Name: Martin Carver

Date: September 27, 2017

I gave a presentation to the Commission this evening in Nelson (Sept 25 2017). I referred to a document that was provided to the Site C JRP and Chair Morton asked that I upload it to the BCUC site. It is attached to this message and can also be found at the following CEAA website: http://www.ceaa.gc.ca/050/documents/p63919/98128E.pdf

Thank you for coming to Nelson and for giving me the opportunity to share my perspective.

Dr. Martin Carver

Response to BC Hydro’s “Rebuttal Report”

Submission to the Site C Joint Review Panel

Prepared for:

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Project #501-06

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Disclaimer

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While the author has endeavored to state factual and relevant information (within the scope of the study), nothing in this report should be constituted as a definitive list of concerns, impacts, needs, rights, and uses nor should it be taken as a limitation on the uses or rights of any of the First Nations.

1.0 INTRODUCTION

This report is provided in response to a submission made by BC Hydro to the Site C Joint Review Panel (JRP) on December 18, 2013 (the "Rebuttal Report"). The Rebuttal Report was provided in response to the submission of Dr. Martin Carver, "Review of Hydrologic and Geomorphic Downstream Impacts of Site C" (the "Carver Hearing Submission") provided to the JRP on November 25, 2013 on behalf of the Athabasca Chipewyan First Nation (ACFN) and the Mikisew Cree First Nation (MCFN).

Given the size of the submission (277 pages, 11 authors) and the late date that it was submitted (December 18, 2013), the present response report (Carver Response Report) focuses on key issues germaine to the JRP's decision about Site C. The report contains three main technical sections. Section 2 responds to BC Hydro's assertion that regulation has not had a discernible directional effect on the hydrologic recharge of the Peace-Athabasca Delta (PAD). Section 3 responds to issues relating to the open-water and ice-cover technical issues associated with the incremental impacts of Site C on Peace-Athabasca Delta hydrologic recharge which were addressed in the rebuttal report. Section 4 responds to cross-cutting scientific issues that affect the value of BC Hydro's assessment information to decision-makers. Three appendices are included.

In this Carver Response Report, the following additional terms are used to refer to existing documents:

- Hearing transcript for January 11, 2013 (CEAR #2420); and
- Parks Canada email submission on January 21, 2014 (CEAR #2618).

Due to tight time constraints, not all issues raised in the Rebuttal Report could be addressed here. The focus has been placed here on those issues considered to be the most significant to understanding Site C's potential to impact PAD hydrologic recharge.

2.0 EFFECTS OF EXISTING REGULATION ON PAD RECHARGE

In the Rebuttal Report, BC Hydro has put forth the perspective that regulation has had no effect on the "drying out" of the PAD. That is to say, regulation has not had a significant effect on the effectiveness of the hydrologic recharge mechanisms, being flow reversals, hydraulic damming, and ice-jamming, that bring water to the PAD and, in particular, to the perched basins. This issue is important in the Site C environmental assessment as an understanding of how the present effects of regulation contribute to understanding Site C's potential effects to those same mechanisms.

Consistent with this "no effect" viewpoint, BC Hydro has disregarded the findings of twenty years of authoritative peer-reviewed science demonstrating that Peace River regulation by BC Hydro has affected the three recharge mechanisms that connect the Peace River to the hydrologic recharge of the Peace-Athabasca Delta. See Carver Hearing Submission for further details and see the present Appendix A1 for a partial listing of the studies, disregarded by BC Hydro. Although, in its Rebuttal Report, BC Hydro states (p6): "Dr. Carver argues that regulation has enhanced that drying", it is actually a wide range of senior Canadian research scientists from Environment Canada and Canadian universities who have collectively reached these conclusions through detailed field observations and sophisticated hydrologic modelling. The Carver Hearing Submission simply assembled these studies for consideration by the Joint Review Panel. BC Hydro provides what appears to be an attempt to defend its scientific disregard for authoritative research (Rebuttal Report, p6):

> "Contrary to Dr. Carver's assertion that '"much [research] is ignored unscientifically by BC Hydro'", BC Hydro has encouraged, assisted, participated in, and funded considerable PAD research. The result of much of that research is described in the appended reports."

That BC Hydro has "encouraged, assisted, participated in, and funded considerable PAD research" has no bearing on the demonstrable fact originally put forth: that BC Hydro has consistently disregarded important PAD research results in the EIS in favour of other opinions (most of which, as discussed below, lack scientific peer-review) that state or imply "no effect from regulation". This dismissal of an authoritative body of peer reviewed work without express justification is troubling, and undermines the credibility of EIS-related materials.

The Carver Hearing Submission (p 49-55) highlighted the elements of a narrative put forth by BC Hydro in its EIS submission to suggest that regulation has not had an effect on the observed drying trend in the Peace-Athabasca Delta. That submission also challenged this "no effect" narrative pointing out the elements of the narrative and the range of weaknesses inherent in the premises of BC Hydro's argument. The submission also indicated that BC Hydro's argument rests largely on only four publications (Wolfe *et al.* 2012; Timoney 2006; Ashton 2003; Timoney 2002). It is noteworthy that despite many paleolimnological studies being undertaken, until the Rebuttal Report, only one was cited in the EIS and in subsequent supporting information.

2.1 The Analytical Challenge: Multiple Stressors and Climate Variability/Change

It appears that the relation between climate and PAD flooding (recharge) is a complex one that cannot be understood easily from the paleo record alone. The linkage between climate and PAD flooding is through the recharge mechanisms which have a complex behaviour in relation to changing climate variabilities. Put another way, climate affects flooding through recharge mechanisms, the effectiveness of which varies in complex ways with climate. For example, the ice-jam mechanism may be affected by spring temperatures more than by many other climate variables and this is difficult to tease out of environmental archives. As multiple stressors (regulation, climate change, and more recently, oilsands water withdrawals) take effect on the system, it becomes increasingly complex to attribute the appropriate proportion of cause to each of the stressors. Situations of multiple stressors can be difficult to analyse, particularly when the nature of impact is the same from each stressor. The analysis of the signals becomes an additional step of complexity in understanding the system's behaviour. This is another aspect of the value of the twenty years of authoritative science that BC Hydro has disregarded in its EIS and supporting information. These papers have thoroughly examined the relative roles of climate variability and regulation.

2.2 Rebuttal Appendices: Evidence from BC Hydro Experts

In its Rebuttal Report, BC Hydro provided five appendices to support the narrative thread that is contrary to well established peer-reviewed science indicating that regulation has reduced hydrologic recharge and contributed to observed drying of the PAD. Instead of discussing the science that it prefers to ignore, BC Hydro presents perspectives and information from five experts that, in BC Hydro's view, collectively promote an alternative view of the effect of regulation on PAD hydrologic recharge. A closer examination of these analyses and opinions, however, reveals a string of flaws and unreliabilities in the information and interpretations that collectively render BC Hydro's conclusion unreliable. The following provides a summary review of the key elements of the new BC Hydro materials that are unreliable. A conclusion is provided in section 2.7 to summarise the implications for the Site C EIS.

A closer look at the content of these five appendices indicates that the narrative is not supported due to a range of deficiencies found directly in these appendices which include:

a) contradictions on matters of fact among the five experts;

b) lack of independent peer-review of the opinions put forth; and

c) opinions put forth that are not substantiated by the evidence put forth.

The remainder of this section reviews the key flaws and unreliabilities presented in these five appendices in relation to the hypothesis that BC Hydro is defending, namely, that *BC Hydro's Peace River regulation has not contributed to the drying out of the delta.* Notably, BC Hydro (Rebuttal Report p6) mischaracterises what was put forth in the Carver Hearing Submission:

> "Dr. Carver's assertions regarding regulation's impact on the PAD are somewhat consistent with a long-standing but out-of-date conclusion that holds the PAD to be an unchanging wetland that has been damaged, if not destroyed, by regulation."

There is simply nothing in the Carver Hearing Submission to this effect. At no time did the Carver Hearing Submission argue the PAD to be an unchanging wetland, but instead reviewed peer-reviewed science that chronicles the way in which BC Hydro regulation has influenced the recharge mechanisms.

BC Hydro Rebuttal Report (p7) summarises the opinion developed by Dr. John Smol based on his review of the paleolimnological studies undertaken in the PAD:

> "The research reveals a delta that had been evolving to a drier state for decades prior to regulation, with no detectable directional change coinciding with regulation."

Dr. Smol has reiterated this opinion on January 11, 2014 at the Site C Hearing (CEAR #2420, p179):

> "Using a weight of evidence approach, I cannot identify any discernible signal related to river flow regulation even though I fully expected to see one when this project began."

He makes a collection of additional related statements:

- "The results of the PAD paleolimnology program are extensively documented in a large number of peer-reviewed, international publications, all of which converge on the same conclusions, namely that there is no directional post-1968 change in hydroecological conditions." (App A, p7)
- "Based on the large volume of paleolimnological data from the PAD, my major conclusion would be that PAD lakes are highly dynamic systems. I do not see any consistent and directional changes coincident with the period of river regulation." (App A, p15)
- "In my opinion, using a weight of evidence approach, the paleolimnological data do not support an argument that regulation has had a discernable, lasting effect on the PAD lakes used in this study. There was a broad range of lakes studied. I see no evidence for directional drying in recent sediments, outside the range of natural variability, that can be linked to post-1968 regulation." (App A, p16)
- "Yes, there is evidence that PAD lakes are drying, but this commenced, based on the paleolimnological data, well before the dam construction (and before onset of instrumental records of river flows and water levels in the delta). The area is getting drier, but this trend was initiated earlier, in response to overall warming." (App A, p16)

The two main elements of Dr. Smol's opinion are clear:

- Drying of the delta began decades prior to regulation.
- There is no evidence in paleodata for directional change coincident with regulation.

Given that BC Hydro has put this argument forth as its "centrepiece" in its Rebuttal Report and at the Hearing, the remainder of this section addresses these conclusions. The detailed examination of the data and of the analyses provided by BC Hydro's five experts demonstrate that the above interpretations are flawed.

Note that the two key elements are echoed in Wolfe *et al.* (2012) which is the one published paper based on the paleo-studies that is referenced in the EIS. Dr. Smol criticizes

Dr. Carver because only the Wolfe *et al.* (2012) paper is referred to in the Carver Hearing Submission despite there being other publications examining the paleo record in the PAD. This criticism is surprising given that it is BC Hydro that puts forth only the Wolfe *et al.* (2012) paper in its EIS and related technical memoranda and did not cite the other paleo papers in the EIS or related materials. Further, Wolfe *et al.* (2012) is a review synthesis paper and as such is merited with the position of integrating the findings of all of the papers.

