Responses from Nalcor Energy to Public Questions on the North Spur
January 2017

1) **This is the first use of a "natural dam" containing quick clay in a hydro facility. Other precedents at Ontario Hydro and Hydro Quebec are far smaller, and have a totally different dam section with far flatter slopes, constructed with selected materials, and therefore are not "natural".**

   Response: The North Spur Dam is not the first use of a natural dam built on sensitive clays. The edge or rim of a reservoir is considered to be a natural dam and there are many examples sensitive clays being part of the reservoir rim. There are also several examples in Quebec and Ontario of dams built partially or completely on sensitive clays. There are two examples of dam built on sensitive clays on Chicoutimi river: Chute Garneau and Pont Arnaud dams. These dams are partially built on sensitive clay deposit. In areas where sensitive clay is present, like in Saguenay-Lac St-Jean, similar cases to the North Spur can occur. The reservoir rim can contain natural sensitive clay deposits like the North Spur. This is the situation for all dams on the Chicoutimi, Aux Sables, Shipshaw, Péribonka Rivers and Kénogami, Lac St-Jean, Shipshaw Chute du Diable reservoirs. The Waba dam in Ontario is another example. Design and construction methodologies have to be adapted with regards of soil and rock properties for any embankment structure, this is true for every natural material and it is true also for the soil and rock present in the North Spur.

2) **The recent comment by Phil Helwig in the use of the same safety criteria as a dam constructed with selected materials all compacted and tested to CDA standards is very pertinent. The natural dam materials have not been compacted nor tested sufficiently to warrant the same safety factor – it should be higher.**

   Response: The safety factor required for a natural dam is not different from a constructed dam. Safety factors are calculated based on the properties of the soils and on the conditions at the site whether the slopes are natural or part of a dam being constructed. The Engineer of Record has the responsibility to define these parameters accordingly with the state of the art to make sure results and evaluation of the stability are in accordance with the recognized practice. Safety factors in geotechnical industry are calculated based in the physical and mechanical properties of the soils/embankments and in the hydrogeological conditions of the site/embankment. A model of the structure is then prepared and safety factors are calculated. This was the case for determining stability of the North Spur and is used for determining stability of constructed embankment structures, like dams, or determining if work is required to protect or stabilize natural slopes.

3) **The Canadian Dam Association was contacted to comment on the application of their guidelines to a "natural dam". They replied within 24 hours advising that at a director's meeting over the phone they had to come to the conclusion that the CDA publications are "Guidelines" only, to be interpreted as required by geotechnical engineers. This means the guidelines may not be relevant to the North Spur.**

   Response: The CDA guidelines include the reservoir rim (or edge) in the overall dam system. The North Spur natural dam is part of the reservoir rim and thus considered in the CDA guidelines. As per the CDA 2007 Dam Safety Guidelines the reservoir rim is included in the overall dam system. The North Spur natural dam is part of the reservoir rim and thus is considered by the CDA guidelines. The North Spur has been correctly considered as a dam and analyses performed have demonstrated that the North Spur will remain stable under all hazards and loading conditions.

4) **The North Spur strata are all sloping slightly downstream. The clay surfaces slope downstream. Water will accumulate on the top of the clay strata, reducing the friction and inducing a slide. This is why Phil Helwig's comments are so pertinent. A constructed dam does not have sloping downstream surfaces.**

   Response: The construction work at the North Spur addresses this concern through the construction of filters and drains so that water does not accumulate. It was demonstrated during the investigations and during the construction works that the stratigraphy of the North Spur is highly complex, it slopes in different directions in different areas and the strata are sometimes not continuous from the upstream to the downstream. In addition, the stratified drift deposit in the North Spur is already saturated.

   Regarding potential induced slides it is important to note that the important factor in this case is the seepage forces (gradient) acting inside the dam which are controlled by the inverted filters and are therefore drastically reduced in the body of the North Spur. Dams are constructed with filter systems capable of dealing with seepage forces which is also the case in the design of the North Spur.

