Scientific errors and ambiguities in prominent submissions to Canadian environmental assessments: A case study of the Jackpine Mine Expansion Project

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In Canada, as in many other developed nations, natural resource development projects meeting certain criteria are required to undergo an environmental assessment (EA) process to determine potential human and ecological health impacts [1, 2]. As part of the Canadian EA process, the Canadian Environmental Assessment Agency (http://www.ceaa.gc.ca/) generally considers submissions (oral and/or written) by members of the public and experts. While the allowance of external submissions (i.e., from sources other than the project proponent and/or government agencies) during EA hearings forms an important component of a functional participatory democracy, little attention appears to have been given regarding the quality of such EA submissions. In particular, submissions to EA hearings by prominent individuals and/or groups (particularly scientists and scientific organizations) may be weighted more heavily in the overall decision making framework than those from non-experts. Important questions arise through the allowance and consideration of external submissions to EAs, such as whether inaccuracies in any such submissions may misdirect the EA decision makers to reach erroneous conclusions, and if such inaccuracies do result in sub-optimal EA processes (e.g., excessively long and/or expensive, potentially reaching decisions based on incorrect information, etc.), how the issues should be addressed.

In the current work, a representative recent external submission [3] by Dr. David Schindler from the University of Alberta as part of the broader Oil Sands Environmental Coalition (OSEC) submission to the Shell Canada Jackpine Mine Expansion (JPME) Project EA hearings (http://www.ceaa.gc.ca/050/details-eng.cfm?evaluation=59540) will be examined. The proposed JPME project is located in the Athabasca Oil Sands Region (AOSR) of northern Alberta near Fort McMurray, includes 'mining areas and associated processing facilities, utilities and infrastructure," and is anticipated to "increase bitumen production by 100 000 barrels per day." In order to evaluate this submission for potential scientific errors and ambiguities, a format of

statement (by Schindler/OSEC) from ref. [3] / response (by the current author) will be employed:

p. 2: "CCME [Canadian Council of Ministers of the Environment] guidelines are much less stringent than other jurisdictions."

References [4] and [5] compare guidelines between selected "jurisdictions." As is evident, "CCME guidelines" do not appear to be generally "much less stringent" than other "jurisdictions." Indeed, in a number of cases, "CCME guidelines" are substantially more stringent than other jurisdictions, including for compounds of concern in the AOSR.

p. 2: "It is widely recognized that many pollutants have synergistic effects, and that others interact with other environmental phenomena to increase toxicity, i.e. some PAHs [polycyclic aromatic hydrocarbons] become much more toxic in the presence of ultraviolet light."

There is evidence that PAH phototoxicity may be a largely ecologically irrelevant phenomenon [6]. As such, this phenomenon should not be given significant attention during EAs until clear and unequivocal environmental relevance has been demonstrated and reproduced in the literature. Furthermore, as is discussed below, a re-analysis of the Timoney and Lee dataset [7] appears to suggest that dissolved phase concentrations of PAHs in the Athabasca River system have not increased over time (despite increasing oil sands development over this period). As a result, even if the PAH phototoxicity mechanism was operative in the oil sands region, the evidence suggests that development activities have not resulted in significantly increased dissolved phase PAH concentrations in the Athabasca River system. Thus, oil sands development does not appear to have significantly increased any PAH phototoxicity impacts (assuming they are active) beyond pre-development baseline levels.

p. 3: "Mercury concentrations in predatory fish species of the Athabasca River and Delta have been high since the earliest measurements were made in the 1970s. While a recent analyses was unable to detect any upward trends in

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fish (Evans and Talbot 2012, Environmental Monitoring), the authors admit that the data base for predicting trends is inadequate, due to small sample sizes, combining fish of several sizes in some samples, analyzing different tissues at different times, using different analytical methods without intercalibration, and comparing fish from several locations in others. In short, past monitoring has been too deficient to reliably assess trends in mercury."

Although Evans and Talbot [8] do acknowledge that "[f]uture monitoring programs investigating mercury trends in fish should be more rigorous in their design," it is important to note that not only were these authors "unable to detect any upward trends in fish [mercury concentrations]," some of the trends they did discover were declines: "When all available data for mercury concentrations in fish were considered and comparisons based on similar river reaches, there was a significant trend for mercury concentrations to decline in walleye over 1984-2011 and walleye and lake whitefish over 2002-2011 in the Steepbank and Muskeg reaches of the Athabasca River. Furthermore, there was a significant trend for mercury concentrations to decline in northern pike in the western Lake Athabasca over 1981-2009 while walleye and lake trout concentrations remained unchanged." Evans and Talbot [8] also appear to have successfully refuted the prior claims of Timoney and Lee [9] regarding increasing mercury concentrations in fish from the Athabasca River system.

p. 3: "A recent analysis that corrects for size and uses consistent collection and analytical methods (2008; Radmanowich draft MSc thesis) indicates that roughly 75% of northern pike, 72% of goldeye and 80% of walleye in the lower Athabasca River exceeded consumption guidelines for frequent consumers (0.2 µg/g wet weight). On the other hand, lake whitefish averaged well below guideline values. Subsistence fishermen must now choose between getting sufficient protein and consuming a potent neurotoxin, which has particularly damaging effects on fetuses and newborn infants."