2.2.1 Ice-Jam Flood Frequency

Timoney (2013) and Smith (Rebuttal Report, AppD) provide accounts of PAD ice-jam floods (IJFs) based on historic data and tree-ring scars, respectively. Figure 1 (from Wolfe *et al.* 2012) plots the historic record of flooding and highlights decadal mean of IJF frequency in the thick blue line, based on data from Timoney *et al.* (1997) and Timoney (2002). The figure shows that the 1960-1967 period is just slightly above the decadal mean for the 20th century. Dr. Timoney has stated (App B, p179) "Although it is common to focus on the 1960 to 1967 period due to the availability of the Peace Point discharge data, that period is not characteristic of the longer term record" because it was anomalously wet and more flood-prone than most other periods. This caution is consistent with Dr. Smol's rejection of the instrumental data in favour of the paleo-data. However, the data record shows that 1960-1967 period is not anomalous in terms of the entire 20th century IJF record. In fact, the regulated period is characterized by IJF frequencies that are on par with the 1870s and are unusual compared to the mean for the 20th century. Note recent information provided by Parks Canada (CEAR #2618) suggests post-1990 IJF frequency shown in figure above are overestimated (due to small magnitude of IJFs in 1994, 2007 and 2008). Further, it appears that Dr. Timoney has assumed the IJF to be naturally low, rather than setting out to determine its natural frequency to detect an effect due to regulation (AppC, p6):

> "The detection of a river regulation effect is complicated by pre-regulation change and variation in the discharge and flood frequency of the Peace River and the level of Lake Athabasca, continued sediment aggradation, the construction of weirs, *and a low natural frequency for spring ice-jam floods*." (emphasis added)

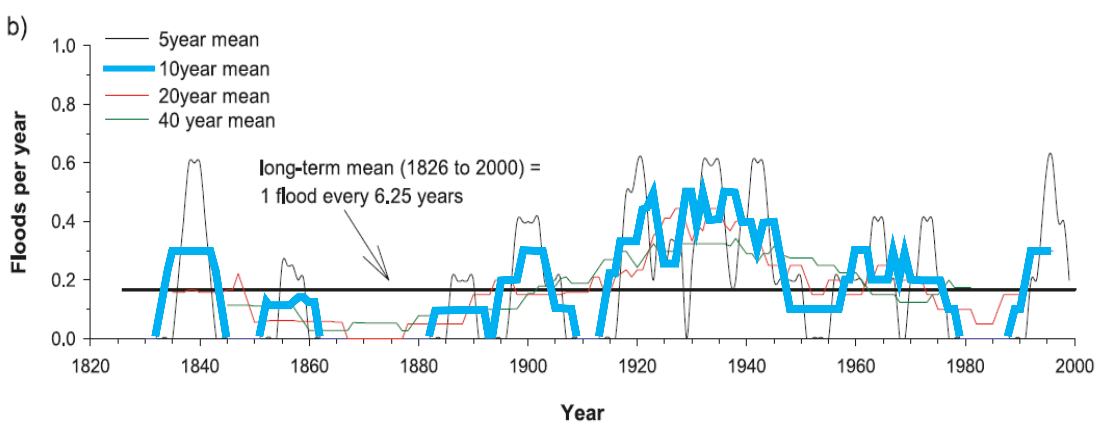

Figure 1. Peace River ice-jam flood frequency reconstruction, 1826–2000, derived from historical and traditional knowledge sources (Wolfe *et al*., 2012; Timoney *et al*. 1997; Timoney 2002). Note recent information provided by Parks Canada (CEAR #2618) suggests post-1990 IJF frequency shown in figure above are overestimated.

Dr. Smith provides another source of data to assess IJF frequency. BC Hydro Rebuttal Report (p8-9) states:

> "Dr. Derald Smith, a researcher with extensive experience studying the PAD, examines the long-term record (up to 1,400 years) of Peace and Athabasca River ice jams and shows that flood frequency has changed little post-regulation. The average ice-jam flood frequency for the Peace River in the PAD was estimated from a combination of ice-scarred trees, visual observations and river stage recorders to be about once in 4.4 years or about a 23% probability of occurrence in any given year. The nearby unregulated Athabasca River has approximately the same frequency."

Dr. Smith (Appendix D) indicates the pre-regulation frequency of IJFs on the Peace River to be about 1 in 4.4 years, based on combination of ice-scarred trees, visual observations and river stage recorders. This value is similar to the estimate of pre-regulation moderate to large IJF frequency based on historic reconstruction (and reported in Timoney 2013). Further, he states that there is very little difference [in frequency] between these two time periods." (AppD, section H under Figure 4). However, the number of moderate-to-large IJFs that have occurred in the 41 years following the onset of river regulation is well documented and does not have to be inferred based on proxy data: according to Timoney (2013, p392), "Since dam construction, there have been five moderate to large Peace River ice-jam floods (1972, 1974, 1994, 1996 and 1997)". However, according to Parks Canada (CEAR #2618), during the 1994 flood the Peace did not breach its banks and generate overland flooding that is necessary for recharge and was similar in magnitude to the 2007 and 2008 IJFs that were categorized as 'small' by Timoney (2013). Consequently, the frequency of IJFs that are large enough to recharge the perched basins has dropped from 1 in 4.4 years during the pre-regulation period to 1 in 10.8 years in the post-regulation period, a reduction in IJF frequency of more than 50%. This decline in IJF occurrence, coincident with regulation onset, again directly contradicts Dr. Smol's claim of "no detectable directional change coinciding with regulation".

In contrast, it is clear that there has been a notable changein IJF frequency as of 1969. According to Timoney (2013), assessing the apparent change in IJF frequency that is coincident with the construction of the Bennett Dam is difficult because "the short time period since dam construction limits the stastical power of such a test." Presumably, this problem also applies to Dr. Smith's estimates of post-regulations and raises a further question regarding the reliability of his assertion that post-regulation IJF frequency has not changed. Hence, there appears to be a large discrepancy between the findings of Drs Smith and Timoney regarding the difference between pre- and post-regulation IJF frequency which raises concerns about the internal reliability of the scientific perspectives being advanced by BC Hydro.

2.2.2 Lake Athabasca Water Level

A second data set that can give insights into long-term temporal changes in PAD recharge is provided in Lake Athabasca. Gauge records of the water levels in Lake Athabasca were initiated in the early 1930s and provide a reliable dataset for the evaluation of the effect of regulation on the level of Lake Athabasca. Lower summer levels in Lake Athabasca were an anticipated outcome of the Bennett Dam (Bennett 1970; Geopac and Card 1973). These early concerns have been verified by recent analysis by one of BC Hydro's experts, Dr. Timoney (Timoney 2013): "Summer levels of Lake Athabasca at Fort Chipewyan changed from pre-1968 to post-1971 (Mann-Whitney U test, $p<0.0001$)."

According to Timoney (2013), since 1971, the most obvious change in Lake Athabasca levels has been a decrease in maximum summer lake levels and he notes that "Some of the changes are attributable to river regulation that caused a decline in summer discharge of the Peace River, and therefore, a decrease in the effectiveness of the hydraulic Dam exerted upon the delta's outflow channels." Not only does Timoney (2013) indicate that the change was coincident with the onset of river regulation (in contrast to Dr. Smol's comment above), he indicates a portion of this is directly linked to flow regulation through the Bennett Dam. Further, Dr. Timoney suggests the change in the level of Lake Athabasca that occurred with the onset of river regulation was very likely not limited to Lake Athabasca and must have caused changes in other sectors of the delta including lake levels in Mamawi Lake and Lake Claire.

Another of BC Hydro's experts provides information in Appendix B of the Rebuttal Report in support of Dr. Smol's opinion. The BC Hydro Rebuttal Report (p7-8) states: "Dr. Burges conducts an extensive review of Lake Athabasca levels, concluding that post-regulation levels show no statistical difference from naturalized levels." Dr. Burges' analysis of Lake Athabasca water levels reaches a conclusion that conflicts with the analysis of Lake Athabasca water levels that has been carried out by Dr. Timoney. Not only did Dr. Timoney identify that a statistically significant change in summer water levels in Lake Athabasca began precisely at the time at which reservoir filling commenced, he also attributes a portion of the observed change to the onset of river flow regulation through the Bennett Dam. As a result, two drastically different interpretations of the same data are arrived at by representatives of the BCHydro position which draws into question the reliability of the results in general. One clear issue associated with Dr. Burges' information is that it does not appear in a peer-reviewed source, but only in an appendix to the Proponent's EIS materials.

The remainder of Appendix B provides a disconnected assortment of analysis that doesn't mention Carver 2013 nor does it clarify what it is trying to say. It does make mention of Peters and Buttle (2009) so perhaps it is trying to refute that papers' peer-reviewed findings. It would have been helpful if BC Hydro had clarified the purpose of this Appendix as the intent and structure of the information presented are not clear.

2.2.3 Flow Reversals (and Water Balance Calculations)

Flow reversals and the consequent expansion of the central Delta lakes (Mamawi Lake, Lake Claire, Lake Athabasca) occur when the Peace River is higher in elevation than Athabasca Lake. By simulating natural flows (ie, modelling the absence of the hydroelectric dams), Peters and Buttle (2009) have shown that with regulation (ie, as of 1969), the extent of flow reversals has declined by 90% compared to a simulated naturalised flow regime. This has previously been reviewed in Carver Hearing Submission (p20). Additionally, however, BC Hydro's experts provide further corroboration of these peer-reviewed findings. According to Timoney (2013), 1) flow reversal days were about 3.6 times more common in the pre-regulation period; 2) the mean reverse flow volume was about 30% larger during the pre-regulated period, and 3) pre-regulation flow reversals lasted more than twice as long as flow reversals during the post-regulation period.

In addition to the flow reversal determinations, it is also possible to construct water budgets of the PAD to identify the change in hydrologic recharge with regulation. Kellerhals (1971) did this and found that the four-to-five foot decline in level of Athabasca Lake (between 1968 and 1970) was attributed evenly between regulation and a change in climate. This has been previously reviewed in Carver Hearing Submission (p20). BC Hydro has also conducted water budget analyses to the present, however it states that it has limited its water-balance analysis to the period since 1976 (previously discussed in Carver Hearing Submission, p20) and thus has disregarded the understanding that it could gain by comparing the water balance of the regulated period with that of the filling and pre-regulated periods. Additionally, Dr. Burges presents results in Appendix B of the Rebuttal Report indicating the percentage of water from the Peace River that inflows to the PAD. However, he provides only the amount as it is averaged across both the regulated and unregulated periods. The two water budget exercises undertaken by or on behalf of BC Hydro do not provide the comparison between the regulated and unregulated periods. However, based on the early findings of Kellerhals (1971) and the flow reversal modelling of Peters and Buttle (2009) I would expect that the water budgets would demonstrate a decline in PAD recharge as of 1969, with regulation.

Again, the hydrologic modelling indicates a change in direction consistent with the onset of regulation, and in contrast to Dr. Smol's claim above.

2.2.4 Paleo-Limnological Data

Lastly, the paleo-data do not support the characterisation put forth by Drs. Smol and published by Dr. Wolfe (and his colleagues). Consider the following:

- Wolfe *et al*. (2006) report "...close correspondence between Spruce Island Lake water balance history (E/I) with independent records of river flood frequency and climate variability indicated that profound changes in hydrological conditions are a natural feature of the PAD."
- Wolfe *et al*. (2012) state "...changes in the overall state of the Peace sector appear to have been driven predominantly by ongoing warming, drying, and naturally declining river discharge over the past century" (p201) and "...the record suggested a decline in flood frequency had begun in the early 1900s, several decades before the Peace River became regulated for hydroelectric production." (p195)

These characterisations of the PAD's flooding and climate history are not reflected in the published paleo-data to which they refer and are unjustified simplistic characterisations of complex variability. Each is elaborated on below in reference to Figure 3 which is a composite plot that has been constructed for this present report based on data plots taken directly from published paleo-limnological papers, as indicated in the figure caption.

Wolfe et al. (2006)

Wolfe *et al.* (2006) refers to the ratio of Evaporation to Inflow as shown temporally in Figure 2c. This plot is derived from cellulose inferred lake water ^{18}O for a high-elevation basin understood to experience minimal flooding. As a result, the authors posit that it is a reasonable surrogate for temperature. This pattern of temperature change through time (increasing) shows no correspondence with the variation in ice-jam flooding (Figure 2b) and Lake Athabasca water levels (Figure 2a), calling into question one central element of Dr. Smol's opinion because implied in his viewpoint is a close correlation of flooding with general climate. This pattern is not evidenced in the paleo-data.

