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January 21st, 2014

To: Site C Joint Review Panel members

Dear Madam and Sirs,

My name is Walter Andreeff and I am the science consultant for the Peace River Environmental Society (PRES) located in the town of Peace River. These are our comments and questions regarding the hearing of the Joint Review Panel on Seismic and Dam Safety issues held on January 13th. Please accept this as our submission as we were unable to present our power point presentation in person on January 13th.

1) In earlier submissions we stated that the site-specific Probabilistic Seismic Hazard Analysis (PSHA) approach used by the Site C proponent (BCHydro) may not be an adequate indicator of the probability of future large or small earthquakes in the Site C area due to a lack of historical earthquakes in the Peace River Arch (PRA). We have changed our position on this matter after reviewing new information presented from BCHydro and Natural Resources Canada at the hearing on January 13th and our own research which suggests the Cornell-McGuire method may be the best available modelling method.

   However, *we still contend there are gaps in the PSHA results of BCHydro on Site C that should be addressed*. There is a factor of uncertainty in the seismic model such as a lack of data on historical earthquakes in the PRA. We believe this is important particularly in light of the Fort St. John graben fault system that is located under the Site C dam location. BCHydro mentioned in their oral presentation on January 13th that there are literally thousands of faults in the PRA area. But BCHydro was unable to locate any recent faulting in the PRA. *We agree with BCHydro that there's no evidence that the faults (large or small) may or may not be seismically active today but we think that further research work on historical earthquakes is required beyond the Lidar work that was used to identify surface features of active subsurface faulting if they existed.* Later we will cite two methods for gathering historical earthquake information from the local area.

   We ask the Chair of the JRP to enquire with BCHydro to present the seismic reports they reference in the Environmental Impact Statement (EIS) for public review on their PSHA methods and results that were mentioned in the hearing on January 13th.
   They are,
   a) BC Hydro. 2012b. memorandum, Site C Clean Energy Project, Probabilistic Seismic Hazard Analysis Results, October 2012, File YM80003.
   b) BC Hydro, 2012, Probabilistic Seismic Hazard Analysis (PSHA) Model, Engineering Report E658, 4 volumes, November.

c) Klohn Crippen Berger Ltd. and SNC-Lavalin Inc., 2009, Site C Clean Energy Project, Task 2: Establish the Maximum Design Earthquake (MOE), Seismic Hazard Assessment, Report No.P05032A02-02-001 R1.

In our review of other materials regarding the seismic modelling method used by BCHydro, Ms. Atkinson of the University of Western Ontario writes in her paper entitled "Challenges in seismic hazard analysis for continental interiors"; that the Cornell-McGuire method is the most widely used site-specific analysis method around the world. We note that BCHydro used this method in their site specific analysis of Site C (EIS Volume 2, 11.2.5.2). She says in her paper that a drawback to the method is that specific work must be done to fully characterize and utilize uncertainty in PSHA within continental interiors. Particularly when evaluating information in regions where earthquake historical records are incomplete. She cites a 1988 example of an earthquake of M 5.8 in Saguenay Quebec where the recorded ground motions exceeded the prediction that had been developed for the region by a factor of 4 suggesting the original prediction by the seismic model was incorrect. Ms. Atkinson adds that new information from the earthquake will lead to a revision of mean and median hazard assessment in a re-evaluation of the uncertainty and an improvement in prediction. (Atkinson, G. W., (2007), Challenges in seismic hazard analysis for continental interiors, Geological Society of America Special Papers 2007; 329-344.)

Note: We present the information below to highlight that there is ongoing discussion on PSHA methods in the academic community on the weaknesses and strengths of the PSHA method.

2) Dr. Seth Stein is a critic of PSHA and related earthquake hazard map's. Dr. Seth Stein said the current methods of hazard mapping in Japan does not adequately predict future earthquakes and cited an example of a map made by the government that failed to predict the large loss of life in areas that were located on the map as low-risk seismic areas. He cites a 2010 Japan hazard map which predicted a low probability in one area of Japan of strong shaking from a large earthquake over a 30 year period. However the year after in 2011, the Tohuko M9.0 earthquake in the low probability area killed many people. Dr. Stein also spoke of a 2008 earthquake in Wenchuan China of M7.9 that was also assessed as a low hazard area with a low probability of an earthquake. Dr. Stein and his colleagues believe that more objective testing of seismic hazard maps and PSHA models are required. (Stein, S., Geller R., and Lui, M. (2011), Bad assumptions or bad luck: Why earthquake hazard maps need objective testing, Seismol. Res. Lett. **82**, 623-626)

