, Ontario Node	2017-2020	1,000,000	CIHR	Richmond, C and 53 others	0%
An autonomous underwater vehicle for the study of remote lakes, Grant	2017-2018	$150,000	NSERC RTI	Branfireun and Swanson, H.	100 %
A spectrophotometer for the rapid characterization of natural organic matter in water	2017-2018	$49,688	UWO SERB Accelerate		100 %
Speciation of Arsenic and Mercury in Volunteers, Traditional Foods and the Environment at Walpole Island First Nation Complemented with Three Repeated 24-Hour Dietary Recall Surveys and a Food Frequency Questionnaire	2016-2017	$99,500	Heath Canada: First Nations Environmenal Contaminants Program	Bend, J. and 7 others	25 %
An investigation of variable fish mercury concentrations in Dehcho lakes,	2016-2018	$52,000	Government of the Northwest Territories – Cumulative Impacts Monitoring program	Swanson H., G. Low, Branfireun B	0% (all funds for field logistics)
Variable fish mercury concentrations in the Dehcho: effects of catchment control and invertebrate community composition	2016-2017	$23,978	Aboriginal Affairs and Northern Development Canada (AANDC) Northern Contaminants Program	Low, G., Swanson, H., Branfireun B	50 %

A portable ultra-trace mercury analysis system	2016-2017	$92,000	NSERC Research Tools and Instruments	Swanson, H, Branfireun, B, Laird B, Power, M	0%
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. Erin 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 and 11 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 and 4 others	50 %
Bioavailability of mercury in aquatic food webs	2014-2015	275 000 DKK	Nordic Cooperation Committee	K. Bishop (Uppsala University)60,650	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 %
Hydrology and mercury biogeochemistry of the Hudson Bay lowland	2009-2016	$240 000	NSERC (Discovery Grant – 3 year extension for NSERC Committee Service)		100 %
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 %

PUBLICATIONS (all time)

REFEREED PUBLICATIONS (My HQP are *; Collaborator HQP are †)

1. Lescord G†, Johnston T, Branfireun B, Gunn J. (2018). Mercury bioaccumulation in relation to changing physicochemical and ecological factors across a large and undisturbed boreal watershed (Freshwater Biology, submitted)
2. Bhavsar, S, Knight A†, Branfireun B, et al. (2018). A comparison of fish tissue mercury levels from homogenized fillet and nonlethal biopsy plugs (J. Env. Sci., accepted with minor revisions).
3. Asemaninejad A†, R Thorn, B Branfireun and Z Lindo. Climate change favours specific fungal communities in boreal peatlands. 2018. Soil Biology & Biochemistry, 120:28-36.
4. Kohlenberg A†, Turetsky M, Thompson D, Branfireun B, Mitchell C. (2018). Controls on peat combustion and resulting emissions of carbon and mercury. Environmental Research Letters, **13** 035005.
5. Lescord G†, Emilson E, Johnston T, Branfireun B, Gunn J. (2018). Optical Properties of Dissolved Organic Matter and Their Relation to Mercury Concentrations in Water and Biota Across a Remote Freshwater Drainage Basin. Environmental Science & Technology. 52(6): 3344-3353.
6. Ma Y*, Branfireun B, Perez C, Guglielmo, C. (2018) Dietary Exposure to Methylmercury Affects Flight Endurance in a Migratory Songbird. Environmental Pollution. 234: 894-901.
7. Asemaninejad A†, Branfireun B, Thorn G, Lindo Z. (2018) Climate change favours specific fungal communities in Boreal peatlands. Soil Biology and Biochemistry. 120: 28-36.
8. Ma Y*, Branfireun B, Hobson K, Guglielmo, C. (2018). Evidence of negative seasonal carry-over effects of breeding ground mercury exposure on survival of migratory songbirds. Journal of Avian Biology. 49(3), UNSP e01656.

9. Lescord G†, Johnston T, Branfireun B, Gunn J. (2018). Percentage of methylmercury in the muscle tissue of freshwater fish varies with body size and age and among species. Environmental Toxicology and Chemistry. 37(10): 2682-2691.