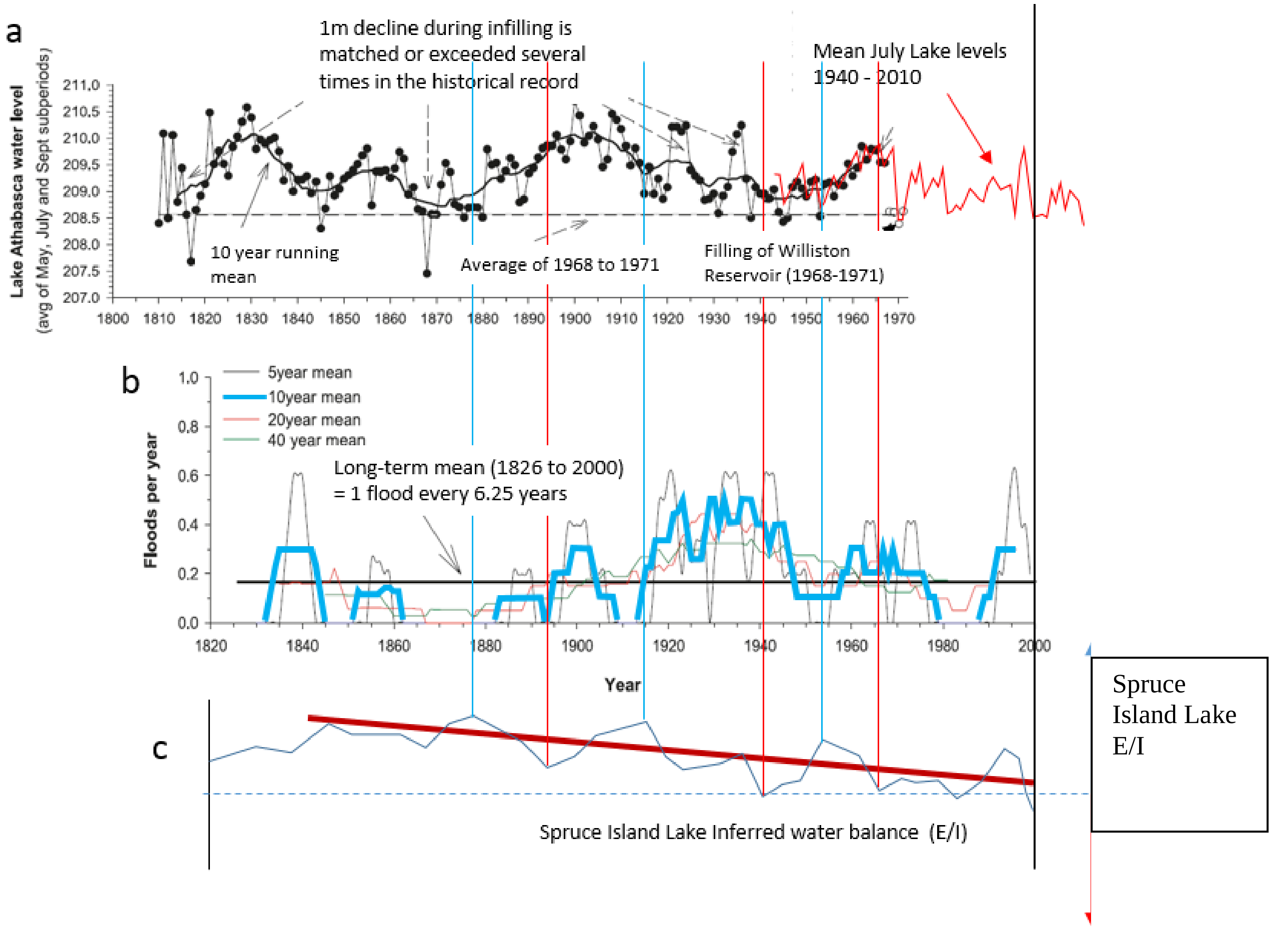

Figure 2. a) Reconstructed Lake Athabasca levels based on tree-ring records (Wolfe *et al*., 2012, Stockton and Fritts, 1973). b) Reconstructed Ice-Jam Flood history (Wolfe *et al*., 2012; Timoney *et al*. 1997; Timoney 2002). c) Reconstructed evaporation-to-inflow (E/I) ratio history for Spruce Island Lake estimated using the cellulose-inferred lake water d18O profile (Wolfe *et al*., 2007). Note that the progressive decline in reconstructed E/I toward dry conditions (Wolfe *et al*., 2007) are not evident in the Lake Athabasca water level reconstruction or the IJF history and that individual peaks in the E/I record to not match peaks in the IJF history or the Lake Athabasca lake level record.

Wolfe et al. (2012)

The interpretation provided in Wolfe *et al.* (2012) reflects the companion element of Dr. Smol's opinion: that there is no directional change reflected in records associated with onset of regulation in 1969. Comparison of Figure 2c with Figure 2a highlights the lack of validity of this claim. In Figure 2a, the water level gauge records for Lake Athabasca have been added to the end of the paleo record to provide a complete record to present time. It is clear that 1969 (and after the reservoir was filled) marked a sharp change in the level of Lake Athabasca, as shown by the paleo-data, thus calling into question Dr. Smol's opinion. Further, this plot also calls into question the claim by Wolfe *et al.* (2012) that the decline in Lake Athabasca water level that came with regulation followed decades of prior declines. Wolfe *et al.* (2012) say "declines prior to reservoir filling suggest climate variation also contributed to onset of lower lake levels" yet, in fact, the two decades prior to regulation clearly show a general increase in lake level that plateaued for a few years just prior to regulation.

2.2.5 Freeze-Up Level: Regulation Effect on Ice-Jam Mechanism

In its EIS and subsequent supporting information, BC Hydro has repeatedly put forth an alternative line of thinking about the effect of regulation on ice break-up, as proposed by Dr. George Ashton at a 2003 conference of the Canadian Water Resources Association. In Appendix E of the Rebuttal Report, BC Hydro provides this analysis from Dr. Ashton, its fifth expert, intended to demonstrate "how regulated flows, although resulting in higher ice freeze-up stage, do not reduce the "efficacy" of ice jams because higher regulated break-up flows more than compensate for the higher freeze-up stage." This perspective, however, is controversial because it is scientifically widely accepted that the high freeze-up level associated with regulation is one of the key primary effects from regulation diminishing the likelihood of ice jams (Beltaos 1997; Prowse and Conly 1998; Beltaos 2003; Beltaos *et al*. 2006; Beltaos and Carter 2009). (This is also discussed in more detail in Carver Hearing Submission, s. 2.2.1.3). Despite being raised in a conference paper in 2003, this proposition has not been published or subjected to a scientific peer-review yet BC Hydro continues to promote this proposition as shown by its Appendix E submission to the JRP.

Dr. Spyros Beltaos is one of the world's leading researchers in ice-jam dynamics. He has carried out a critical examination of Dr. Ashton's alternative analysis and identified flaws in it that render its conclusions faulty. This critical analysis has been provided by Dr. Beltaos as a technical note (dated December 2013) and is included in its entirety in Appendix B of this present report. In brief, his technical review examines Dr. Ashton's "flow-enhancement postulate" that proposes that the enhanced freeze-up level caused by regulation creates an "excess storage release" (of water) that compensates for the downward effect (on ice-jam occurrence) of the higher freeze-up level leading to either unchanged or even enhanced ice-jam frequency. Dr. Beltaos examines the data record at Peace Point and demonstrates that the additional water postulated by Dr. Ashton does not exist in the data. Dr. Beltaos supports his criticism with a series of supplementary weaknesses of the Ashton postulate generally involving implausible assumptions and the neglect of other important processes that would dispute his hypothesised mechanism.

Dr. Beltaos concludes: "Regulation-induced enhancements of breakup flows, if any, are much smaller than postulated. As such, *they do not compensate for the negative impacts of increased freezeup levels on ice jam frequency*." (emphasis added). Based only on Dr. Ashton's non-peer-reviewed approach, BC Hydro concludes that (Rebuttal Report p9) "the scientific evidence does not support the assertion that regulation has significantly altered the delta." The reliance on this hypothesis to such an extent in its EIS and supporting materials casts further and significant scientific doubt on the plausibility of the EIS as a whole, especially in light of Dr. Beltaos' statements at the hearing and this technical note.

2.3 Integration

The above observations call into question Dr. Smol's non-peer-reviewed, non-published "weight of evidence" opinion. Below are a few suggestions that may shed light on how BC Hydro has come to put forward novel and unsubstantiated scientific conclusions in the face of extensive peer-reviewed research demonstrating the known effects of regulation on the PAD's hydrologic mechanisms.

2.3.1 The Importance of the Scientific Peer-Review Process

The work of Drs. Burges and Ashton as presented in the Appendices of the Rebuttal Report and the opinion of Dr. Smol as provided in Appendix A and presented verbally at the January 11, 2014 Site C hearing all remain without an independent scientific peer-review. Some of the perspectives held by Dr. Timoney also appear to be without peer-review. The scientific peer-review process provides a valuable check on the accuracy of interpretations made. However, the peer-review process is not perfect and occasionally individual papers can be published with interpretations contained in them that may later be found to be weak or false. Such may be the case with some statements put forth in Wolfe *et al.* (2012) and Wolfe *et al.* (2006): an additional independent review of elements of those papers may be called for, particularly given that they are being looked at to contradict decades of highly respected research findings, and have been well funded by BC Hydro ($2,000,000 according to Wolfe *et al.*, 2012, p206). It is in the JRP's interest to heed the findings of the extensive collection of research papers that have been disregarded by BC Hydro in the EIS and related materials (see this Appendix A1) because these have been peer-reviewed in the world's top hydrologic journals. Given the extent of publications of this quality, it would be unlikely that their findings are all incorrect.

Given the demonstrable value of the independent peer-review process, it would be beneficial for the JRP to convene an independent team of applied scientists skilled in the interpretation of impact assessment to come to a joint determination of the impact of regulation before making determinations on the validity of the claims put forward by BC Hydro.

2.3.2 The Value of the Early 1960s as a Point of Reference

At length, BC Hydro (Rebuttal Report, AppC) criticises the use of data from the early 1960s as a point of reference for evaluating the effect of existing regulation. BC Hydro states (p8) that "focusing on a short time frame, such as the early 1960s, can lead to erroneous conclusions." Ironically, the PAD's relatively wet period associated with the 1960s may be a reason why the hydrologic studies, that have used those data comparatively and to calibrate and validate hydrologic models, *have been successful* in isolating the effects of regulation on PAD recharge. If the prevailing extent of flooding had been low when regulation came into being, the smaller differences may have prevented successful assessment of the potential effects of regulation and a lack of statistical significance of effects and differences. Of course, the same processes that create downward pressure on recharge mechanisms during relatively wet periods would be present during drier periods, but possibly smaller in relative influence and thus potentially more difficult to detect. Also, as long as the temperatures are cold enough that winter river-ice processes are sustained, effects of regulation on the important ice-jam mechanism can also be effectively studied.

Dr. Timoney, states (AppC, p6):

> "The detection of a river regulation effect is complicated by pre-regulation change and variation in the discharge and flood frequency of the Peace River and the level of Lake Athabasca, continued sediment aggradation, the construction of weirs, and a low natural frequency for spring ice-jam floods. In short, the answer to the question, "*has river regulation had an effect on the delta's vegetation and habitat" , depends on what time period is chosen for comparison. If the period 1960-67 is chosen, the answer would be yes.* However, evidence presented in sections C and E demonstrates that the 1960-67 period was wetter and more flood-prone than most other documented periods. The exclusive use of the 1960-67 period as a benchmark for the pre-regulation delta is unwarranted by the scientific evidence." (emphasis added)

Given his own work assembling the historic ice-jam flood history and presented in Figure 2b (section 2.2.4 above), the statement above is questionable. His own record shows that the 1960s were a period where flood frequency was only slightly above average in the context of the last century. It simply doesn't stand up to dismiss the use of the 1960s as a point of comparison with this rationale. It was not a particularly flood-prone period according to Timoney's reconstruction. In any case, the value of having flow gauging for building and calibrating hydrologic models for testing impact hypotheses cannot be dismissed. Impact pathways due to hydroelectric development that are evaluated during periods of average or slightly above average flood frequency would be expected to also be present during periods experiencing other rates of flood frequency. The impact pathways created by hydroelectric development that are implicit in Dr. Timoney's above acknowledgment (the italicised section) are present regardless of the prevailing rate of flood frequency creating the downward pressure on hydrologic recharge that he recognises in saying "yes".