Dr. Stein has critics as well. A paper published from scientists Hanks, Beroza and Toda suggested that Stein and his co-writers were confused and misunderstood the concepts of Probabilistic Seismic Hazard Analysis (PSHA) in their paper of 2011. They said that the Tohuko earthquake did not surprise all scientists in Japan and that several had evidence of historical earthquakes that were unfortunately not included in the PSHA map of 2010. In the paper they mentioned other earthquakes such as the Darfield (2010) and Christchurch (2001) earthquakes that were in

located in low seismic hazard areas. They suggest that damaging and destructive earthquakes occur less frequently in low-hazard areas and are lower priorities for management and more vulnerable for larger losses than high hazard areas. In their conclusions they said they found no basis to support the assertions by Stein et al that that the method and results of PSHA should be discarded. (Hanks, C. T., Beroza, G., Toda, S., (2012), Have Recent Earthquakes Exposed Flaws in or Misunderstandings of Probabilistic Seismic Hazard Analysis, Seismol. Res. Lett. 83, 759-764)

We ask the Chair of the JRP to enquire with BCHydro to present information regarding the Site C PSHA results, assumptions, and uncertainties as well as any internal or independent testing of the PSHA methods used for the EIS assessment of the Site C project.

3) We introduce two scientific methods that can be used to determine the presence of paleo-seismic events in any earthquake area where seismic records may not be complete. Dr. Stein suggests that earthquake history can be extended back farther in time through paleo-seismology applications such as mapping soft sediment deformation and faulting in quaternary sediments near areas of noted paleo-seismic activity. Others have applied methods of using lake sediments as natural seismographs. Scientists in Switzerland have used lacustrine mass-movement event stratigraphy to recognize and identify paleo-earthquakes in several lakes of northern and central Switzerland including Lake Zurich. The timing of the earthquake events (mass-movements) go back over 16,000 years into the past. Their research shows the method as a tool to determine the timing, magnitude and epicentre locations of seismic events before the pre-historic period. They comment that this method approach is useful in intraplate settings. (Strasser, M., Monecke, K., Schnellmann, M., Anselmetti, F. S., (2013), Lake sediments as natural seismographs: A compiled record of Late Quaternary earthquakes in Central Switzerland and its implication for Alpine deformation, Sedimentology **60**, 319-341.)

   We ask the JRP Chair to enquire with BCHydro to request that they initiate a paleo-seismology study in the PRA to gather information on historical earthquakes in the region. We note that BCHydro has utilized a paleoliminological study on the long term ecological changes interpreted from lake sediments in the area of the Peace Athabasca Delta through a presentation given by Dr. Smol on January 11th, 2014 in Peace River.

4) BCHydro stated in the EIS and further at the hearing on January 13th that a Magnitude 7.6 earthquake was considered in the Earthquake Design Ground Motion (EDGM). This means in part that BCHydro has considered the possibility of earthquakes impacting faults underneath the dam structure and shaking the ground at 0.25 g. From this perspective they assure us that the dam structure will handle a M7.6 event without a uncontrolled release of the reservoir. (January 13 2014, BCHydro Presentation). Other areas such as the generating station, spillways and some parts of the dam have an operating basis earthquake of 1/475 (2.2% g) and a design basis earthquake of 1/2475 (8.7% g). However, BCHydro does not mention in the EIS the design criteria or specific locations for other parts of the project that could become severely damaged or where economic losses could be tolerated. (EIS Volume 5, 37.1.8.11)

We ask the Chair of the JRP enquire with BC Hydro to describe the differences in seismic shake parameters at Site C and what additional risks or hazards might be present in the project infrastructure and associated facilities when specific areas of Site C have a lower rating in terms of the operating and design basis earthquake?

Fluid injection and Fracking

We have stated that local industrial subsurface activities constitute an element of "outside influence" as defined by the CDA Dam Safety Guidelines (2013). We believe the "outside" risk elements could potentially be initiated through drilling waste fluid disposal in local subsurface rock formations or through subsurface fracking (aka hydraulic fracturing) activities within 50km distance of the Site C reservoir or Dam location from industrial activities that are not managed by BCHydro.

The Canadian Dam Association Guidelines (2007, section 6.5) writes that to arrive at a sufficient earthquake design ground motion parameter a proper seismic hazard assessment must be conducted. The assessment should be based on local and regional geo-tectonic information, historical earthquakes, and all potential seismic sources capable of contributing to the seismic hazard at the site. We believe that Oil and Gas activities near the Site C dam should be rigorously reviewed by the BCHydro Site C project.

There is growing concern that injection of fluids in the subsurface has the potential to induce seismicity where injected fluids can cause earthquakes. Documented examples of induced seismicity in the Western Canada Sedimentary basin related to oil and gas activity are known. Therefore, it's important that a balance be found between stimulating geologic formations and risking potential earthquakes resulting from fracking activities and subsurface fluid injection. And this is especially important where these activities may be taking place within 50 kilometers of the Site C project.

