MUSKRAT FALLS NORTH SPUR
INDEPENDENT ENGINEER COMMENTS ON REPORTS BY DR. S. BERNANDER & OTHERS

The North Spur is a natural embankment comprised of marine and estuarine deposits that is being utilized, with engineered improvements, to provide a portion of the reservoir retention works for the Muskrat Falls hydroelectric development. The IE has observed the design and construction process for the North Spur works since 2013, and has provided comments on those activities in the periodic site visit reports submitted to Natural Resources Canada. The IE's comments below should be read in conjunction with its site visit reports.

With reference to previous site visit reports, the IE notes in summary:

- Investigations of the North Spur and design measures to preserve its integrity as a natural dam forming part of the overall impoundment of the future reservoir have been carried out over the last 40 years.
- Design of the North Spur works was done by a major engineering firm with substantial experience in design of dams, and in accordance with international standards and practices. The designers consulted with various specialist consultants, including consultants with recognized expertise in landslides in sensitive clays. The design was also reviewed by another major engineering firm with substantial experience in design of dams.
- Construction of the North Spur works comprising flattening of the slopes, upstream cutoff walls, a toe berm and drainage improvements was successfully completed with no reported problems. Construction was completed to a high standard. Only a few very localized occurrences of clay/silt materials with "highly sensitive" or "quick" behavior were found in the excavations.
- The North Spur is well-instrumented and initial monitoring since construction was completed has not detected any anomalous behaviour.

In keeping with typical practice regarding Independent Engineer engagements for project financing, the IE's review of project design and construction is not so comprehensive as to constitute a full peer review. However, the IE sometimes makes recommendations for additional work. For example, in 2013, the IE and other reviewers commented that the stability studies for the North Spur had not considered the special liquefaction and strength loss properties under earthquake loadings and that further studies were needed to deal with this issue. Nalcor commissioned several studies to address this recommendation in 2014, and the IE subsequently considered that the various geotechnical concerns for the North Spur were generally satisfied by those studies.

The IE has recently been requested by Natural Resources Canada to comment on several reports regarding the North Spur, prepared for Grand Riverkeeper Labrador, Inc. by Dr. S. Bernander in 2015-16. Dr. Bernander is a retired Adjunct Professor at Luleå University of Technology in Sweden. A specific field of study by Dr. Bernander is a type of landslide referred to as "progressive failure." His particular focus is on "downslope progressive failure", for which he has developed a numerical analysis approach using a finite difference method.

In addition to the 2015-16 reports prepared for Grand Riverkeeper Labrador, Inc., Dr. Bernander and Dr. L. Elfgren, an emeritus professor at the same university, published a Luleå University technical report in 2017 titled "*Comments on the North Spur Dam at Muskrat Falls in Churchill River, Labrador, Newfoundland*".

Also in 2017, R. Dury, a student at Luleå University of Technology, published a Master's Thesis applying Dr. Bernander's method to the North Spur.

For reference, these documents are listed below:

1. S. Bernander - *Lower Churchill River Riverbank Stability Report*, Prepared for Grand Riverkeeper Labrador, Inc., 26 November 2015.
2. S. Bernander - *Errata: Lower Churchill River: Riverbank Stability Report (November 26, 2015)*, 13 October 2016.
3. S. Bernander - *Safety and Reliability of the Muskrat Falls Dam, in Light of the Engineering Report of 21 December 2015 by Nalcor/SNC-Lavalin*, Submitted to the NL Public Utilities Board's Investigation and Hearing into Supply Issues and Power Outages on the Island Interconnected System on behalf of Grand Riverkeeper Labrador, Inc., 13 October 2016.
4. S. Bernander & L. Elfgren - *Riverbank stability in loose layered silty clays, Comments on the North Spur Dam at Muskrat Falls in Churchill River, Labrador, Newfoundland*, Technical Report, Luleå University of Technology, July 2017.
5. R. Dury - *Progressive Landslides Analysis, Applications of a Finite Difference Method by Dr. Stig Bernander, Case Study of the North Spur at Muskrat Falls, Labrador, Canada*, Civil Engineering, Master's Thesis, Luleå University of Technology, June 2017.