2.4 Conclusion

In summary, and contrary to Dr. Smol's statements, there is, in fact, various clear examples of detectable and directional changes in PAD recharge that coincide exactly with the onset of river regulation, are associated with significant ecological and hydrological change, *and are drawn from both the paleo-record and other historic and instrumental data*. Dr. Smol has said that "(u)sing a weight of evidence approach, I cannot identify any discernible signal related to river flow regulation…" (CEAR #2420, p178) and provides his opinion in the Rebuttal Report (AppA, p16): "In my opinion, using a weight of evidence approach, the paleolimnological data do not support an argument that regulation has had a discernable, lasting effect on the PAD lakes used in this study", however, he does not appear to have clearly provided the details of the evidence that has created the weight in his opinion. In particular, Dr Smol does not describe how a body of peer-reviewed research demonstrating the effect of regulation on the PAD has been factored into his "weight of evidence assessment". Instead, he has emphasised (Appendix A) the strength of the paleo-limnological approach and the extent to which the basic paleo-limnological PAD publications have been published in peer-reviewed scientific journals, neither point of which is controversial in nature or relevant to an objective assessment of the scientific evidence that is required to resolve the complexities of what is driving the observed changes in the PAD.

It is the *interpretation* of the findings from these basic papers, to infer causality, or lack thereof, from myriad sediment archives that is in question, and particularly given that multiple stressors are creating pressures on PAD hydrologic recharge in the same direction and with the same outcome (generally downward). In fact, it appears that Dr. Smol has *never* published these PAD interpretations thereby putting them up for scientific peer-review. It is a group of *other* published researchers who put forth statements epitomised by the following statement from their synthesis/review paper (Wolfe *et al.* 2012): "Notably, these and other hydroecological reconstructions...provided no compelling evidence to suggest that flow regulation of the Peace River has had any discernible, directional hydrological or ecological effects on the perched basins of the Peace sector of the delta." Yet, as with the opinion of Dr. Smol, these definitive statements of cause and effect simply do not stand up to scrutiny based on the data, including the paleo-data. In particular, key interpretations from this review paper (and its supporting papers) related to the frequency of the ice-jam floods and what drives that frequency are not credible. The credible explanation comes from the large time-tested and established body of peer-reviewed research that is disregarded by BC Hydro and which tells a story of a mixed role of regulation and climate change/variability shaping the pattern of hydrologic recharge to the Peace-Athabasca Delta.

This section 2 has clarified that regulation has had a demonstrable effect on PAD recharge. Understanding how existing regulation impacts PAD recharge is a key to understanding how additional incremental regulation (Site C) will affect the PAD, particularly as it is increasingly under pressure from multiple stressors. BC Hydro states (Rebuttal Report, p7):

> "It is important to note that the question of whether regulation has had any influence on the PAD is not one that has to be resolved for the purpose of this environmental assessment. The evidence demonstrates that the Project would have no noticeable influence on the PAD."

The next two sections respond to deficiencies and weaknesses in BC Hydro's Rebuttal Report that continue to render invalid this claim of "no noticeable influence on the PAD." As Dr. Smol has emphasized in his presentation on January 11, 2014: "No one ever said delta systems were simple." The detection of small incremental change can be difficult amid complexity. It is this complexity that is challenging for BC Hydro given the simplifications inherent in its assessment approaches, and is further discussed in the next two sections.

3.0 INCREMENTAL SITE C IMPACTS TO PAD RECHARGE

3.1 Open-Water Recharge Issues

3.1.1 Recharge Decline due to Increased Active Reservoir Storage

BC Hydro (Rebuttal Report, p10) misrepresents the Carver Hearing Submission with respect to concerns about increased reservoir storage with Site C. BC Hydro claims that the Carver Hearing Submission suggested that BC Hydro "failed to thoroughly assess the degree of storage offered by the Site C reservoir" which is incorrect. It is the *implications for PAD recharge* of the increased storage that is of concern and that is unassessed in the EIS. The simplified analysis provided in Carver Hearing Submission was necessary due to the absence of an analysis in the EIS that examines the implications of this storage capacity on the PAD hydrologic recharge mechanisms. In its defense, BC Hydro states that "Site C would not have sufficient active storage to change the seasonal timing of flows" and refers to Figures 2 and 3 of the Spatial Boundary Technical Memo in support. Its comment is not responsive to the concern that was raised. The Carver Hearing Submission didn't assert that the Site C reservoir would change the *seasonal timing of flows.* Rather it pointed out that additional storage of this magnitude could further negatively affect PAD recharge by putting additional downward pressure on the open-water recharge mechanisms– flow reversals and hydraulic damming. This concern remains outstanding.

BC Hydro's reference to Figures 2 in the Rebuttal Report creates further confusion, rather than resolving the concern. The figure shows average hydrographs during a simulated decade of flows. Differences are averaged over the decade and thus are unavailable for examination on a year-to-year basis. Further, the differences are compared in light of a historic range of flows during an unspecified period. Moreover, 1996 is not included in this range without explanation. Lastly, it is unclear why the maximum simulated summer flow at Town of Peace River is higher than the maximum flow at Peace Point when this is contrary to the historic data available from those gauging stations.

Notwithstanding the above issues, the Rebuttal Report has provided new information that partially quantifies the downward effect of Site C on open-water PAD recharge. As previously indicated in Carver Hearing Submission, BC Hydro has acknowledged this effect in its EIS and this passage is repeated here (p11-78):

> "During the spring, when natural inflows are typically high in the tributaries between Peace Canyon and the Site C dam site (including flows from the Halfway and Moberly Rivers), there would be the potential for the Site C reservoir to store some of the inflows, *thereby reducing the peak flow experienced downstream*." (emphasis added)

Appendix F of the Rebuttal Report provides the first assessment made available by BC Hydro providing an indication of the amount of PAD recharge that will be lost due to Site C. The assessment takes a 10-year historic period (1965-1974) and determines the difference in recharge due to open-water mechanisms with and without Site C in place. Using an assumed level of Lake Athabasca of 208.5 m, the assessment finds that in one of the ten simulated years, there would be a loss in recharge equivalent to 1cm on the three main lakes (Lake Athabasca, Mamawi Lake, Lake Claire – total area of 9430 km^2.) During the other years, the amount of lost recharge is lower, and unspecified by BC Hydro. This is equivalent to 0.943 x 10^8 m^3 of recharge water – for higher declines, this total is directly higher (for example, for 4 cm, the total is 3.77 x 10^8 m^3. The flow reversals since 1972 (not including hydraulic damming effects) have averaged 4.4 x 10^8 m^3/year (excluding 1996 and 1997 which were heavily influenced by unprecedented BC Hydro releases – with these years, the total is 6.2 x 10^8 m^3/year). See Figure 4 (p19) of Carver Hearing Submission for the full data set. Thus, although a direct comparison is difficult because the flow reversal values do not tell the entire story, the change estimated by the assessment in Appendix F appears to be a significant percentage of the total degree of limited flow reversals now available under the regulated flow regime. This raises questions about the subjective determination provided in Appendix F (p9) that these declines due to Site C have "no effect or minimal effect". It highlights, again, the need for BC Hydro to carefully consider the context in which its projected impacts are happening. As the level of Lake Athabasca drops due to climate change and other factors (eg, oilsands withdrawals), these lost flow-reversal volumes may be increasingly damaging to the maintenance of aboriginal and Treaty rights. As the level of Lake Athabasca drops, it would tend to amplify any flow declines in the Peace River that might come about due to Site C. This is because flow reversals would potentially become more likely due to lower elevation of Lake Athabasca (relative to the Peace River).

The assessment in Appendix F also explains the sensitivity of the effect to the elevation of Lake Athabasca. A limited sensitivity is provided for levels of 208 m and 209 m and the outcome indicated to be 4 cm (for 208 m) and 1 cm 209 m. Given that the result is indicated to be 1 cm for 208.5 m, the outcome of the sensitivity test also appears to require clarification or correction. Regardless, it can be interpreted that as Lake Atahabsca declines, the annual average decline in flow reversals will rise for all years and will become quite significant with low levels of Lake Athabasca. Further, BC Hydro considers only past conditions in its assessment and does not include consideration of climate change. Given the general downward pressures on Lake Athabasca suggested by various sources (e.g., Burn 2009; Gill and Rood 2009; Lebel *et al.* 2009; Rasouli *et al.* 2013), it is important that BC Hydro provide a complete assessment of this effect, given the indefinite commissioning period of its proposed Site C facility. Given the functional curves provided in the assessment, it appears that flow reversals would be very sensitive to the level of Lake Athabasca, particularly if they drop below about 207-208 m, though this is difficult to estimate given the lack of consideration provided by BC Hydro to this aspect of the effect.

Given BC Hydro's Appendix F, the expected open-water loss in PAD recharge with Site C is not controversial, though it does remain inadequately assessed. In the Carver Hearing Submission, reductions in downstream peak flow impair recharge effectiveness were considered through calculation of "hold back" via rough bounded estimates, required at that time to compensate for BC Hydro's lack of assessment of this potential effect of this change in the surface flow regime on PAD recharge. This assessment requires sophisticated modeling which cannot be conducted by the First Nations participants.

3.1.2 Open-Water Assessment Assumptions and Simplifications

The surface flow regime assessment embodies a range of assumptions and simplifications that haven't been adequately assessed and/or communicated in the EIS, the subsequent information materials, and now in the Rebuttal Report. These include:

- The one-dimensional numerical hydraulic model (MIKE11) used to simulate downstream flows in the Peace River does not consider the effect of ice on flow and water levels. Ice effects can modify MIKE11 results through changes in flow rates and time-of-travel estimates and effects on flow of extreme ice formations such as ice jams (see Environment Canada Hearing Submission for further details).

- Future changes in flow due to climate change are not considered in the EIS, including no consideration with respect to mitigation options.
- Changes in the future flow regime due to climate change are not assessed.
- BC Hydro is silent on the potential for reservoir filling to affect the open-water PAD recharge mechanisms.
- Effects due to Site C can be expected to grow as the climate warms – this aspect has not been discussed anywhere in the EIS. See section 4.1 for further discussion.
- The new Appendix F contains a range of assumptions and simplifications that raise questions about its quantitative outputs. Given the novelty of this assessment to the EIS process (it was only provided on December 18, 2014) and its important relevance in beginning to quantify the impact of Site C on the open-water recharge mechanisms, a listing of preliminaryconcerns associated with this assessment are provided below:

    - The assessment does not consider future climates.
    - It is unclear how representative the assessment results are in light of the decade chosen for simulation.
    - The decade chosen for the assessment (1965-1974) includes pre-regulated and filling years and as a result, it is unclear how applicable the comparison is. Additional details are needed to understand these implications and potential assessment limitations.
    - The assessment does not consider ice effects
    - The assessment appears to not quantify the lost recharge through the entire open-water period. For example, peak recharge loss is calculated based on only "the 3-day period centered on the day of the peak hourly flow" (Rebuttal Report, p13).
    - A minimal reporting out is given of the lost recharge for the full simulated decade and its pattern of increase in relation to lower levels of Lake Athabasca.
    - The assessment reports the same result (1cm; "about 1cm") for both 208 m and 208.5 m elevation for Lake Athabasca, creating uncertainty.
    - The Rebuttal Report states (p13) "(t)he upper bound estimate of lake level change during the three-day period is less than 0.5 cm" and also states (p14) "the maximum difference in PAD annual lake levels ... during the open water period was estimated to be approximately 1 cm in one of the simulated years." These various reporting differences create confusion and imply uncertainty in the assessment results.

These are in addition to the assumptions and uncertainties inherent in the discussion of sections 3.1.1. Most of these open-water uncertainties are neither quantified nor communicated to the JRP.

3.2 Ice-Cover Recharge Issues

Two substantive recharge issues of concern with respect to the Site C proposal remain unresolved by BC Hydro as of the Hearing on January 11, 2014. Further, BC Hydro's comments in its Rebuttal Report raise further concern for the potential additional and unassessed downward pressure on the PAD's hydrologic recharge.

3.2.1 Ice-Jam Occurrence Decline due to Site C Impact on Jave Potential

The Carver Hearing Submission highlighted what BC Hydro's EIS did not: that ice in the Smoky-Carcajou reach (approximately 400-650 km downstream of the Bennett Dam) "fuels" the ice-jam mechanism in the Delta reach through the progressive formation and release of ice jams in what are are called "javes" (Beltaos 2007). The Rebuttal Report finally recognises this important process linkage within the Peace River system: (p17):

> "Dr. Carver correctly describes that "jams in the Delta reach are "fuelled" by the formation of ice-jams upstream of the Delta reach". In particular, ice-jam release waves have their genesis in the relatively steeper reach between the Smoky River confluence and Carcajou. Beltaos (2007) suggests that break-up in the lower reach of the Peace River is typically triggered by these ice-jam release waves."