10. Burke S†, Zimmerman C, Branfireun B, Koch J, Swanson H. (2017). Patterns and controls of mercury accumulation in lake sediments from three thermokarst lakes on Arctic Coastal Plain of Alaska. Aquatic Sciences. 80:1., UNSP 1

11. McCarter C†, Branfireun B, Price J. (2017). Nutrient and mercury transport in a sub-arctic ladder fen peatland subjected to simulated wastewater discharges. Science of the Total Environment. 609:1349-1360.

12. Dieleman, C*, Branfireun, B, Lindo, Z. (2017). Northern peatland carbon dynamics driven by plant growth form — the role of graminoids. Plant and Soil. 415(1-2): 25-35.

13. Gordon J†, Quinton W., Branfireun B, Olefeldt, D. (2016). Mercury and methyl mercury biogeochemistry in a thawing permafrost wetland complex, Northwest Territories, Canada. Hydrological Processes. 30(20): 3627-3638.

14. Dieleman, CM*, Branfireun BA, McLaughlin, JW, and Lindo, Z. Enhanced carbon release from a northern poor fen under future climate conditions: Role of phenolic compounds, Plants and Soil, 400: 81-91, 2016.

15. Dieleman, CM*, Lindo, Z, McLaughlin, JW, Craig, A. Branfireun BA. (2016) Climate change effects on peatland decomposition and porewater dissolved organic carbon biogeochemistry. Biogeochemistry. 128(3): 385-396, 2016.

16. Farrick, KK*, Branfireun, BA. Flow pathways, source water contributions and residence times in a Mexican tropical dry forest. J. HYDROLOGY, 529, 854-865, 2015.

17. 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.

18. 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, in press.

19. 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

20. 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.

21. 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.

22. 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.

23. 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.

24. 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.
25. 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
26. 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.
27. 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
28. 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.
29. 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
30. 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.
31. 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
32. 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.
33. 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.
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BOOKS AND/OR CHAPTERS (Peer-Reviewed)

69. Kolka, Randall K.; Mitchell, Carl P.J.; Jeremiason, Jeffrey D.; Hines, Neal A.; Grigal, David F.; Engstrom, Daniel R.; Coleman-Wasik, Jill K.; Nater, Edward A.; Swain, Edward B.; Monson, Bruce A.; Fleck, Jacob A.; Johnson, Brian; Almendinger, James E.; Branfireun, Brian A.; Brezonik, Patrick L.; Cotner, James B. Mercury Cycling in Peatland Soils and Watersheds. In: Kolka, Randall K.; Sebestyen, Stephen D.; Verry, Elon S.; Brooks, Kenneth N.Peatland Biogeochemistry and Watershed Hydrology at the Marcell Experimental Forest. : 349-370. CRC Press. 2011.

70. 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.

PRESENTATIONS (last 5 years)

SELECTED PAPERS PRESENTED AT SCIENTIFIC MEETINGS & SYMPOSIA (Last 5 Years. My HQP are *; Collaborator 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).