In this statement, Schindler cites an apparently "draft MSc thesis" by "Radmanowich" from "2008." This document did not appear to be publicly available for review at the time of submission, and thus its claimed findings should have no influence on an EA process. One also assumes Schindler is referring to Radmanovich (i.e., Roseanna Radmanovich - one of Schindler's graduate students), and one wonders how a M.Sc. thesis could remain in apparent draft form between 2008 and 2012.

p. 3: "Kelly et al. (2010, Proc Nat. Acad. Sci. USA) showed that mercury deposition in snow has increased near oil sands development."

Based on apparent problems [10] found in depositional loading calculations for PAHs by this group in ref. [11], there is doubt regarding the analogous calculations reported in Kelly et al. [12]. The raw data from ref. [12] were requested from Schindler by this author, but no reply was received. In order for EA proponents to adequately assess the claimed findings in ref. [12], Schindler would have needed to release all raw data for independent analysis. An apparent deficiency in ref. [12] is the lack of rigorous contextualization for reported depositional estimates of "elements considered priority pollutants [PPEs]." Short-term CCME "Water Quality Guidelines for the Protection of Aquatic Life" do not exist for PPEs. Consequently, comparing possible very short-term exposure (i.e., on the order of days to a few weeks at most) concentrations of PPEs in melted snow to long-term CCME "Water Quality Guidelines for the Protection of Aquatic Life" appears to be invalid, which seems to negate a number of the risk-based conclusions in ref. [12]. Short-term exposure limits are generally much higher than long-term exposure limits for contaminants, and one cannot reasonably pick the shortest-term highest concentration datapoints (e.g., spring snowmelt pulses) and compare them to long-term water quality guidelines and expect any rational ecotoxicological insights.

p. 3: "Harris et al. (2007 Proc. Nat. Acad. Sci. USA) experimentally added mercury that was tagged with a stable isotope to a small lake. The added mercury was reflected in the lake's fish within months. Given the inadequacies of the monitoring data base for the Athabasca River, the Harris et al. results suggest that adding more mercury to the oil sands area will aggravate an already serious problem."

The results of the Harris et al. [13] study are complex, as was even noted in the *Proceedings of the National Academy of Sciences* commentary by Engstrom [14] on the Harris et al. [13] manuscript. It is important to note that not all aquatic systems respond equally to inputs of mercury. Thus, the findings of Harris et al. [13] cannot necessarily be applied to all aquatic systems in the oil sands region. Engstrom [14] notes the following in his commentary on this subject: "For example, a recent study of lakes in Voyageurs National Park along the U.S.-Canadian border of Minnesota found that mercury levels in northern pike (*Esox lucius*) varied by an order of magnitude, despite a regionally uniform rate of atmospheric mercury deposition, largely because of differences in the methylating efficiency of the lakes and their watersheds." Harris et al. [13] reached the following conclusions: "Because upland and wetland mercury exports were essentially unchanged (<1%) by spike additions, the only significant increase in mercury loading to the lake occurred as a result of spike additions directly to the lake itself." Engstrom [14] goes on to note that "[s]uch is the complexity of mercury cycling, where side-by-side lakes can show greatly different responses to the same (or changing) inputs of atmospheric mercury."

Overall, the findings by Harris et al. [13] were reasonably expected. Namely, it was reasonable to expect that adding a potentially bioaccumulative substance di-

rectly to a lake will result in that lake's biota taking up the substance in a relatively short period of time. But Harris et al. [13] and Engstrom [14] also highlight the need to understand the site-specific behavior of mercury cycling within a watershed. In some aquatic systems, atmospheric mercury inputs to the watershed in upland and wetland regions may not reach fish-bearing lakes for centuries (or longer depending on the system's hydrology). There is no reason to believe that fish in the Athabasca River system will rapidly reflect changing atmospheric mercury inputs to the surrounding watershed (other than direct atmospheric mercury inputs to surface waters, which likely form a small portion of total atmospheric mercury inputs into the watershed).

pp. 3-4: "Curtis et al. (2010) show that mercury emissions from the oil sands are also contaminating lakes of the area, with increases in a Lake northeast of the oil sands about 40% higher than they were in 1980. Petrogenic spherules increased as well, strongly implicating combustion sources in the oil sands rather than natural sources."