Setting aside the concern that BC Hydro has nowhere mentioned or assessed this key linkage in its EIS, BC Hydro attempts to justify this exclusion in its Rebuttal Report, suggesting that Site C will not influence javes:

> "As shown in the ice front simulation plots included in Appendix C of the EIS Downstream Ice Report, although Site C is predicted to have a slight influence on the timing of ice formation in the Smoky River to Carcajou reach, there would be no influence on the timing of ice front recession in this reach as a result of the Project. ... Since the Project would not influence the timing of the ice front recession downstream of the Smoky Rive confluence, it would correspondingly not influence the occurrence of ice-jam release waves that could lead to dynamic ice-jamming in the lower reach of the Peace River."

This confidence is unjustified given the assumptions on which it is based. One key concern involves the assumption that the flow model (used to test the new operating regime) has been calibrated with the Peace Canyon Dam flows rather than with the potential flows from Site C (see Caveat No. 3 and Recommendation 3.2 in the Environment Canada written submission, dated November 25, 2013, p 20-21). This difference introduces effects that have not been assessed and that may change freeze-up levels. Changes to freeze-up levels can lead to changes in ice-jam occurrences (see section 3.2.2 of the Carver Hearing Submission).

Dr. Spyros Beltaos has also considered this claim by BC Hydro and provided the following directly to the JRP Secretariat (Email, January 21, 2014):

> "Within the uncertainties associated with the CRISSP model, acknowledging our limited knowledge of certain river ice processes and provided BC Hydro's assumption of a run-of-the-river condition is fulfilled in practice, BC Hydro's statement is plausible."

Accordingly, there remains many uncertainties about the non-linear processes associated with ice-jam release waves. Further, the Site C proposal involves sufficient storage capacity that the operating regime departs from the behaviour of a run-of-the-river facility. Thus, there remains considerable doubt about the validity of this claim made by BC Hydro of no effect on the "occurrence of ice-jam release waves that could lead to dynamic ice-jamming in the lower reach of the Peace River".

As a result, it remains important to assess Site C's effects on the river ice within the reach situated between the Smoky River mouth and Carcajou (also well within the spatial boundary of the study, to date). Within this reach, the EIS Downstream-Ice Assessment projects that ice will no longer occur at TPR (near the upper end of the Smoky-to-Carcajou reach) in all years. Also, the freeze-up level, and the winter flow variation may fluctuate more than it has in the past. In turn, changes will become more complex and uncertain under future climates. BCH continues to be silent on how this range of changes may affect the behaviour of ice-jam release waves initiating in the Smoky-to-Carcajou reach.

Additional unresolved concerns about BC Hydro's downstream-ice modelling and interpretations:

- Although CRISSP is a leading model, it has limitations that pertain directly to these non-linear phenomena critical in the present regard (ie, modeling ice-jams and javes; incorporating secondary consolidations – see this Appendix A2 for comments by Dr. Beltaos). BC Hydro emphasises that these processes are "represented" (p21) in its CRISSP model, however it also admits that these processes "can't be applied in a routine modelling exercise" (p21).

- BC Hydro claims (p20) that "there is no effect of the Project on ice front position beyond Carcajou" however reference to the downstream-ice plots show this to be untrue. BC Hydro further claims that "(i)n fact, during the break-up period there is no influence of the Project on ice front position downstream of the Smoky River confluence." Again, this is demonstrably inaccurate through reference to many of the downstream-ice plots (including climate change). As pointed out in the Carver Hearing Submission, the downstream-ice plots provided in the EIS show differences at the edge of the plots however, as pointed out, it is unknown (based on the plots) what these differences are further downstream. Perhaps BC Hydro is referring to averages, again, which would be inappropriate. BC Hydro acknowledges a mistake in its EIS modelling of the ice-front for the 2004-2005 season, raising the concern that other modelled years may contain mistakes.

- In its Rebuttal Report (p20), BC Hydro justifies that this "was done so that the changes further upstream (where there is an influence) could be seen more clearly." This is a weak response because these objectives are not mutually exclusive and BC Hydro should reveal the differences at least to the limit of its spatial boundary.

3.2.2 Effect of New Operating Regime on Freeze-Up Level

Freeze-up level plays critical role in affecting ice-jam likelihood

Concern persists about Site C's potential to bring changes to the freeze-up level and subsequent potential to affect the likelihood of ice-jam occurrences in the jave source area and in the Delta reach. Environment Canada shares this concern and as a result, put forth a recommendation to the JRP that the operating regime be carefully managed so as to ensure that "fall and winter flows do not increase relative to present conditions so that ice-jam flooding potential in the Peace-Athabasca Delta is not impacted" (EC Site C Submission, p21). Rather than responding to these concerns with the appropriate assessments and/or changes to its proposed operating regime, BC Hydro has put forth the ideas of Dr. Ashton to posit that higher freeze-up levels don't reduce the likelihood of ice-jam occurrences (Rebuttal Report, AppE). As discussed in section 2.1.6 of the present report, that analysis is not credible (see technical note from Dr. Beltaos provided in this Appendix A2). Additionally, BC Hydro understates the concern in the Rebuttal Report (p16/17):

> "Results of the surface water regime analysis show the Project would not increase flows at Peace Point at the time of freeze-up."

Setting aside the concern with the validity of this statement, the above is misleading because it is does not recognise what is discussed in the previous section: ice-jam occurrence in the reach between TPR and Carcajou is of critical importance because they subsequenty translate energy downstream via javes to create ice-jams in the Delta reach. As a result, BC Hydro's assertion noted in the quote above *doesn't address the concern*.

Dr. Beltaos has also submitted an email response to the JRP Secretariat (January 21, 2014) confirming that based on:

(a) his empirical data;

(b) his 40 years of field observations on various Canadian rivers; and

(c) the known physics of ice breakup and jamming processes;

increased freeze-up levels reduce ice-jamming frequency (other factors being equal) and that this cause-and-effect relationship operates independently of climate related cycles.

Flow attenuation greatly reduced in winter thus flow changes translate downstream

In its EIS, BC Hydro has dismissed the downstream importance of its proposed new Peace River flow regime (with Site C) because they will be "largely attenuated" at the Town of Peace River and beyond (EIS Section 11, p 11-79). In the Carver Hearing Submission, it was pointed out that BC Hydro's downstream-attenuation argument is largely relevant to the high-flow period, and does not address downstream flow translation during low-flow periods (late fall; winter) when the degree of flow attenuation is highly limited (largely due to channel characteristics). Rather than acknowledging the obvious validity of this concern, in its Rebuttal Report, BC Hydro has emphasised the modest attenuation present in the winter due to effects resulting from channel characteristics. Further, BC Hydro incorrectly asserts the following: "In Carver 2013 it is suggested that flow variations are unattenuated in the winter." This is untrue. In fact, the Carver Hearing Submission indicated that the winter attenuation effect is much smaller than the high-flow one and as a result, higher high flows and lower low flows in the winter (and late fall) periods "can be expected to translate to Peace Point more effectively than they would in the freshet period when attenuation is prominent." (See Carver Hearing Submission, p42 for further details.) This key outstanding point made in the Carver Hearing Submission continues to be ignored by BC Hydro, presumably to downplay the significance (on ice-jam potential) of the new new flow regime it is proposing for the Peace River.

In summary, low-flow attenuation due to storage and roughness effects is far less effective than high-flow attenuation due to inflow of major downstream tributaries. BC Hydro obscures this fact it its response. BC Hydro remains silent on the fact that its defense of downstream flow attenuation is largely a defense applicable to summer flows, not to winter flows. Hence, the concern put forth in Carver 2013 remains outstanding and unaddressed by BC Hydro.

Unassessed effects of proposed Site C operating regime on ice-jam probability

BC Hydro has not provided an assessment of the effect of its proposed new Peace River flow regime on the likelihood of ice-jam occurrence in the TPR to Carcajou reach or in the Delta reach. And as illustrated in the previous section, ice-jam occurrence in these reaches are linked through the jave process. As discussed immediately above, the "downstream attenuation" argument is very weak during the low-flow period. Instead of providing an assessment, BC Hydro provides its unsubstantiated assertion that the effect is not of concern (Rebuttal Report, p18):

> "The increase in the daily range of water levels expected at the Site C tailrace would be attenuated in the downstream direction. By the time the flow release reaches the ice front, the daily pattern of flows would be dampened, and would not influence the ice processes."

The unsubstantiated dismissal continues in the Rebuttal Report (p18-19) with another unsubstantiated claim:

> "Consequently, and *accepting for the purpose of this analysis that higher freeze-up levels are related to a lower probability of ice-jams*, the lower discharges in November in some years in the scenario with Site C would not lead to a change in the probability of dynamic ice-jamming in any of the scenario years." (emphasis added)

BC Hydro again repeats this claim later in the Rebuttal Report (p21):

> "Site C would have no influence on the flows or pre-break-up ice conditions downstream of the Town of Peace River (just downstream of the Smoky River confluence) and hence would not influence the ice-jam likelihood downstream of that point."

Again, this is unsupported – in this case, this statement is demonstrably untrue from BC Hydro's own flow simulations provided in the EIS surface flow regime assessment.

Given the well established significance of freeze-up level to ice-jam potential, and the crucial role of ice-jams in bringing hydrologic recharge to the perched basins, it is inadequate for BC Hydro to dismiss the importance of its proposed flow-regime changes in this regard. BC Hydro makes these unsupported claims despite acknowledging that its winter flows will rise subsequent to November thus yielding "a higher freeze-up level as flows increase" (particularly with climate change). BC Hydro is aware that the magnitude of this concern has caused Environment Canada to make a recommendation that the operating regime be adjusted in such a way as to not alter the freeze-up level, yet it continues to promote the perspective of "no influence of freeze-up level on ice-jam mechanism" despite scientific work clearly demonstrating the weakness of this position (Beltaos 1997; Prowse and Conly 1998; Beltaos 2003; Beltaos *et al.* 2006; Beltaos and Carter 2009). Rather than providing unsupported assertions dismissing the concern and claiming "no effect", and promoting speculative ideas about the lack of a freeze-up effect (Ashton 2003; see this Appendix B), BC Hydro should instead provide appropriate assessments for the JRP's consideration.

3.2.3 Ice-Cover Assessment Assumptions and Simplifications

The ice-related assessments embody a range of assumptions and simplifications that haven't been adequately assessed and/or communicated in the EIS, the subsequent information materials, and now in the Rebuttal Report:

- Downstream-ice assessment disregards changes in the surface flow regime
- Ice-extent modelling under future climates ignores changes in water flow expected with climate change; its effects on the ice-jam mechanism is further disregarded.
- The ice assessment under future climates ignores the *ranges* of climate projections
- The CRISSP model is applied to future climates which take the model outside the range of its available calibration and validation. Although BC Hydro is of the opinion that "the calibrated model reliably demonstrates the influence of a change in climate on the ice regime" (p25), there may be additional uncertainties associated with this extrapolation and these have not been adequately addressed in its Rebuttal Report.
- The filling assessment ignores consideration of its effects on ice-jam potential.
- Effects due to Site C can be expected to grow as the climate warms – this aspect has not been discussed anywhere in the EIS. See section 4.1 for further discussion.

These are in addition to the assumptions and uncertainties inherent in the discussion of sections 3.2.1 and 3.2.2. Most of these uncertainties are neither quantified nor communicated to the JRP.

4.0 CROSS-CUTTING SCIENCE ISSUES

A collection of issues arises from the different technical areas of the EIS. These are addressed here.

4.1 Climate Change

Due to the indefinite commissioning period of the Project and because effects of regulation on the Peace River are sensitive to climate, it is necessary to carefully consider climate change in the EIS. The Carver Hearing Submission raised a number of concerns with the scientific approach followed by BC Hydro in its Site C EIS. BC Hydro has responded to these concerns in part in its Rebuttal Report and at the January 11, 2014 Hearing. The present section responds in four sub-topics: methods, underestimates, and climate extremes.