June 2018	Burke S†, Zimmerman C, Branfireun B, Swanson H. Drivers of mercury accumulation in the sediments and food webs of lakes on the Arctic Coastal Plain of Alaska. American Society for Limnology and Oceanography, Victoria, Canada. ORAL. (This student paper was presented in a session that I co-proposed and co-organized).
June 2018	Tian J*, Lindo Z, Petrone R, Branfireun B. Greenhouse gas fluxes and carbon storage functions in two contrasting fen-peatland types: Implications for global warming. Joint Assembling of the Canadian Geophysical Union and Canadian Meteorological and Oceanographic Society, Niagara Falls, Canada. ORAL.
June 2017	Tian J*, Lindo Z, Branfireun B. (2017). Climate Change Alters Peatland Carbon Cycling through Plant Biomass Allocation. Canadian Geophysical Union Annual Assembly, Vancouver, Canada POSTER
June 2017	Branfireun B, Zabel N, Swanson H. (2017). Mercury in Water, Sediments and Fish in Kluane Lake, Yukon Territory, Canada. Canadian Geophysical Union Annual Assembly, Vancouver, Canada ORAL.
Jan 2017	Germain B*, James A, Branfireun B. (2017). Applying a Hydrologic Classification Approach to Low Gradient Boreal Catchments. Canadian Conference For Fisheries Research/Society for Canadian Limnologists, Montreal, Canada POSTER
Jan 2017	DeJong R†, Johnston T, Gunn J, Branfireun B, Swanson H. (2017). Life history variation and mercury concentrations in three northern food fishes in the Hudson Bay lowlands.Canadian Conference for Fisheries Research, Montreal, Canada ORAL
Jan 2017	Branfireun B, Gunn G. From microbes to migratory fishes: a synthesis of far north research from the NSERC Canadian Network for Aquatic Ecosystem Services (CNAES). Canadian Conference For Fisheries Research/Society for Canadian Limnologists, Montreal, Canada ORAL
Nov 2016	Swanson H, Low G, Branfireun B, Low M, Evans M.(2017). Drivers of Spatial Variability in Fish Mercury Levels in the Dehcho region, NT, Canada. Society of Toxicology and Chemistry World Congress, Orlando, United States ORAL
June 2016	Zabel N†, Hall R, Branfireun B, Swanson HK. (2016). Québec-Ontario Paleolimnology Symposium (PALS), Kingston, Canada. ORAL.
June 2016	Burke, SM†, Zimmerman CE, Branfireun BA, Swanson HK. (2016). Québec-Ontario Paleolimnology Symposium (PALS), Kingston, Canada. Historical changes in mercury (Hg) in three Arctic Alaskan lakes with different temperature regimes. ORAL.
June	Dieleman C*, Branfireun B, Lindo Z. (2016). Linkages between plants and soils

2016	in northern peatlands under experimental climate change. Canadian Society of Ecology and Evolution Conference, St. John's, Canada ORAL
May 2016	Swanson H, Low G, Alatini N, Kassi N, Branfireun B. Understanding and predicting mercury concentrations in northern lakes. Canadian Ecotoxicity Workshop, Edmonton, Canada ORAL
May 2016	Twible, L* McCarter, C Price, JS Branfireun, BA.. Canadian Geophysical Union Annual Meeting, Fredericton, Canada. Linking Mining Wastewater Discharge to Methylmercury Production and Persistence in a Sub-Arctic Peatland. POSTER
Feb 2016	Dieleman C*, Branfireun B, McLaughlin J, Lindo Z. (2016). Enhanced carbon release under future climate conditions in a peatland mesocosm experiment:. Canadian Geophysical Union Eastern Student Conference, Guelph, Canada ORAL
Jan 2016	Ma, Y*. M.; Perez, C. R.; Branfireun, B.A., Guglielmo, C. Flight Performance In A Migratory Songbird Exposed To Elevated Dietary Methyl-Mercury. Annual Meeting of the Society-for-Integrative-and-Comparative-Biology, Portland OR. ORAL.
Dec 2015	Swanson HK, Low G, Low M, Branfireun B. Mercury levels in food fishes used by Dehcho community members. Northern Contaminants Program Results Meeting, Vancouver, Canada
Dec 2015	Alatini M, Kassi N, Zabel N, Branfireun B, Swanson HK.. Contaminants, nutrients, and the traditional value of food fishes in Kluane Lake, YT. Northern Contaminants Program Results Meeting, Vancouver, Canada ORAL
May 2015	Branfireun, BA, Lindo ZL and McLaughlin, J. Joint Assembly of the American Geophysical Union, Canadian Geophysical Union, Geological Association of Canada - Mineralogical Association of Canada, Montreal, QC. Lower water tables, not increased temperature, increase methylmercury production in northern peatlands under climate change. POSTER.
May 2015	Branfireun, BA. Joint Assembly of the American Geophysical Union, Canadian Geophysical Union, Geological Association of Canada - Mineralogical Association of Canada, Montreal, QC. Natural and anthropogenically-induced hydrological connectivity produces methylmercury hotspots in the Hudson Bay Lowlands, Canada. ORAL (invited).
Nov 2014	Branfireun, BA, Lindo ZL and McLaughlin, J. Soil Science Society of America Annual Meeting, Long Beach CA. Lower water tables, not increased temperature, increase methylmercury production in northern peatlands under climate change. ORAL (invited).
May 2014	Despault T*, Branfireun BA Joint Assembly of the Canadian Geophysical Union and the Canadian Society of Soil Science, Banff AB. , 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	Farrick KK*, Branfireun BA, Joint Assembly of the Canadian Geophysical Union and the Canadian Society of Soil Science, Banff AB. Wetting the sponge: Stor-