The Curtis et al. [15] manuscript does not appear to support Schindler's broad conclusions. As can be seen in Figure 1 from Curtis et al. [15], their 12 study lakes are relatively broadly distributed around the so-called "[m]ain area of oil sands extraction and processing." And yet, in Table 1 from ref. [15], where the authors report "[s]ediment Hg concentration," it is evident that no clear spatial patterns exist in mercury concentrations among the lakes. Curtis et al. [15] explicitly note this in their paper via the following statement: "Mercury concentrations in lake surface sediments varied between 67-138 ng/g with no obvious spatial pattern (Tab. 1)."

Furthermore, in their Figure 8, Curtis et al. [15] present "[c]oncentration and sediment deposition flux of mercury in lake NE7" (i.e., the lake that Schindler appears to be referring to in his critique). This figure clearly shows that current surficial (i.e., core depth=0 cm) mercury concentrations in the lake sediments are at the same level as they were back in the year 1880 (core depth ~12.5cm), and there appears to be no clear temporal trend between these two end members. Indeed, it appears that mercury concentrations decline significantly between a depth of about 4 cm (whatever date that corresponds to between 1880 and the present) and the surficial sediments (i.e., the present).

Similarly, while mercury fluxes have increased in lake NE7 since 1980 (see inset (b) in Figure 8 from ref. [15]), they appear to be declining since the early 1990s. Curtis et al. [15] appear to reach less definitive conclusions than Schindler about the source of the increased mercury flux to sediments in lake NE7 since 1980: "Fluxes of mercury to lake sediments at this site have increased in the last 20 years, again suggesting local inputs, but these could be driven by increases in sedimentation rates which, in turn, could have climatic or other drivers."

Schindler also makes reference to petrogenic spherules and oil sands derived mercury emissions that are claimed to be contaminating nearby lakes. Curtis et al. [15] make the following statement on this subject: "[P]atterns of Hg accumulation in lake sediments of the Oil Sands Region could warrant further investigation. SCP [spheroidal carbonaceous particle] analysis indicates that there are no major local sources, suggesting that coal and fuel oil combustion are not locally important or if they are used, flue gas emissions are effectively scrubbed of particulates."

p. 4: "There are also concerns about other metals that are not addressed in the EIS. Gueguen et al. (2011, Journal of Environmental Monitoring) concluded that colloidal dissolved organic carbon increased in water as the result of oil sands mining. This changed the speciation and hence the mobility of many trace metals. In the authors' words: 'It was also found that a significant amount of metals were associated with the non-DGT labile fraction (i.e. colloidal DOM [dissolved organic matter]) and colloid abundance was more important than suspended particulate matter abundance in influencing metal mobility near Athabasca oil soils development. Since changes in colloidal DOM levels are likely to be the result of surface mining activities, this confirms the serious effects of oil sands activities on metal biogeochemical cycles in the lower Athabasca River.'"

The argument put forward by Gueguen et al. [16] appears to be that DOM releases during surface mining activities mobilize metals into nearby streams, and that most of these mobilized metals are associated with the DOM and are therefore generally less bioavailable. If true, this would seem to suggest minimal negative impacts of mining activities (i.e., some metals are being released from development activities relative to baseline conditions, but the released metals are in a generally non-bioavailable form). The authors appear to also claim that a hypothetical decrease in DOM inputs (perhaps once land clearance is complete?) will cause many of the previously complexed metals to be released to a dissolved and more bioavailable form, thereby causing potential ecological harm. There appears to be a problem with this argument. The water sample pH values under consideration are generally high (all but one are >7, with many/most >8; see Figure 1 from the Gueguen et al. [16] electronic supplementary material). At these pH values, trace metal solubility is generally low. Thus, DOM inputs appear to be solubilizing otherwise insoluble trace metals in these aquatic systems. Consequently, if one lowers the DOM inputs, there appear to be fewer vectors available to mobilize metals into nearby streams. If we use the results and reasoning apparent in Gueguen et al. [16], this would seem to suggest that development/post-development phase bioavailable metal inputs into nearby streams may be lower than under baseline conditions.

p. 4: "Kelly et al. (2010 PNAS) showed that concentrations of mercury and other toxic metals were elevated in snow for a radius of approximately 50 km around the upgraders in the oil sands, including the Muskeg River basin.

3

While few concentrations exceeded CCME guidelines, the critical snowmelt period when chemicals are likely to be highest and in most toxic form were not sampled. Data for the snowmelt period are inadequate for the entire oil sands area, despite an extensive literature showing that it is the most sensitive period for toxic effects from acids and trace metals."