4.1.1 Methods

The Rebuttal Report states (p31): "It is unclear how Dr. Carver can state that BC Hydro's climate change assessment is unreliable when in the same report it is stated that the results of the Pacific Climate Impacts Consortium (PCIC) work (on which the EIS Climate Change Report is based) '"were robust to climate-change projection methodology suggesting confidence in the findings'". The EIS Climate Change report is not "based on" the PCIC work, but rather uses the quantitative outputs from the PCIC work, which is a very different thing. BC Hydro makes analytical choices of what to do with those outputs and it is these choices that are brought into question in the Carver Hearing Submission.

A standard element of applying climate change projections (and well established at PCIC) is that outputs from no one Global Climate Model (GCM) should be considered "more likely" than the others. As a result, the range of projections from ensembles of GCMs should be retained in the subsequent physical applications. Contrary to this approach, BC Hydro pursues averages of the GCM outputs - an approach which inherently assumes some outputs to be more likely than others. The Rebuttal Report (p21) reminds us that the "influence of the Project has been investigated under historic climate and also under two future climate change scenarios" but fails to acknowledge that BC Hydro has carried out this analysis in a manner that is contrary to accepted practice as supported by PCIC, which BC Hydro funds. In fact, Environment Canada (Site C Written Submission, p22) has also recognised this deficiency and identifies "the value of BC Hydro taking the range of projected climate values into account (as opposed to only the median values) in project modelling, design and planning activities through the construction and operations stages of the Project."

Not only does BC Hydro use only averages of GCM outputs, but it further averages the outcomes in reporting on the results of the downstream-ice simulations. Its climate change assessment of the ice regime consists of applying the average future climates to historic climate records then averaging the ice extent changes: "The major influence would be to reduce by about 40 km, on average, the distance upstream that the ice cover would advance each year." These subsequent averages are then used by BC Hydro to justify the spatial boundary it has chosen. Again, BC Hydro's persistent use of averages masks the variability and uncertainty inherent in these simulations under future climates. As discussed above, changes to ice far upstream of the PAD can have implications for ice-jam flooding in the PAD. By using averages to depict the impacts of Site C in future climate scenarios, BC

Hydro may be masking potential changes to the ice regime that could well point to changes relevant to PAD recharge mechanisms. This methodological choice creates confusion and uncertainty.

4.1.2 Underestimates

The Carver Hearing Submission overviews recent scientific analyses that increasingly demonstrate that the GCMs are likely missing key feedbacks expected to become active in the global climate system as climate change progresses. These feedbacks mean that global climate can be expected to warm further than earlier estimated. Rather than consider these important scientific findings, BC Hydro states (Rebuttal Report p 32-33):

> "The notion that the current understanding of the earth's system is complete and will not change with time is a misconception. It is also a misconception to assume that every progress in our understanding of the earth's climate and its inclusion in GCM model codes will automatically result in increased future projections of temperature or precipitation as suggested by Dr. Carver."

There is simply nothing in the Carver Hearing Submission to this effect. At no time did the Carver Hearing Submission argue that all understanding of the climate system leads to increased projections of temperature or precipitation. In contrast, the Carver Hearing Submission alerted the Panel to recent scientific findings of some potentially significant feedback mechanisms that have not been incorporated in model simulations thus far and that may come into play in the coming decades. These underestimates cast doubt on the validity of BC Hydro's Site C climate change assessment and its application throughout the EIS. Rather than recognise this concern that is being increasingly recognised in the scientific community, BC Hydro has remained silent in its Rebuttal Report with respect to these important feedbacks.

In addition to the concern for unmodelled feedbacks, there is growing concern that emissions scenarios are being consistently underestimated in the GCM simulations. As explained in the Carver Hearing Submission, current emissions scenarios are tracking well above all the emissions scenarios BC Hydro has used in its GCM projections and the pace of emissions shows no sign of slowing down. Given that global CO_2 emissions are currently tracking above the worst-case scenario (RCP8.5 of AR4), and that there is no indication that humanity is changing that course anytime soon, it is sensible to at least *include* this emissions scenario – the one we are currently on - in the future plausible/possible range of human activity and associated emissions scenarios. BC Hydro's statement that the chosen emissions scenarios (A2, A1B and B1) "provide such a range" (p32) is incorrect because it does not include the emissions path we are following. Although BC Hydro's statement (p32) "emission scenarios are merely scenarios and, as such, have no associated probability of occurrence" is technically correct, there is one important exception: the emissions path we are currently on has a very high probability of occurrence in the near-term, and unless some very significant changes in the world's energy use are made in the very near future, we can say with certainty that the RPC8.5 will have a much higher probability of occurrence that any of the less carbon intensive scenarios in the coming decades.

At the January 11 2014 Hearing, Dr. Andres explained how BC Hydro chose the GCM scenarios it used in its EIS (CEAR #2420, p122-123):

> "And we sort of canvassed climate experts, people in Environment Canada, people in the PCIC as to what would be the best representation of the future

> climate, and we were advised at that time that, yes, there is a high variability in what the climate projections indicate. There are some better models than others, and the kind of models that would be the best models would be the made-in Canada model, the Hadley model, that's the UK model, and those models gave us numbers that fell in the middle of the range of the models -- of the deviations from the climate that the models were predicting.
>
> So we chose somewhere in the middle on the basis of expert advice based on people who understood exactly how reliable these models were.
>
> Certainly it was beyond our expertise to determine which models were good and which models were bad, but we took advice from people who we felt knew about the models and which ones would be the most reliable for the North American situation."

BC Hydro appears unwilling to acknowledge the string of underestimates that it has incorporated into its approach to considering climate change in its EIS. Independently, Environment Canada has raised this concern with respect to the GCM-scenario projections. In addition, however, there is a rapidly increasing awareness in the scientific community that the GCMs may be underestimating the extent of climate change because of missing feedbacks.

BC Hydro points out in the Rebuttal Report (p33): "The GCMs used by PCIC have been shown to accurately reflect historical climate trends (as represented by global average temperatures) since 1860." This is true and an important reason for this is that the feedbacks now identified have not been active during these past periods and the appropriate emissions scenarios were selected. In both cases, the future is likely to be underestimated given the choices made by BC Hydro in its climate change projections.

BC Hydro raises Fyfe *et al*. (2013) as possible evidence that climate models may be overestimating expected climate change:

> "In fact, climate models have overestimated the atmospheric warming trend over the last approximately 15 to 20 years. Although the reasons for this are not fully understood, recent research seems to indicate that this discrepancy could be related to some combination of internal climate variability (i.e., the fact that this is a short term trend which is sensitive to beginning and end dates, and may not reflect the long-term climate trend), errors in external forcing, and model response (Fyfe *et al*., 2013)."

The discrepancy referred to here is related to the fact that this is a short-term trend which is sensitive to beginning and end dates. Fyfe *et al*. (2013) note that there is very close agreement between model simulations and observations over the long-term (1900-2012). Given the timescales involved in the construction and operation of the proposed Site C dam, to focus on short-term discrepancies between model simulations is inappropriate, especially when the long-term relationship between model simulations and observed climate is made clear in that same paper.

4.1.3 Climate Extremes

In its Rebuttal Report, BC Hydro defends ignoring mid-winter thaws in its Site C assessment based on the present-day characteristics of this northern region. BC Hydro believes that the basin's climate will stay in its current form sufficiently that mid-winter thaws will remain a concern only in "southern British Columbia and the Maritime Provinces" (p23). Given the indefinite commissioning of the Site C facility, this is a weak assumption and thus the absence of an assessment in this regard remains a gap in the EIS. After indicating the likely increase in secondary consolidations that would be expected to accompany mid-winter thaws, BC Hydro provides another unsubstantiated opinion as follows (p24):

> "If the occurrence of mid-winter thaws were to increase with climate change, this would be the case with or without the Project and mid-winter thaws would not have a greater adverse influence on the stability of the ice cover post-Site C."

Rather than dismissing important physical phenomena, it would be preferable for BC Hydro to provide an assessment of the role of Site C under a future climate where secondary consolidations occur more often. It is plausible that as the climate warms, the behaviour of this northern river system will approach thresholds of change; the existence of Site C may be the "tipping point" during certain periods when, for example, ice jams will instead not happen, all things being equal. It would be preferable for BC Hydro to review these phenomena and conduct appropriate assessments rather than dismissing their importance out of hand.

4.1.4 System Complexity

The Peace-Athabasca Delta is a complex system with myriad interactions with the Peace and Athabasca Rivers (and others) and pressures from climate change and a range of stressors, including regulation. I discussed in the Hearing the way in which small effects from Site C today will become amplified under future climates. Both open-water and ice-cover mechanisms are vulnerable to this potential. As Lake Athabasca declines, the extent of flow reversals from Peace River would increase. The downward pressure on open-water hydrologic recharge that BC Hydro has partially quantified in its Rebuttal Report will increase in magnitude under future climates. Similarly, the effect of changes in freeze-up level, if small today, will increase in importance under future climates as the size of the snowpack-dependent freshet from the lower tributaries (notably the Smoky River) declines. These are system complexities that remain disregarded by BC Hydro but which bear greatly on the determination of effects on PAD hydrologic recharge than can be expected to be brought about by Site C.

BC Hydro correctly notes that the difference in ice extent (with and without Site C) diminishes as climate warms. However, BC Hydro fails to mention in this dismissal that a host of other system characteristics change under a warmer climate that would progressively *heighten* the risk level under future climates. Again, the Peace-Athabasca system is more complex than is recognised in BC Hydro's assessments.

4.2 Subjectivity

BC Hydro does not address the concerns raised in the Carver Hearing Submission regarding the excessive and inappropriate use of subjectivity in the EIS. Rather than addressing this pervasive issue, BCH has instead excused it. The reasons provided by BC Hydro for its subjectivity are largely disregarded in the instances themselves. Furthermore, the reasons provided do not acknowledge the importance of considering the context in which the change will occur. In its Rebuttal Report, BCH continues its EIS practice of providing unsubstantiated subjective assessments of change. Some examples include:

- P4 - BC Hydro indicates that the changes in the surface flow regime when considered in isolation from other effects from Site C "would have no *noticeable* influence on lake levels" (emphasis added).
- P3 - BC Hydro states "(d)ue to natural channel attenuation and the moderating effect of tributary flows downstream of Site C, these changes would become *increasingly less noticeable* with distance downstream and would be *largely attenuated* by the Town of Peace River" (emphasis added).
- P18 – "There would be *limited* active storage in the Site C reservoir and thus the Project would have *limited ability to change* the downstream flow regime."
- P18 – "Flow releases from Peace Canyon or Site C during the critical freeze-up period at the Town of Peace River would be *similar to* what they are now...".
- P23 – "...the increases were small and hence would have a limited influence..."
- P24 – "Releases from BC Hydro facilities to the Peace River under a future climate change scenario would continue to be driven by the operation of the Williston reservoir and would be similar with or without Site C." The word "similar" is left undefined, yet Environment Canada is sufficiently concerned about this potential future change that it provided a recommendation at the January 11, 2014 hearing as follows: BC Hydro to include "the projected effects of climate change, including extreme events on the timing and magnitude of streamflow generation in assessing downstream flow/levels." (CEAR #2420, p247).

In many instances of subjectivity, the central concern with BC Hydro's determinations are that the context in which the effect is occurring is not evaluated. It may be generically mentioned (eg, "the range of variability") but it is rarely if ever evaluated in the context in which it will occur. This is a very important point in the context of the PAD because it is a system under stress, having experienced decades of depressed hydrologic recharge due to a range of stressors, including regulation.

4.3 Uncertainty and Scientific Fragmentation

Climate change, subjectivity, system complexity, and other factors create considerable uncertainty in this environmental assessment, much of which is not assessed and communicated to the Panel. BC Hydro's Rebuttal Report does not address the issues surrounding uncertainties that are raised in the Carver Hearing Submission. One concern raised was the fragmentation of this complex system into components more amenable to deterministic assessment using physical models. While these assessments form an important part of the overall EIS, BC Hydro (p37) does not re-assemble these parts in a manner that appropriately recognises the uncertainties and system complexities involved. BC Hydro states (p37):

> "BC Hydro is not aware of a single model or expert that is capable of adequately studying/resolving all of the physical processes that were included in EIS Section 11 (Environmental Background)."