5) **Experts such as Dr. Bernander, a professor at Lulea Technical University, Lulea (Sweden), with extensive experience investigating quick clay slides, has criticized the design, but has been dismissed almost as a crackpot for questioning the design. Instead, his opinions should be thoroughly investigated to determine whether his different approach to the calculation of the dam stability factor is correct, requiring a different design or whether it verifies the current design.**

   Response: Dr. Bernander's opinions about the North Spur have been taken into consideration and the type of analysis he recommended was done with the assistance of a worldwide recognized expert in landslide on sensitive clay. This expert, Dr. Leroueil, is very familiar with Dr.

Bernander's approach and methodology, having co-author papers on sensitive clays with Dr. Bernander ("Progressive failures in eastern Canadian and Scandinavian sensitive clays" and "Study of a lateral spread failure in an eastern Canada clay deposit in relation with progressive failure: The Saint Barnabe-Nord slide."). The expert undertook a thorough review of all information and data available and reviewed all the design criteria. He also looked at the approach and to the design philosophy adopted for the stabilization work.

Bank stability studies of the Muskrat Falls reservoir were performed in 2008 and 2010 (LCP-AM-CD-0000-EA-RP-0003-01, Bank Stability Study for the Proposed Lower Churchill Hydroelectrical Generation Project, June 2008 and LCP-AM-CD-2110-CV-RP-0001-01, Bank Stability and Fish Habitat, 2010 Field Investigation Reports. Vol 1 – Bank Stability Assessment, June 2011).

The Lower Churchill River valley shows numerous landslides scarps suggesting a flowslide type. To address the potential for occurrence of progressive failure landslides (both downward and upward) a specialized study was performed (MFA-SN-CD-2800-GT-RP-0001-01, North Spur Stabilization Works – Progressive Failure Study, December 2015). The reports referenced above are available on the Muskrat Falls website:
https://muskratfalls.nalcorenergy.com/newsroom/reports/

It is understood that Dr. Bernander has based his comments on his 40 years of experience in sensitive clay in Sweden. He has also stated that he did not go through all the data available and his calculations did not consider it.

The design team is very experienced and there are engineers who also have more than 40 years of experience in sensitive clay, both in research and in construction. These engineers performed the investigations in 2010 and in 2013, made the calculations, and prepared the technical specification and drawings.

6) **Dr. Bernander has indicated that the use of cut-off walls where the horizontal force will be concentrated may have a detrimental effect on the stability. This has not been investigated.**

Response: The presence of the cut-off walls and their implication during and after the stabilization works has been thoroughly studied as part of the design. Factors of safety for stability greater than those recommended by the Canadian Dam Association were obtained. During the construction work, no instability occurred.

7) The upstream slope is too steep as demonstrated by the "slips" detected during construction. At 2.5:1, it has the same slope as the downstream face, but there are no clear photos of the downstream face to determine whether it also has "slips". Yes, the lower half of the upstream face is flatter at 3:1, but it is not known whether this is flat enough.

Response: It's important to note that no "slips" occurred during construction. During construction, there were no landslide events that could be referred to as "slips". There was minor surficial movement of material and erosion in areas that had not been stabilized yet, both of these are normal occurrences during any construction project and was addressed during construction.

For clarification on the upstream geometry and slopes and the associated safety factors for the different loading conditions of the structure, typical cross-sections of the stabilization works are presented in document MFA-SN-CD-2800-GT-RP-0004-01, "North Spur Stabilization Works – Design Report", January, 2016. IFC drawings also show the different cross-sections.

Below elevation 29.0 m the final slope of the works is 2.5H:1.0V, above this elevation up to elevation 43.0 m the slopes vary between 2.5 to 4.5 H:1.0V, finally between elevation 43.0 m and the top of the North Spur the slopes were regraded to 2.0H:1.0V.

Stability analysis performed for the different load conditions (temporary excavations, end of construction, partial pool, steady state at full supply level static and dynamic conditions, rapid drawdown static and dynamic conditions and permanent slopes static and dynamic conditions) shown that the slopes as designed are stable and safe and comply with the safety factors suggested by the Canadian Dam Association (CDA).

8) The "slips" should have been used to back-calculate the average friction angle used in the dam design. It is suspected that is will result in a lower friction, requiring flatter slopes.

Response: Previous landslides were used to back-calculate how flat the slopes would need to be to prevent landslides from occurring. The last major landslide at the North Spur occurred in 1978 and information from that landslide was used in the analysis to determine how flat the slopes would have to be. The landslide from 1978 was used during design works to calibrate the selected parameter. The calibrated properties were used in all the analyses performed in the North Spur.