	age, rainfall and runoff relationships in a Mexican tropical dry forest ORAL. (Award Winner)
Aug 2013	Goacher, J*. and Branfireun BA, 11th International Conference on Mercury as a Global Pollutant, Edinburgh Scotland. Evidence of millennial trends in mercury deposition in pristine peat geochronologies. ORAL.
Aug 2013	Morris, M*. Spencer, K, Belyea, L and Branfireun BA, 11th International Conference on Mercury as a Global Pollutant, Edinburgh Scotland. Patterns of total and methylmercury in natural and restored coastal wetlands in south-east England. ORAL.
Aug 2013	Branfireun BA, 11th International Conference on Mercury as a Global Pollutant, Edinburgh Scotland. 150 years of mercury accumulation in bogs in Eastern Canada. ORAL.
Jun 2013	Kline, MI*, Branfireun BA, Joint Assembly of the Canadian Water Resources Association, Canadian Geophysical Union, and Canadian Meteorological and Oceanographic Society Saskatoon, Sk. Base and event-flow hydrologic and biogeochemical connectivity in a fen-stream transition in the central Hudson Bay Lowland, POSTER. (Award Winner)
Jun 2013	Farrick, KK* and Branfireun BA , Joint Assembly of the Canadian Water Resources Association, Canadian Geophysical Union, and Canadian Meteorological and Oceanographic Society Saskatoon, Sk. Iinfiltration and percolation in a Mexican tropical dry forest soil: controls on near-surface soil water storage dynamics, POSTER. (Award Winner)
Jun 2013	Branfireun BA , TR Moore, NT Roulet and J Turunen, Joint Assembly of the Canadian Water Resources Association, Canadian Geophysical Union, and Canadian Meteorological and Oceanographic Society Saskatoon, Sk. 150 years of mercury accumulation in bogs in Eastern Canada ORAL.

INVITED PRESENTATIONS

Sept 2017	Mine-derived sulphate and mercury methylation in pristine northern peatlands: A little goes a long way...Workshop on Advances in Catchment Mercury Science, Uppsala, Sweden.
Sept 2016	Climate and Land Use Change Impacts in Far North Peatlands: Implications for Carbon and Mercury Cycling. Laurentian University - Earth Science Speakers Series, Sudbury, Canada.
Nov 2017	**When the Arctic isn't cold:** Risk, environmental change and food security in Canada's North. TEDx Western: The Human Condition.
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	Mercury cycling in Ontario's northern peatlands. Invited by: K. Bishop as part of the first international Workshop on Catchment Mercury Cycling. Workshop on Advances in Catchment Mercury Science, Uppsala, Sweden.

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.

Broadcast Interviews

2017/03/06 - How do you clean up mercury contamination?, Up North, CBC Radio http://www.cbc.ca/player/play/891362371602

2014/07/10 - "Warming will change wetlands, release CO2: study", The Link, Radio Canada International http://www.rcinet.ca/en/2014/07/10/warming-will-change-wetlands-releaseco2study/

Text Interviews

2017/03/14 "What Can we Do About Mercury in Our Water?", InfoSuperior.com
2017/03/01 "Report shows mercury still leaking into river system", KenoraOnline
2017/02/28 "Study claims mercury still leaking from mill near Grassy Narrows: Chief", The Globe and Mail
2017/02/28 "Site near Grassy Narrows likely leaking mercury, study finds", The Toronto Star
2017/01/12 "Mercury-tainted soil found upstream from Grassy Narrows First Nation", The Toronto Star
2016/11/23 "Grassy Narrows residents eating fish with highest mercury levels in province", Toronto Star
2016/06/20 "Province ignores information about possible mercury dumping ground: Star Investigation" (expert advice and fact checking on article), The Toronto Star
2016/05/30 It's possible to safely remove mercury from Wabigoon River, report says, The Toronto Star