Other approaches are available to assessing stochastic phenomena and these are not applied in this EIS. Complex systems require complex models and suitably complex decision-support tools. In the present situation, a collection of small effects within segregated analyses diminishes the understanding of their overall impact, particularly when they are also not considered in context.

BC Hydro recognises two uncertainties in the Rebuttal Report:

> "...many other factors will determine the actual operation of the Peace generation complex in the future. In most cases, the data that would be required for meaningful system modelling are not yet available." (p34)
>
> "...equally important is the variability around future inflows, particularly in terms of any prolonged and even seasonal drought events. As described above, scientifically based assessment of this variability is not yet available." (p35)

These two statements constitute clear recognition by BC Hydro of deep uncertainties associated with the future states that it purports to be assessing under Site C. Nowhere in the EIS are these uncertainties communicated to the Panel.

4.4 EIS Shows Effects Beyond Its Own Spatial Boundary

In its EIS, BC Hydro has repeatedly stated that changes in average downstream change in extent due to Site C will be within the spatial boundary, that is well upstream of the Delta reach. In its Rebuttal Report, BC Hydro has changed its view and now states that "the influence of the Project would not extend to the lower reach of the Peace River" (p16) which is obviously beyond the spatial boundary of the ice assessment. Given that it admits that it will change the ice regime much further downstream than assessed in the EIS, the spatial boundary is again identified as inappropriate. (See section 4.5 for further details.)

Despite the limited downstream extent shown on ice extent plots and notwithstanding the methodological limitations associated with applying climate change averages rather than ranges, the effects of the project extend beyond the spatial boundary but this remains unrecognised by BC Hydro.

Although the Rebuttal Report states (p13) that "various federal agencies have indicated their agreement with BC Hydro on its selection of spatial boundaries", it fails to mention the strong disagreement that Parks Canada holds with BC Hydro's selection of spatial boundary: "…it would be reasonable to conclude the spatial boundary should extend beyond the present EIS RAA boundary at Peace Point..." (Parks Canada Hearing Submission, p19).

4.5 Mitigation

In the Rebuttal Report, BC Hydro provides new information on mitigation that would have been appropriately included in the EIS. The Rebuttal Report provides (p45) a quote from Beltaos (2006: the citation is not provided in the reference list) that summarises a viewpoint he puts forth that an intentional release may have to be "impractically large" to be effective in supporting PAD flooding, given that there are other communities located along the river. As a result, a "combination of freeze-up stage reduction and spring flow enhancement may be the most effective strategy for enhancing the probability of ice-jam flooding in the lower Peace." It is positive to see BC Hydro exploring the concept of a reduced freeze-up level so that the required spring-time release can be lessened.

BC Hydro asserts (p46):

> “Not mentioned in Carver 2013 is the major role of Peace River tributary flows (downstream of the BC Hydro facilities) and the very high Athabasca River flows that contributed to high lake levels in 1996. High water levels on the main PAD lakes (Lake Athabasca, Lake Claire, and Mamawi Lake) were also experienced in 1997 and 2013 despite average to below-average BC Hydro releases in the spring and summer. Dr. Carver neglects to mention these years in his report.”

These comments are inaccurate. The Carver Hearing Submission clearly recognises the wide array of factors that shape the occurrence of PAD hydrologic recharge. In fact, as a result of these many factors, the Carver Hearing Submission suggested the use of a probabilistic approach to predicting the likelihood of ice-jamming (p75-76):

> “...Mahabir *et al.* (2006a) successfully demonstrate the use of multiple linear regression for estimating maximum water level in the lower Athabasca River during spring breakup using 106 input variables. This same sort of approach could be used to investigate the break up of the Peace River at Peace Point including the role of regulation in this behaviour.”

Inherent in this proposal is clear recognition of the stochastic nature of this phenomenom. Single “exceptions” are the norm in probabilistic phenomena controlled by many factors.

4.6 The Need for Independent Perspectives

Section 2 of this response report has made it very clear that this EIS would benefit from an infusion of independent perspectives. This system is so complex that it is difficult to be clear that the assessments and interpretations have considered the full range of concerns and information.

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APPENDIX A2. DR. BELTAOS TECHNICAL NOTE RE: ASHTON (2003)

This appendix contains a verbatim *copy of a technical note provided to Martin Carver on January 11, 2014 by email from Dr. Beltaos at Environment Canada.*

Immediately belowis the contents of the cover email.

From:	Beltaos,Spyros [Burlington] [Spyros.Beltaos@ec.gc.ca]
Sent:	Saturday, January 11, 2014 10:15 PM
To:	Martin Carver
Cc:	Peters,Daniel [PYR]; Jasek, Martin; Dave Andres
Subject:	technical note request
Attachments:	SBcomments_Ashton 2003_Jan 6_2014.docx

Hi Martin,

I appreciated the opportunity to meet you earlier today and to listen to your very informative presentation. Per your request, I attach my technical review of the Ashton 2003 paper in the CWRA proceedings. As mentioned, I am routing a copy to Martin Jasek, as well as to Dave Andres who also requested one.

With best regards

Spyros

COMMENTS ON THE PAPER BY ASHTON (2003).

(Prepared by S. Beltaos, December 2013, with reference to Site C EIS hearings)

Main points of the Ashton (2003) paper

The paper first demonstrates the roles of certain key variables, by empirically establishing that ice jams can only form when the quantity J, which is defined as

$$J = (H_b - H_f)/t_i \qquad (1)$$

exceeds a value of about 2. Here, H_b is the peak breakup level; H_f is the freezeup level; and t_i is the thickness of the ice cover, excluding any slush that may have accumulated under the solid-ice sheet. All of the hydrometric data used to derive the above equation refer to the Water Survey of Canada (WSC) gauge at Peace Point. Thickness generally grows during the winter, but the value we should use in equation 1 is the maximum thickness, which is attained at the end of the "winter" season, i.e. just prior to the onset of relatively mild temperatures. The value 2 for the "threshold" of R is not well defined, owing to considerable scatter in the data, but the key point is that J decreases when H_f increases. This means that higher freezeup levels reduce the chances of ice jamming, other factors being equal. By different methods and analyses, this effect has also been demonstrated by others in peer reviewed publications (Beltaos, 1997; Prowse and Conly, 1998; Beltaos, 2003; Beltaos *et al.* 2006; Beltaos and Carter, 2009).

After making a minor point concerning flow-friction effects on ice thickness (Appendix A), Ashton (2003) next suggests that regulation has, on the average, enhanced breakup flows in the lower Peace River by ~2260 m^3/s. This figure comprises estimated increases of 610 m^3/s due to higher flows issuing from the dam at the time of breakup, and 1650 m^3/s due to a dynamic hydraulic effect, herein called "excess storage release". The postulated increase in post-regulation flow would lead to higher values of the peak breakup water level (H_b), so that the parameter J in equation 1 has remained unchanged or has even increased in the post-regulation period. In turn, this should lead to either unchanged or even enhanced ice jam frequency. However, this hypothesis is not supported by the available hydrometric data, as is discussed in the following section.

Hydrometric record evidence

Before examining the suggested flow enhancement processes in detail, let us consider whether the available hydrometric data at Peace Point actually support the postulated discharge and H_b increases. Figures 1 and 2 below show respective time series of two characteristic discharge values: the discharge at the time of occurrence of the peak breakup water level (Q_b); and the maximum discharge during the breakup period (Q_{max}). [These quantities are often equal but not always, because ice-related backwater can persist beyond the time of the peak breakup level]. Had the postulated flow enhancement of nearly 2300 m^3/s been real, post-regulation flows would be conspicuously larger than pre-regulation flows. This is not the case in Figures 1 and 2.

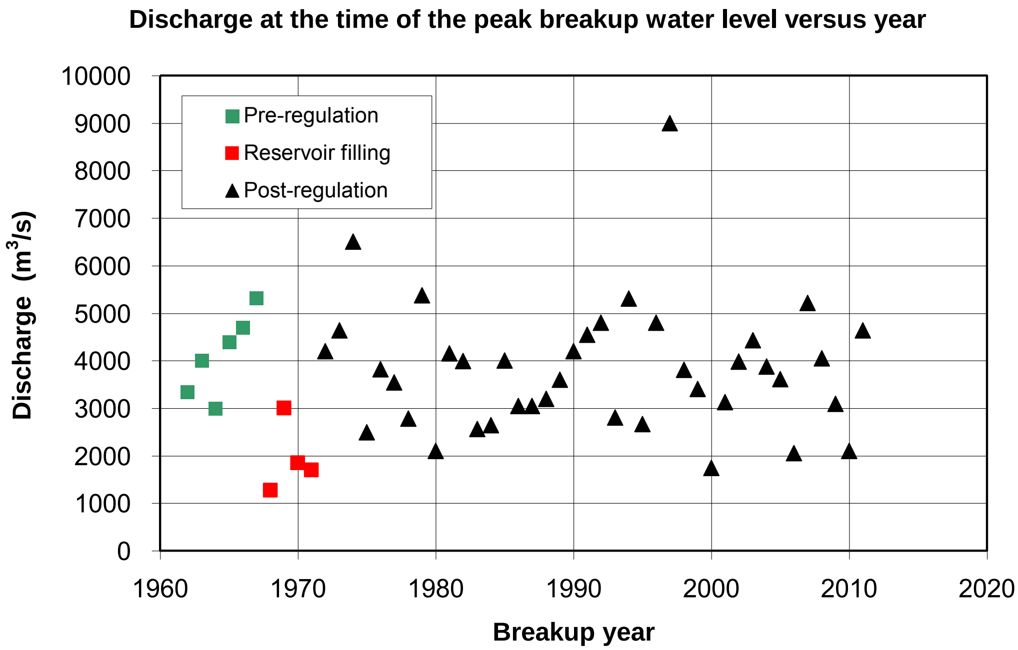

Figure 1. Peace Point time series of Q_b, 1962-2011, showing minor, if any, differences in pre- and post-regulation data sets. Flows were reduced during the reservoir filling period.

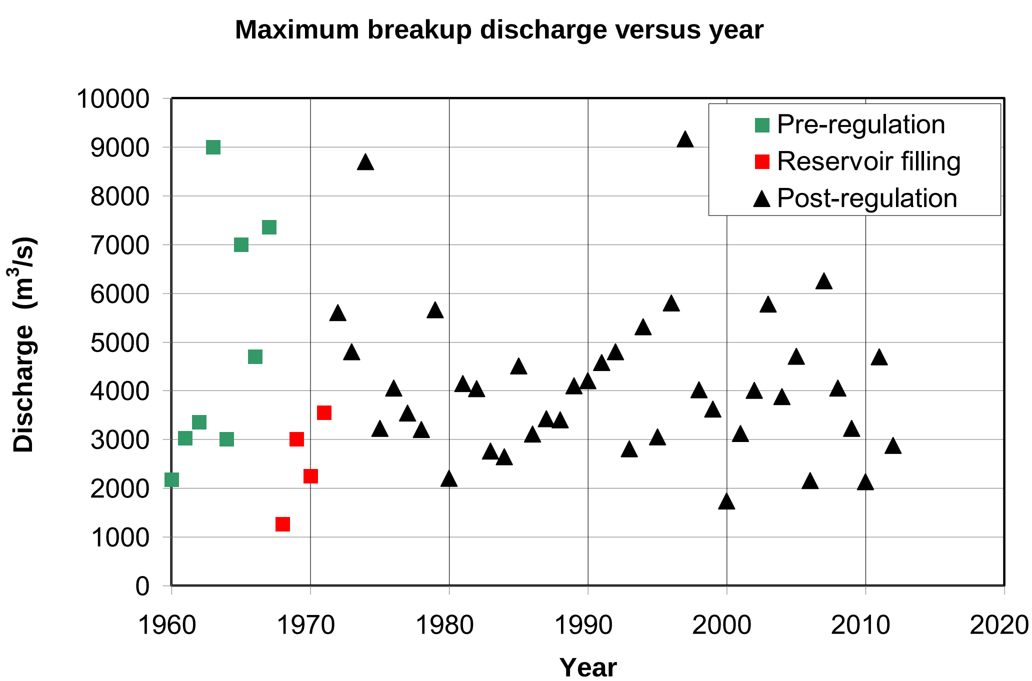

Figure 2. Peace Point time series of Q_{max}, 1960-2011, showing minor, if any, differences in pre- and post-regulation data sets. Flows were reduced during the reservoir filling period.