As was discussed previously, there is uncertainty regarding actual loadings of "mercury and other toxic metals" from oil sands activities as presented in Kelly et al. [12]. As is discussed below, existing work suggests there is a minimal impact of snowmelt derived runoff acidification and concurrent metal mobilization in the Muskeg River.

p. 9: "In appendix 3.2, air emissions and predictions, it is concluded that 23 lakes in the area already suffer from deposition of acidifying sulfur and nitrogen compounds that exceed their critical loads. In addition, lichens and other sensitive forest plants are threatened."

In recent work, Wieder et al. [17] came to the following conclusions: "Across 10 ombrotrophic bog sites in the AOSR over four years (2005-2008) ... [w]e found no significant correlations between N or S deposition and distance from the heart of the oil sands mining area (the Syncrude mine site facilities) and/or prevailing wind direction. Our low values for N and S deposition suggest that elevated deposition from mining activity is restricted to areas closer to and/or immediately downwind of the active mine sites ... Overall, our N and S deposition values are quite low and typical of unpolluted areas ... Across our 10 study sites, we found no evidence for elevated N or S deposition, no consistent site differences in N or S deposition, no consistent site differences in Sphagnum fuscum growth, and no relationships between either N or S deposition and S. fuscum growth."

In their study, Vitt et al. [18] show that nitrogen deposition in this region is well below critical thresholds for *Sphagnum fuscum*: "Therefore, across the wide range of N deposition values encompassed by the studies cited in Table 5, negative impacts on *S. fuscum* production begin to occur, on average, as N deposition reaches 14.8-15.7 kg/ha/yr. We argue that this approach reveals a critical N deposition value (between 14.8 and 15.7 kg/ha/yr) for the production of these bryophyte species ... Current N deposition in the oil sands region of Alberta of about 4 kg/ha/yr, is well below this critical range."

In another study, Hazewinkel et al. [19] report the following findings in their work on a suite of lakes from the AOSR: "Diatom assemblages in dated sediment cores from eight acid-sensitive lakes were analyzed to assess the effects of acidifying emissions on boreal lake ecosystems. There is no evidence that these lakes have become acidified. Instead, many of the lakes show characteristic changes towards greater productivity and occasionally greater alkalinity. The absence of evidence for acidification does not imply that emissions from the Oil Sands are environmentally benign, but rather suggests that the biogeochemistry

of these lakes differs fundamentally from well-studied acidified counterparts in northern Europe and eastern North America. Complex interactions involving in-lake alkalinity production, internal nutrient loading, and climate change appear to be driving these lakes towards the new ecological states reported."

In their article, Aherne and Shaw [20] reach the following conclusion: "The assessment of lakes in northern Alberta using macroinvertebrate, paleolimnological and hydrogeochemical modelling approaches suggest that industrial activities associated with the oil sands presently have limited influence on lake acidification."

Whitfield et al. [21] found the following: "In this study MAGIC [a software program] was used to predict the impacts of increased sulfur (S) emissions on acid-sensitive forest soils at 11 jack pine stands across the AOSR ... The sites were chosen to represent the most acid-sensitive ecosystem in the AOSR at locations that receive variable levels of acid deposition ... Model simulations for the hindcast period (1900-2006) indicate little change in BS [soil base saturation], suggesting that soils at the study sites have not acidified in response to elevated S deposition. Instead, small increases in base saturation are suggested for most of the sites, presumably due to BC [soil solution base cation] binding on soil exchange sites stimulated by higher BC deposition and soil solution concentrations ...

The regional effects-based emissions management framework stipulates that: (1) no further emissions increases will be permitted if model simulations indicate that BS or BC:Al [aluminum] chemical thresholds will be reached within 30 years; (2) emissions reductions are required if model simulations predict that the chemical thresholds will be reached within 15 years ... Although critical chemical thresholds for BS and BC:Al range widely, none of the 11 sites are expected to reach a threshold for BS that would trigger an action to control emissions under either deposition scenario ... Given the nature of the chemical thresholds designated by the management framework, acid-sensitive soils in the AOSR appear to be protected against potentially harmful effects to sensitive biota."