Back-analyses were performed using this information in representative upstream and downstream slopes of the North Spur to confirm the measured and interpreted physical and mechanical properties of the soils and the hydrogeological conditions prevailing in the North Spur.

9) **The west slope in the deep hole downstream of the Spur is very steep, at a slope of 1.5:1, is steeper than the downstream natural slopes in the Spur where the factor of safety is about 1.0. No geotechnical analysis of this west slope has been undertaken. Any failure in this slope is likely to migrate upstream into the Spur.**

Response: The deep hole underwater at the downstream side of the North Spur was considered and analyzed and found to be stable. No stabilization work was required in this area. Stability analyses and assessment of potential progressive failure were performed for a cross-section through the depression in the downstream side of the North Spur. Results of these analyses showed that the slope was stable and safe for the different loading conditions and the stabilization works are adequate to avoid a potential progressive failure.

10) **Below the low-drawdown reservoir level, the upstream slope in the re-shaped North Spur increases from 3:1 to 2.5:1, where it is not necessary to design for a "rapid drawdown". This indicates that the designer lacks experience – a steeper lower slope is never used - it reduces the safety factor.**

Response: It's important to note that the slope below elevation 29.0m is designed for the construction condition with the water level at elevation 25.0m (Winter Headpond). Above elevation 29.0m, the design is for the final reservoir level at elevation 39.0m, and a flatter slope is required.

The embankment below elevation 29.0m (final slope of 2.5H:1.0V) was built in order to counteract uplift water pressure during the construction works due to the nature of the foundation behind the till embankment. This feature has driven the decision to build the embankment with two different slopes. The slope of the till embankment, which has a greater impact in this loading condition doesn't change.

The calculated factor of safety of the stabilization works shows that the designed slopes are stable and safe for the rapid drawdown condition. For clarification, the stabilization works and all construction dam works in general are planned taking into account all load conditions, construction, short-term and long-term conditions. The North Spur Stabilization Works design took into account all these scenarios. This is outlined in document MFA-SN-CD-2800-GT-RP-0004-01, "North Spur Stabilization Works – Design Report", January, 2016.

11) **There is no mention of any pump tests to determine whether the lower aquifer is not connected to the upstream reservoir. In at least one upstream-downstream cross section through the Spur, the lower aquifer slopes upward in the upstream direction, indicating that a connection to the upstream river water is likely. Several pump tests at different locations are required to verify the assumed lack of a connection. It is essential for the safety of the dam that there is no connection.**

Response: For clarification, pump test were completed in previous studies and the results were integrated into the 3D hydrogeologic model which was specially developed for the purpose of examining the behaviour of the lower and upper aquifers.

Potential connection between the lower aquifer and the upstream reservoir was taken into account during the stabilization works design. Instrumentation and stabilization measures are already in place to counteract this potential feature.

12) **The AMEC report on the test holes undertaken by a vibratory drill across the North Spur indicated that the drill casing dropped under its own weight through very soft clay in several holes. This is very troubling. Yet, there is no mention of the implications in the dam design document prepared by SNC.**

Response: In a deep investigation holes in sensitive clays it is common to locally exceed the bearing capacity with the casing or with any metal stem. Experienced engineers undertaking investigation done in sensitive clays are aware of this and recommend that measures be undertaken to retain the casing and rod so that this does not occur.

The Geotechnical Investigation Report, 2013 Field Investigations (MFA-AM-SD-2800-GT-A99-0002-01, November 2013) reports that only in borehole NS-02-13 the core barrel dropped two times over a depth varying between 3 and 5 m and in borehole NS-09-13 the Shelby tube dropped 9 cm.

13) **The geotechnical investigation relies, in part, on a past data extending back to 1965. This data should have been verified since test equipment and methodologies may have changed over the last 50 years. Also, according to Dr. Bernander, several types of tests were not undertaken, all necessary in determining dam safety.**

Response: For clarification, it is the North Spur design, not the geotechnical investigation, which relies on data dating back to 1965. The design relies on all the geotechnical, geological and hydrogeological data collected over the years since 1965 up to and including the current day. Equipment, methodologies of investigation and tests were performed with the latest technology available at the time of the investigation campaigns and in accordance with the available state-of-the-art for this type of activities and for this type of industry at the moment of the investigations. All data has been reviewed for relevance and reliability for use in the final design.