There wasn't considerable federal government seismic history of small earthquakes in Alberta and North East BC prior to the 1950s. Alberta seismic stations were first installed in Banff in 1957. Additional stations were installed at Suffield, Edmonton and BC up to 1992. According to studies, the sparse distribution of stations in the Alberta and northern BC area made it difficult to link the frequency of earthquakes to hydrocarbon production. In 2009 several stations were added in Alberta including near Grande Prairie, Manning and High Level. (Stern, V., Eaton, D., (2010), Documenting Seismicity in Alberta Poster, GeoCanada 2010)

The earthquake near Dawson Creek in 2001 (M5.4) has not been attributed to any geologic feature such as a subsurface fault or waste injection. Since that event, monitoring instruments have recorded a M4.4 earthquake that occurred in May 2013 and in the fall over 40 other smaller M1.6 -4.4 events occurred within 50km of the proposed Site C Dam location. These small to medium sized quakes have been described as human induced according to a news story on December 5th that quoted a GeoScience B.C. Oil & Gas official discussing a study that is underway to understand the risk of induced earthquake

events by local industrial activity. The record of the earthquakes this year suggests there are industrial activities in the subsurface that could potentially impact the Site C project.

The M4.4 earthquake event mentioned earlier occurred near a North East BC Disposal well that injects fluid into a cretaceous age rock formation known as the Cadomin reservoir. The reservoir is located near the underlying Dunvegan Fault within the Fort St. John graben system. It's not known in public if the earthquake in the fall of 2013 and the well injection activity at that time are related as an investigation is still in process. It's important to note the dam site has about roughly ten disposal wells within 100km of the site and most wells are injecting fluids into the subsurface at pressures over 10 Million Pascal and may be considered as an outside influence risk to the Site C dam. (B.C. Oil and Gas Commission, (2012), Map: Active Disposal Wells, Cumulative Injection Volume and December 2012 Rate and Pressure.)

However, many others have written about the risks of injection of waste fluids in causing earthquakes. For example,

Mr. Horton with the Centre of Earthquake Research and information at the University of Memphis wrote in 2012 that waste fluid injection from fracking activities triggered a series of earthquakes from M1 – M4.7 in Arkansas. He concluded that one particular earthquake in 2010 was due to a local fault that was stimulated by earthquake activity was likely caused by fluid injection. (Horton, S., (2012), Disposal of Hydrofracking Waste Fluid by Injection Triggers Earthquake Swarm in Central Arkansas with Potential for Damaging Earthquake, Seismol. Res. Lett. **83**, 250-260)

Mr. Ellsworth with the U.S. Geological Survey in California states in his review of injection-induced earthquakes that waste water disposal poses a high risk as the practise of fluid injection in subsurface can induce strong earthquakes. He cites examples of 2011 and 2012 events where there were several earthquakes in the mid-continental US that may have been triggered by nearby disposal wells. The largest earthquake was an M5.6 event that destroyed 14 homes in central Oklahoma. The earthquake was believed to be induced by weakening a pre-existing fault by elevating fluid injection pressure in a local well. (W. L. Ellsworth, Science 341, 1225942 (2013), DOI: 10.1126/science.1225942)

Extensive scientific and engineering references from the U.S. Geologic survey on the relationship between induced earthquakes and human activities that can be found online at http://earthquake.usgs.gov/research/induced/references.php.

Closer to home, the BC Oil and Gas commission noted in a report regarding the Horn River Basin that small seismic earthquake events ranging from M2.2 to M3.8 occurred from 2009 – 2011. The report said they were caused by fluid injection during hydraulic fracturing and some of the larger magnitude earthquakes were noted to occur near faults in the subsurface. (BC Oil and Gas Commission, (2012), Investigation of the Observed Seismicity in the Horn River Basin)

Other scientists in the U.S. have commented on the presence of earthquakes from hydraulic fracturing. One writes of an earthquake that occurred in South-Central Oklahoma in 2011. The earthquake events were captured on a seismic station that noticed initial small magnitude earthquakes from fracking activities but it also impacted a larger longer fault that was oriented sub-parallel to the existing fracking

area about 2 kilometers distant from the initial fracking activity. (Holland, A. A., (2013), Earthquakes Triggered by Hydraulic Fracturing in South Central Oklahoma, Bulletin of the Seismol. Soc. Of America, **103**, 1784-1792.)

To conclude, we note there is a substantial amount of ongoing and planned activities associated with the exploitation of the hydrocarbon resource plays utilizing horizontal wells and fracking methods near the Site C dam area in North East B.C. There is also ongoing subsurface waste disposal near the location of the dam site. We believe there should be subsurface activity exclusion zones in proximity to the dam and reservoir particularly in locations and subsurface depths where subsurface cretaceous faults are located and may be potentially reactivated by injected disposal fluids or impacted by smaller earthquakes through fracking operations. We noted in the hearings that both BCHydro and Natural Resources Canada representatives talked about the presence of induced seismicity (fracking, injecting fluids) in the region of North East B.C in proximity to the Site C dam location.

We request that the Chair of the JRP panel enquire with BCHydro in detail on the scope and scale of potential seismic impacts to the Site C location with BCHydro to fully understand and disclose to the public the potential seismic risks and hazards to the proposed Site C Project from local hydrocarbon activities. We also request that the Chair enquire with BCHydro on what internal management actions along with dialogue with B.C. Oil and Gas Commission are being undertaken to manage the potential seismic risk's and hazards to the Site C Dam and Reservoir.

Thank you very much for your time.

For PRES,

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