Subsequent work by Whitfield et al. [22] concluded the following: "This suggests that to date SO_4^{2-} deposition levels in the AOSR have resulted in only limited removal of base cations from the soil exchange complex as a buffer of mobile SO_4^{2-} in soil waters. At present, S deposition across much of the AOSR remains low relative to other polluted regions of eastern North America where the density of SO_2 sources is high and contributes to a much higher SO_4^{2-} deposition level. Further, hindcast base cation deposition scenarios suggest that deposition has increased from the pre-industrialization level, which has likely offset some of the increase in SO_4^{2-} deposition in the AOSR region. Across the southern sub-regions base cation deposition averages approximately 70-80% of SO_4^{2-} deposition on an equivalent basis, while at the northern sites base cation deposition is approximately equal to SO_4^{2-} deposition. Evidently, little change in soil chemistry should be

expected under the base case forecast scenario. Under elevated acid deposition (double acid scenario) only marginal decreases (mean = 0.1%) in base saturation are predicted within the simulated timeframe (30 years) ...

Forecast scenarios under base case deposition suggest that negligible change in ANCCB [charge balance acid neutralizing capacity] will take place within the 30 year period of interest for the EMF [emissions management framework] (average change = 0.9%). Small increases in ANCCB may take place over the short term under base case deposition levels, owing to low effective SO_4^{2-} deposition at many catchments and sustained base cation deposition at elevated deposition levels. Forecast simulations predict that small relative decreases in ANCCB will occur at the study catchments in the event that deposition of S and N increases to a level twice that of 2005 deposition. Few lakes have ANC in the range of the critical threshold (2005 median ANCCB: 359 μeq L^{-1}), and consequently the impacts from acidification are expected to be very limited. Only one lake (SM08) is projected to be depressed below the critical threshold ANCCB of 75 μeq L^{-1} under this forecast scenario and consequently acidification patterns within the timeframe of interest for the EMF are unlikely to stimulate an action to introduce emissions controls ...

[T]he regional lake response to changes in acid deposition was coherent and model simulations suggest very limited change in surface water chemistry, thus there is reasonable confidence that impacts of acidification on lakes in the AOSR will be limited ... In view of projected N deposition levels, the risk of N saturation is low, and because the majority of lakes have high ANCCB, N deposition is not high enough to cause widespread acidification (depression of ANCCB to the critical threshold) ... The model simulations presented here for 28 forest plots and 50 lake catchments suggest that lake and soil chemistry have shown limited response to changes in acid deposition across the AOSR. While a future increase in atmospheric acid deposition is likely to coincide with expanding oil sands production, this is unlikely to invoke acidification of acid-sensitive ecosystems in the AOSR ... The vast majority of lakes are at low risk of acidification."

On the other hand, some studies in this region are also employing methods and assumptions that warrant further validation/clarification. For example, Scott et al. [23] acknowledge the following: "Common 'default' model values, as applied in eastern Canada, were used ... The value of S [the base cation flux] has been estimated to be 400 meq/m^2/y from studies in Norway, and this value has been applied in eastern Canada." The base cation flux is a fundamental input parameter to acid-base modeling of aquatic systems. It seems potentially problematic that the authors are not only using default model values as applied in eastern Canada (i.e., this appears to be a model unverified for application to western Canada), but also using core input parameters from Norwegian studies.

p. 9: "There has been no long-term biological moni-

toring to assess biological damage to lakes in the regions (Parsons et al. 2010, J. Limnol.). In a study of 32 lakes in the oil sands area, these authors found that the macrobenthos community of five nearest to the oil sands had impaired benthic communities. The EIS makes no mention of such damage."

In contrast, Parsons et al. [24] reach the following conclusions: "Overall, while significant differences were observed between test and reference lakes it appears unlikely that these are due to emissions from the AOSR ... Our findings indicate that impacts from atmospheric pollution [in the AOSR] are negligible at present."

p. 9: "Recent publications documenting acidifying airborne emissions from the oil sands are not presented. McLinden et al. (2012, Geophys. Res Letters) state: 'The magnitude of these enhancements, quantified in terms of total mass, are comparable to the largest seen in Canada from individual sources.' They particularly underscore the enormous rate of increase in NO_x between 2005 and 2010, which was assessed at 3.5%/year."

Schindler's quoted rate of NO_x emissions increase appears to be incorrect. It appears Schindler quoted the error bar on the annual rate of NO_2 emissions increase (3.5%) from McLinden et al. [25], not the actual annual rate of increase (10.4%) as is evident by the following statement from McLinden et al. [25]: "The magnitude of these enhancements, quantified in terms of total mass, are comparable to the largest seen in Canada from individual sources. The rate of increase in NO_2 between 2005 and 2010 was assessed at 10.4±3.5%/year and resulted from increases both in local values as well as the spatial extent of the enhancement."

p. 9: "Curtis et al. (2010 J. Limnol.) illustrate that at least one sensitive lake in the area has been acidified by oil sands, and that emissions from oil sands combustion sources are reaching lakes over quite a large area."