14) In the geotechnical data there is an anomaly in the relationship between tested shear strength and the liquidity index, as discovered by Maurice Adams. This relationship is well outside the normal range, indicating that one or the other in incorrect. This anomaly needs to be investigated since any incorrect data will affect the dam safety. If the liquidity index is correct, then the shear strength should be lower by about one magnitude. If the shear strength is correct, then the liquidity index is too high by about one magnitude.

Response: The writer mentions that the value coming from test results on the North Spur clay are not in agreement with a relation between the *liquidity index* and the *undrained shear strength resistance*. His conclusion is that there is a mistake in the result for one or the other parameter.

The writer refers to values of *intact* *undrained shear strength* of the clay. The relation between the Liquidity Index and the Undrained *Remolded* Shear Strength Resistance has been known for many years (Leroueil, 1983; Demers and Locat, 1988; and others). This relation is valid for the *remolded* clay, not for the *intact* clay.

The results of the tests performed in the clay are in agreement with the relation proposed in the literature. These results were taken into account in the design of the stabilization works of the North Spur.

Locat, J. and D. Demers, 1988. "Viscosity, yield stress, remolded strength, and liquidity index relationships for sensitive clays." Can. Geotech. J., 25, 799-806 (1988).

Leroueil, S., F. Tavenas and J-P Le Bihan, 1983. "Proprietes caracteristiques des argiles de l'est du Canada." Can. Geotech. J., 20, 681-705 (1983). ("Characteristic properties of the clays of eastern Canada.")

15) There have been at least three designs for the dam, including downstream groin extending out into the water and infilling of the deep downstream hole. Why should the current design not address these issues and particularly the slope of the Spur as it extends to the bottom of the hole.

Response: All the engineering studies performed since 1965 and their evolution was reviewed by the design team. The design evolved as more information became available. All previous designs are presented in the document MFA-SN-CD-2800-GT-RP-0004-01, "North Spur Stabilization Works – Design Report", January, 2016.

Outcomes of the field works and interpretations presented in the different engineering studies shaped the basis of the current design. The final design took into account the basis and assumptions for the previous designs and all the geotechnical information collected.

16) Acres, now Hatch, have reviewed the geotechnical design. Their main concern was found to be the natural water table level as it changes with the introduction of the upstream reservoir. Apparently, the water table level affects the stability more than expected and Hatch had to develop a 3D computer model to calculate the new water table levels. This effect of the water level was verified by Dr. Bernander in his report. The water table problem was so complex, that the work was undertaken by geotechnical engineers with postgraduate degrees. There has been no review of this very complex work.

Response: All recommendations issued from the Cold Eyes Review performed by Hatch were addressed. As part of these recommendations, a 3D Hydrogeological Study was performed (MFA-HE-CD-2800-GT-RP-0003-01, "Three Dimension (3D) Hydrogeological Study for the North Spur, October 2015).

The assumption regarding effect of water table level changing the stability more than expected and as a consequence a 3D hydrogeological model was developed is not correct. Ground water pressure is very important in soil mechanics and its impact on stability is recognized by experienced geotechnical engineers. The 3D hydrogeologic model was developed to help the designer follow the impact of construction and impoundment on the stability of the North Spur. The model was developed by Hatch with a weekly supervision of the design team.

17) Quick clay has been detected at two locations on the downstream slope. But the extent has not been determined. If extensive, it will have serious implications for the dam safety. This will require more drilling of boreholes.

Response: The presence of high sensitivity clay in the North Spur was known from the first investigation works performed in 1965, which found it in some samples coming from two boreholes. All investigation works done since then confirmed the same fact: some samples coming from the upper clay (part of the stratified drift deposit) show high sensitivity.

The design of the stabilization works was done with consideration of the presence of high sensitive clays in the North Spur.

During the construction works (2015 and 2016 seasons), more than 1 million m^3 of soils were excavated from the spur, including about 600,000 m^3 of soils excavated in the stratified drift unit. From this volume, less than 0.1% was observed as being very high sensitivity clay and it occurred in two small, localized areas.