The post-regulation flow series suggest a mild decreasing trend in breakup flows; this trend has been noted in earlier publications (Prowse and Conly, 1998; Beltaos *et al.*, 2006) and attributed to climatic factors. Because this effect is gradual and small, it could not possibly compensate for a post-regulation increase of some 2300 m3/s. The effect of regulation on breakup flows for the PAD (Peace-Athabasca Delta) has also been considered by Beltaos *et al.* (2006), who concluded that "*the regulation effect, if any, is too small to be discernible (Beltaos et al., 2006, p. 4026)*". This conclusion is fully supported by Figures 1 and 2.

As a final check on the flow-enhancement postulate by Ashton (2003), the time series of the peak breakup water level (H_b) is shown in Figure 3. No post-regulation increase in the values of H_b can be discerned; on the average, there is actually a decrease (~ 1 m). This is consistent with the graphs of Figures 1 and 2 and suggests that the postulated increase in H_b has not materialized.

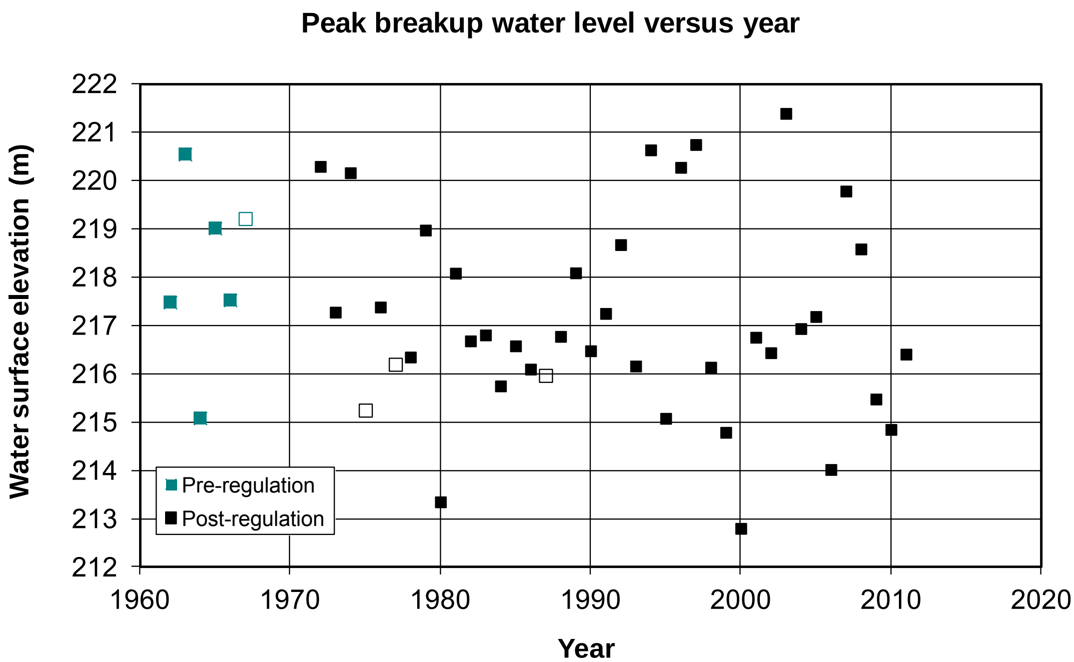

Figure 3. Peace Point time series of H_b, 1960-2011, showing no post-regulation increase in peak breakup water levels. Hollow data points indicate instances where water level was only known to have exceeded the plotted elevations.

<u>Physics of postulated flow-enhancing mechanisms</u>

At this point, it is of interest to consider why Ashton's (2003) hypotheses regarding regulation-induced flow enhancements are not supported by the historical data record. The first such hypothesis relates to the claim that flow releases from the Bennett dam "*have resulted in approximately 607 m^3/s higher flows at breakup during the post-regulation period relative to the pre-regulation period (Ashton, 2003, p. 323)*". This opinion is based on the following argument: "*The gauging station at Hudson's Hope is just downstream of Bennett Dam and that record of discharge well represents the discharges from Bennett Dam. Using this lag time, the contributions from Hudson's Hope, averaged over a three–day period, were determined for the dates of breakup at Peace Point. The average discharge for these three–day periods was 474 m^3/s for the years 1963 to 1971, and increased to 1081 m^3/s for the years 1972 to 1998. This represents an increase in the flow contribution at Peace Point at time of breakup of 607 m^3/s (Ashton 2003, p. 322)*".

I cannot comment on the validity of these figures because no details were given, such as dates of breakup at Peace Point, and corresponding discharges seven days earlier at Hudson Hope for each of the mentioned years. For instance, I got different numbers for the pre-regulation years using the last day of backwater, which at Peace Point typically occurs in the first half of May. While the Peace Point gauge record has been used extensively as a surrogate to help us understand breakup processes in the Delta reach of Peace River, we need to keep in mind that the ice cover of the latter reach, which is key to ice-jam flooding of the PAD, breaks up later than at Peace Point. Consequently, there is considerable uncertainty in the assumed dates of breakup. Moreover, there are inevitable errors in the assumed Hudson Hope-to-Peace Point time of travel, which depends on prevailing discharge magnitude and ice conditions in the river. Timing is particularly important in this context because early May is the time when the effect of regulation on flows reverts from positive values (increased flow) to negative (reduced flow). Another question arises from the fact that the reservoir was filling up in the years 1968-71, which may not be representative of natural flow conditions.

Be that as it may, the largest component of the postulated flow enhancement is a calculated regulation-generated increase of 1650 m^3/s due to dynamic release of "excess storage" of water during the spring breakup. Added to the previously calculated increase of 607 m^3/s, the effect of regulation on discharge is supposed to equal ~2260 m^3/s, and thence to compensate for the effect of the increased freezeup levels via a concomitant increase in H_b (see equation 1). The excess-storage release argument overlooks several important points:

(i). The calculated excess storage release cannot materialize when the spring flow is not sufficient to lift and mobilize the ice cover; the latter then simply rots in place by thermal inputs (thermal breakup event). With higher freezeup levels, and all other factors being equal, the frequency of thermal breakups will increase; therefore the frequency of ice-jam formation will decrease.

(ii). For those events where the flow can dislodge the ice cover, the average breakup progression speed was assumed to be equal to the celerity of the peak flow, or "170 km/day". This seems far too large relative to what has been actually observed. In Volume 2, Appendix G of the EIS, the rate of downstream advance of the ice front in the spring can be gleaned from the graphs presented on pages 99-107. The data points describing observed locations of the ice front at different times suggest rates of advance that are no more than ~50 km/day and often much less. The higher advance rates indicated occasionally by the CRISSP model are contradicted by the observations, likely as a result of ice jamming processes, which CRISSP cannot simulate.

(iii). Assuming for the moment that Ashton's (2003) calculation is correct, we note that the figure 1650 m^3/s is not the total flow enhancement that results from the release of backwater storage, but merely the difference between the post- and pre-regulation values of such flow enhancements. To determine the full, post-regulation enhancement, let us use the corresponding average H_f value of 214.16 m (=average pre-regulation value of 212.76 plus average regulation-induced increase of 1.4 m, per Ashton, 2003); let us also assume that the ice cover is dislodged when the water level exceeds H_f by 2.8 m [average value for mechanical events - Beltaos *et al*. (2006)] and that the applicable discharge is 4000 m^3/s (value used by Ashton, 2003). The open-water level that corresponds to this discharge is 214.10 m (per WSC's gauge rating table for Peace Point). Therefore, the average backwater caused by the ice cover at the time of its dislodgment is 214.16+2.8-214.10 = 2.86 m. From this, we can deduce that the post-regulation flow enhancement should, on the average, be equal to 1650(2.86/1.4) = 3370 m^3/s. This figure, which follows logically from the assumptions made by Ashton (2003), suggests that the non-enhanced, or "carrier", flow of the river during spring-runoff conditions would be a mere 630 m^3/s. This figure is far too small to be believable, given that it comprises the flow issuing from the Bennett dam plus the sum of all tributary contributions between the dam and Peace Point under spring runoff conditions.

(iv). Ashton (2003) appears to assume that the dynamic flow enhancement, which results from the release of "stored" water as the ice cover is being dislodged in upstream reaches, eventually finds its way undiminished to the Delta reach of Peace River. This hypothesis, which might, under certain conditions, apply to straight prismatic rectangular channels (Jasek *et al*. 2005) is unrealistic, at least for Peace River. Natural streams are neither straight, nor prismatic, nor rectangular. Consequently, the resistance of the winter ice cover to dislodgment varies considerably along their length (Beltaos 1997, 2007; Beltaos and Carter 2009). The wave generated by the storage release eventually encounters a high-resistance reach and fails to dislodge the ice cover; without the sustaining influence of storage release, the wave then attenuates, eventually becoming imperceptible. At the same time, the ice run that follows the wave is arrested at the edge of the undislodged ice cover and forms an ice jam. As the jam lengthens in the upstream direction, drastically raising local water levels, large volumes of water go into storage; as a result, the flow decreases, eventually becoming equal to the carrier flow of the river. Jams remain in place for typical time intervals of a few days and then they release. Each jam release generates a wave that renews the ice-dislodging and breaking process, until a new jam forms and the process is repeated. As discussed in Beltaos (2007) and Beltaos and Carter (2009), breakup in the flat lower Peace progresses in an intermittent sequence of jam-release-jam events. Consequently, the notion that waves occurring hundreds of km upstream can enhance the flow at Peace Point or the Delta reach of Peace River is unrealistic.

(v). One may also note that the flow enhancement postulate was proposed in order to show that the parameter J (see equation 1 above) is unaffected by the increased values of H_f because regulation has also supposedly resulted in increased values of H_b (remember, we want H_b-H_f to be more that ~$2t_i$ for ice jamming to occur). It is well known that in ice-jam years, the peak breakup stage occurs when a jam is in place and has fully formed. In that condition, dynamic effects on discharge cease and the flow under the jam becomes equal to the carrier flow of the river. Therefore, we cannot really say that storage release contributes to higher H_b values. It could be argued that while the jam is forming, the discharge may be higher than the carrier flow and thence the jam may be thicker than what it would have been with only the carrier flow, resulting in higher water levels. We have no way of actually measuring such effects, but all of the available evidence to date, comprising numerous case studies and research findings, indicates that use of the carrier flow gives good predictions of measured ice-jam water levels. Two physical mechanisms are likely behind this finding: (a) moving rubble will not be arrested to form a jam at very high flow because the sheet ice cover downstream is itself being mobilized or the rubble is simply carried underneath a stationary cover and does not stop to prime a jam; and (b) once a jam is primed, the flow decreases as a result of the storage created by the rising water levels. This decrease may even result in a flow that is lower than the carrier flow; eventually, however, the supply of rubble to the jam ends, and the flow returns to the carrier value.

Conclusion

Regulation-induced enhancements of breakup flows, if any, are much smaller than postulated. As such, they do not compensate for the negative impacts of increased freezeup levels on ice jam frequency.

Appendix A. Effect of regulation on ice thickness

Ashton (2003) noted that the higher winter flows accompanying regulation cause increased boundary friction and therefore reduce the end-of-season ice thickness by about 5.5 cm, which represents some 6% of the average thickness value (given as 0.875 m by Ashton, 2003). However, the 5.5 cm figure is based on an assumed water surface slope of 0.000111 (Prowse and Conly, 1998). The measured slope for the site of interest (Peace Point) is 0.000064, meaning that the thickness difference should be not 5.5 cm but 3.2 cm or 3.7% of the average thickness. Moreover, frictional melting does not influence the thickness of the solid-ice layer when there is a thick porous accumulation of slush under it, as is often the case at Peace Point.

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