There does not appear to be supporting evidence for this statement. Curtis et al. [15] conclude the following: "Spheroidal carbonaceous particles (SCPs) provide an unambiguous indicator of contamination from high-temperature fossil fuel combustion (coal and fuel oil, but not gas) because they are not produced from wood, biomass or charcoal combustion (e.g., forest fires) and hence have no natural sources ... Both SCP inventories and SCP/^{210}Pb inventory ratios confirm the low contamination status of all the lakes. Analysis of the full dataset shows no relationship of any SCP parameter (surface and peak concentrations; surface fluxes; inventories and inventory ratios) with distance from the centre of the Oil Sands processing activities. This indicates that these activities are not a major source of these particulate contaminants. The SCP data also show no agreement with the Hg surface sediment concentrations ... These trends commence in the 19th Century and therefore do not indicate any changes

in N biogeochemistry concurrent with increased industrialisation in the region associated with Oil Sands activities ...

Only one of the 12 study sites, lake NE7, shows acidification according to diatom analysis ... The main diatom assemblage changes observed in NE7 are coincident with the period of industrial development in the region. Fluxes of mercury to lake sediments at this site have increased in the last 20 years, again suggesting local inputs, but these could be driven by increases in sedimentation rates which, in turn, could have climatic or other drivers ... SCP analysis indicates that there are no major local sources, suggesting that coal and fuel oil combustion are not locally important or if they are used, flue gas emissions are effectively scrubbed of particulates ... In most of the lakes studied, diatom analysis indicates increasing pH/alkalinity ... Overall, the isotope and C/N ratio profiles for the study sites do not show any systematic changes in the biogeochemistry of the lakes that can be attributed to recent Oil Sands activities related to the extraction of oil ... The various palaeolimnological analyses described here indicate that acidification does not appear to be a widespread problem in northern Alberta and largely support the conclusions of Hazewinkel et al. (2008)."

Thus, Curtis et al. [15] find no general acidification impacts among their study lakes (indeed, they find no evidence of acidification in 11/12 of the lakes, with 6/12 lakes exhibiting an increasing pH trend), and their other findings suggest that the acidification of lake NE7 may be unrelated to oil sands development (i.e., there is no clear causal relationship established in the manuscript at NE7, and the SCP, isotope, and C/N ratio profiles in their study area indicate no significant impact from industrial activities). Also note that the SCP and other data of Curtis et al. [15] appears to contradict some of Schindler's claims in his studies [11, 12] about the importance of atmospherically deposited pollutants from oil sands activities in the region.

Whitfield et al. [26] also consider the potential acidification of the lake in question (NE7) and arrive at the following conclusions: "Paleolimnological reconstructions of lake chemistry at NE07 suggest that pH has been depressed in recent decades (Curtis et al. 2010, this issue). Given that the model simulations presented here indicate little acidification of this lake due to elevated atmospheric deposition of inorganic acids, another mechanism (e.g., organic acid production) is more likely responsible for this change ... The study catchments are predicted to have minimal chemical response to changes in atmospheric deposition level, and appear to be at limited risk of acidification due to elevated emissions of acid precursors from the oil sands industry ... NE07 in particular is very well buffered, retains the majority of S deposition in the terrestrial catchment, and is at very low risk of impact from acid deposition."

pp. 9-10: "The JPME EIS concluded that the streams in the area are not acid sensitive (Volume 4, pdf page 283; Appd 3.2., pdf page 130). There are some erroneous assumptions that skew model results. Firstly, it is assumed that the alkalinity of streams measured in summer is representative of that during spring melt. This is not the case, as studies have repeatedly shown. Streamflow in the spring is highly diluted with low-alkalinity, low conductivity snowmelt water, which is poorly able to buffer against acidification. For example, measurements of conductivity for the Steepbank and Firebag rivers showed a great dilution by snowmelt (Schindler 1996 Report to Clean Air Strategic Alliance). Due to the amounts of strong acids in snow at that time (1990), pH declines of more than 2 units (>100X increase in acidity) were occurring in these two rivers already in 1990. Minimum pH values were <6.0 (i.e. in the range where biological damage is known to occur) ... This discrepancy is exemplary of the errors that can occur when predictions are based on models unverified by actual measurements ... In addition, such acid pulses usually mobilize high concentrations of aluminum and other trace metals from soils and shallow ground water, sometimes reaching toxic concentrations. Such pulses of acids and toxic elements will add to the releases that are certain to occur as the result of mining activity in the Muskeg River watershed."