In summary, the presence of sensitive clay was known and expected. The design and construction, including all the activities, methods and operations during and after construction have taken this into account.

18) **Nalcor insist that the geotechnical design has been reviewed by two independent experts, namely Dr. Lerouell and Dr. Idriss. Dr. Lerouell is currently a professor at Laval University in Quebec City. He advised that he is not qualified to undertake such a review since he is not an expert in dynamic analysis, was not provided with all the data (no report appendices) and hence confined his review to only Chapter 2 in the voluminous geotechnical report. His conclusions, on less than two pages, were that "the stabilization works increase the factor of safety from about 1.0 to 1.6, which is very significant". Not a full endorsement of the design. Dr. Idris is a retired earthquake specialist, from the University of California at Davis, who attended several meetings, made some comments but never issued a report.**

    Response: Technical reviews of the current engineering were performed by the Advisory Board (April and October 2013), by the Independent Engineer (September 2013) and by Hatch (September 2013). During the reviews, additional specialized studies (Dynamic and Hydrogeological) were recommended by these reviewers.

    Additional assessment of the potential liquefaction of granular soils and cyclic softening of cohesive soils under a seismic event was performed by Drs. Leroueil and Idriss. Results of this assessment are presented in section 5.12 of the design report (MFA-SN-CD-2800-GT-RP-0004-01, "North Spur Stabilization Works – Design Report", January, 2016).

    Dr. Leroueil also participated in the progressive failure study. Results can be found in section 5.13 of the design report (MFA-SN-CD-2800-GT-RP-0004-01, "North Spur Stabilization Works – Design Report", January, 2016).

    Geotechnical design was not reviewed by Leroueil and Idriss. These two external experts were part of the study to ensure the design is in accordance with the expected seismic loading. Leroueil is a worldwide expert in sensitive clay behaviour and Idriss is the same in impact of dynamic on the soil behaviour. Both experts gave advice while the study was underway. Idriss gave a presentation and report during and after the study was completed.

19) **There is a reference (Nalcor 2016 report on the spur design, page 120) to the Independent Engineer (MWH) having reviewed and approved the design of the North Spur – quote – The Independent Engineer commented that "the stabilization works have been designed in accordance with currently accepted geotechnical design practices and effectively stabilizes the North Spur when the reservoir is impounded". – end quote. An email to the Independent Engineer asking for confirmation of this statement resulted in the following reply – "MWH have never at any stage been involved in the design of the North Spur. We act as Lender's Engineer to the Federal Government and have never at any point been actively involved in the design of any of the project components". This contradiction needs to be resolved.**

    Response: It is not the mandate for the Independent Engineer to approve any aspect of the design. They are engaged by the federal government to review aspects of the Muskrat Falls

Project. They present their comments, observations and recommendations to the federal government. The provincial government is permitted to rely on same. Nalcor also is privy to these comments, observations, and recommendations and incorporates that input when and where appropriate.

The Independent Engineer stated on page 9 of in its Interim Independent Engineer's Report Lower Churchill Project, "The stabilization works have been designed in accordance with currently accepted geotechnical design practices and will effectively stabilize the north spur when the reservoir is impounded." The report is located at the following link: http://muskratfalls.nalcorenergy.com/wp-content/uploads/2013/03/November-29-2013-Independent-Engineer-Report1.pdf. There is no mention of "approval" by the Independent Engineer or by any other expert reviewers or advisors.

For clarification, the reference stated above in the writer's reference should be page 210 (Section 5.3 Current Engineering Technical Reviews).

20) **Finally, there is the question of insurance for the dam. This can be purchased, but if there is a failure, the insurance company will deny payment since this was a known and unacceptable risk assumed by Nalcor.**

Response: Construction All Risk as well as Wrap Up Liability and Pollution Liability has been purchased for the Muskrat Falls Project. Detailed discussions with the current underwriters as well as their engineers were undertaken so they could fully understand the risks associated with the project including the North Spur before the project even started. The insurance underwriters made their own assessment of the risk before accepting to underwrite the project. The insurance companies also continue to monitor the project and have their engineers visit the site twice per year and have had no issues with the design or construction of the North Spur infrastructure.