These concerns appear unwarranted. The Muskeg River is a well buffered stream. This is even acknowledged by Timoney and Lee [9], two well-known oil sands development critics: "The Muskeg River is a brown-water stream; calcium and bicarbonate are its major ions. Peatlands cover 50-90% of the area of some sub-basins and are the main source of the river's high levels of dissolved organic carbon. The river is somewhat alkaline and well-buffered; suspended solids and turbidity are low; dissolved oxygen is low during the period of ice cover. The majority of the river's discharge appears to derive from shallow groundwater, much of which may flow through shallow organic soils at the peat/mineral interface."

The specific issues raised by Schindler appear to have been addressed in a study by Western Resource Solutions (WRS) using data collected by Alberta Environment [27]. WRS reached the following conclusions: "The Alberta Environment data provide a very detailed record of the chemical changes that occur in the Steepbank, Firebag and Muskeg Rivers during the spring melt ... In the three streams in this study, the initial ANC was always greater than 2000 μeq/L and the base flow pH was often greater than 8.0. Even in the worst case, for the Firebag River in 1990, the pH dropped below 6.00 for only one day and bottomed out at pH 5.91. In the Steepbank River, for that year, the pH dropped below 7.00 to a minimum of 6.05 for only two days. The year 1990 appears to have been very unusual in the low pH values observed. In general, the data suggest that pH depressions in these streams, although measurable, will not have a significant effect on aquatic organisms ...

The consistent release of aluminum during the melt season was of considerable interest because of its association in the literature with episodic fish kills. The toxicity of aluminum is related to pH, hardness, alkalinity and organic content of the water, all factors which control its speciation. The Surface Water Quality Guidelines for Use in Alberta define a guideline level for total aluminum of 100 μg/L at pH$\geq$6.5, Ca$\geq$4 mg/L and DOC$\geq$2 mg/L. Peak concentrations of aluminum in these stream are generally orders of magnitude greater than this. For example, in the Steepbank River in 1996, aluminum concentrations approached 45.7 μm/L (1230 μg/L). As fish mortality is not observed, the factors listed above likely mitigate potential toxic effects ...

The pH decline associated with peaks in [H$^+$] averaged 0.63 units over all thee rivers. The maximum pH depressions (1.50 and 1.37) were observed on the Steepbank and Firebag Rivers in 1990 during an unusually rapid decrease in conductivity (rapid dilution by melt waters). The low pH values seen in this year were not repeated. As the pH and buffering capacity of the rivers are relatively high, and the pH declines short lived, even the extreme case of the pH decline in 1990 does not represent a significant threat to aquatic organisms ... Concentrations of aluminum during the melt sometimes surpassed water Alberta's water quality guideline for the conditions of the river (100 μg/L) by several orders of magnitude. As fish mortality is not observed, the hardness, pH and DOC levels of the river waters may be mitigating potential toxic effects ... Muskeg River: The maximum pH depression and minimum pH observed in the Muskeg River were 0.23 pH units and 7.01, respectively."

Consequently, conclusions that the Muskeg River is not significantly acid sensitive - even during the spring melt period - appear to be supported by this work.

p. 16: *"The JPME EIS consistently concludes that neither the base case nor the proposed development will have any significant effect on water quality of groundwaters, streams, lakes or rivers in the area. For PAHs, where guidelines are predicted to be exceeded, natural sources are deemed to be responsible. However, there is little mention of airborne sources to water, and of some groups of PAH related compounds, such as alkylated PAHs and dibenzothiophenes, which are known to be increased in airborne emissions (Kelly et al, 2009, Proc. Nat. Acad. Sci. USA). These are now known to travel at least 90 km from upgraders in the area, and to have increased the background burden of lakes by from 2.5 to over 50 fold (Kurek et al. in review). Detailed analysis shows that the compounds are from petrogenic sources, rather than combustion (i.e. forest fires) that are commonly used to explain recent PAHs in the area in the absence of detailed data (Kurek et a, 2012, in review)."*

The reference "Kurek et al. in review" appears to be unavailable for public review as of the date of Schindler's submission. As such, no weight should be accorded to any

claimed findings in "Kurek et al. in review." during an EA unless the document is made publicly available. With regard to the manuscript by Kelly et al. [11], there appear to be potential problems in this work as described in ref. [10]. The authors of ref. [11] should release all raw data sets from this paper into the public domain to ensure its findings have been accurately reported.

pp. 16-17: *"On page 494, many references are given to justify the conclusion that development of the oil sands does not contribute PAH to local lakes and rivers. All of the studies were done when the oil sands were operating at half or less their current capacity, and most were 'gray literature' that has not been peer reviewed. The above conclusion is in contrast to the detailed studies of deposition over time of Kurek et al. 2012. It also ignores the recent analysis of RAMP data by Timoney and Lee (2011, Environ. Sci. Technol.). At page 529, a 2003 study is used to conclude that there is no increase in PAHs in sediments of the Athabasca River. This study uses data from when capacity of the oil sands was less than half that at present. It ignores Timoney and Lee (2011)."*

As noted above, because "Kurek et al. 2012" does not appear to have been publicly available for scrutiny at the time of Schindler's submission, any claims made regarding the findings of this manuscript should be ignored in an EA.

Timoney and Lee's study [7] appears to employ incomplete analytical methods and may potentially have reached erroneous conclusions. These authors appear to conduct temporal analyses of total PAHs in sediments with concentrations on a dry weight basis. This is not an optimum means of conducting time series analyses for highly hydrophobic contaminants. Highly hydrophobic contaminants such as PAHs dominantly reside in organic matrices. In biota, this may mean that most of the PAH burden resides in lipids (fats). In sediments, this means that PAHs generally reside in the organic carbon component of these materials. Consequently, much as lipid normalization is required in order to derive meaningful insights into hydrophobic contaminant patterns and trends in biota, organic carbon normalization is generally required to obtained meaningful insights into hydrophobic contaminant patterns and trends in sediments.

In other words, compounds such as PAHs generally reside in the organic carbon portion of sediments, and the PAH concentrations in the organic carbon portion are generally assumed to be in equilibrium with the surrounding water. Thus, if 1 kg of a sediment sample contains 10% organic carbon by mass, and if another 1 kg sediment sample contains 20% organic carbon by mass, and if both sediment samples are allowed to equilibrate with the same water sample containing a given dissolved phase concentration of PAHs, the second sediment sample (i.e., with higher organic carbon content) will accumulate significantly more PAHs than the first sediment sample (all other factors being equal, the accumulation will be twice as large). As

a result, the non-organic carbon normalized PAH concentration (i.e., the dry weight of sediment normalized PAH concentration) in the second sediment sample will be twice as high as in the first sample. But if the PAH concentrations are normalized to the respective organic carbon contents of the two sediment samples, the concentrations will be equivalent (as they should be), thereby accurately reflecting exposure to the same concentration of PAHs in the water column.

Thus, when Timoney and Lee [7] make the following statements it suggests their data analysis approach may be flawed: "Normalizing total PAH to total organic carbon explained 34% of the variance in the PAH content of individual stations in the ARD [Athabasca River Delta] and removed the correlation between year and PAH concentration (r=-0.166, df=31, NS), indicating that both total PAHs and total organic carbon are increasing over time." By this statement, Timoney and Lee [7] appear to be inadvertently admitting that their own data analysis concludes that PAH concentrations in the water column (which is what sediment based PAHs are assumed to be in equilibrium with) are not changing over time. Timoney and Lee [7] also state the following: "Total PAH concentration in the sediment of the ARD increased over the past decade, as did total organic carbon. That both total PAHs and total organic carbon increased over the past decade suggests that landscape disturbance within the watershed causes increased loading of both PAHs and organic carbon." Landscape disturbance is not the only possible cause of increased organic carbon loadings to, and production in, surface waters. Changes in ecosystem productivity may also play a role, if not a dominant one. One should never confuse correlation with causation.

If, as Timoney and Lee [7] appear to find, dry weight normalized PAH and organic carbon concentrations in sediments are increasing over time, but that organic carbon normalized PAH concentrations are not increasing over time, it appears the correct conclusion is not what was reached by Timoney and Lee [7], but instead that the PAH loadings/water column concentrations are not increasing over time, and that any increased PAH concentrations in sediments on a dry weight basis over time are due solely to the increased capacity of the sediments to retain PAHs over time.

Hall et al. [28] have also published a manuscript that appears to - at least partially - refute some of Schindler's concerns. These authors reach the following conclusions: "Based on analyses of lake sediment cores, we provide evidence that the Athabasca Delta has been a natural repository of PACs carried by the Athabasca River for at least the past two centuries. We detect no measureable increase in the concentration and proportion of river-transported bitumen-associated indicator PACs in sediments deposited in a flood-prone lake since onset of oil sands development. Results also reveal no evidence that industrial activity has contributed measurably to sedimentary concentration of PACs supplied by atmospheric transport."

In conclusion, this case study submission to the JPME EA hearings appears to contain a number of significant scientific errors and/or ambiguities. Readers should keep in mind that the analysis presented herein takes neither a position for or against development of the resource under discussion. In contrast, the goal is to demonstrate that the EA process in Canada appears to allow potentially flawed submissions from prominent individuals and/or groups, and these problematic submissions may result in unnecessary delays, expenses, or even erroneous decisions. From a public policy perspective, it is desirable that the Canadian EA process be reformed to minimize contributions that may not result in an accurate assessment of the underlying science for the project(s) under consideration.

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