The IE has reviewed these documents, but in keeping with typical practice as noted above, this review is not so comprehensive as to constitute a full peer review.

The IE notes that in documents 1, 2 and 3, Dr. Bernander has challenged the analysis of the North Spur and the design of the measures that are now constructed. His opinion is that filling of the reservoir could initiate a downslope progressive failure and that an "*up-to-date progressive failure analysis*" (i.e. using his method) is required. In his reports he presents various statements and calculations to support his view.

Document 4 by Bernander & Elfgren is essentially a synthesis of documents 1 to 3, which are appended to document 4. Based on a quick internet search, Dr. Elfgren is an Emeritus Professor of Structural Engineering with expertise in design and assessment of concrete structures. It is not stated what role he provided in co-authoring this report.

The thesis by Dury (document 5) is also referenced in the Bernander & Elfgren report.

Nalcor has already commented on Bernander's views in a document titled "*Responses from Nalcor Energy to Public Questions on the North Spur*" dated January 2017 and posted on the public website. Nalcor's designer, SNC Lavalin, has also published at least two technical papers describing the North Spur, the stability analyses and the design of the constructed works:

1. A. Ceballos, G. Snyder and R. Bouchard, *Stabilization of the North Spur at Muskrat Falls: An Overview*, Canadian Dam Association, Annual Conference Proceedings, October 2015.
2. D. Leahy, R. Bouchard and S. Leroueil, *Potential Landsliding at the North Spur, Churchill River Valley*, Landslides in Sensitive Clays pp 213-223, 2017.

These documents show that downslope progressive failures were considered during the design, including analyses to confirm that reservoir loading would not trigger a failure. The IE notes that Dr. Leroueil, one

of the co-authors of the second paper, is a professor at Laval University who is a recognized expert regarding sensitive clays and their stability.

The IE also notes that some of Dr. Bernander's computations and interpretations are apparently based on incomplete data. For example, in Section 2 of the Bernander & Elfgren report it is stated that "*As no deformation properties are given in Leahy (2015) the stiffness values **are guessed***". In that case, analyses based on such values cannot be considered reliable.

With respect to the Dury thesis, the two objectives stated in section 1.2 are "*to set up software based on the (Bernander) method permitting to carry out **rough landslide analyses***" and "*to use the software to solve a problem encountered by Nalcor Company on the hydro power construction project of Muskrat Falls*".

The IE has not attempted to evaluate if the first objective was correctly achieved. That would require a detailed review and validation of the methodology and numerical computations presented in sections 4 and 5 of the thesis, which is beyond the IE's scope.

With respect to the second objective, Dury does not introduce any new information to support his selection of the North Spur as a case study for application of his software. In any case, Nalcor has noted in discussions with the IE that Dury has made several simplified or incorrect assumptions in his analysis. For example, one of the critical assumptions is the location and orientation of potential failure surfaces. Dury's Figure 3-3 shows the simplified geologic section adopted for his analyses, with the stratigraphy dipping several degrees downstream. No reference is provided for the source of this geologic section, and Nalcor notes that this does not accurately reflect actual conditions. Section 5.2.1 of Dury's thesis appears to indicate that the analyses assumed a downstream dip of 4 degrees. In section 5.2.4, reported sensitivity results seem to indicate that the computed stability is highly sensitive to the assumed gradient of the failure surface (safety factor >1 for gradient of <2%; <<1 for gradient of >2%).

The thesis abstract has a definitive-sounding conclusion: "*The investigation has led to the conclusion that the situation will be risky for many combinations of soil properties if the water level is raised as high as initially planned.*" However, other statements in the thesis are less conclusive and somewhat conflicting, for example:

- Section 1.4 - *This work is mainly based on **rough assumptions** as concerns the mechanics and geometric properties of the slope studied. **Thus we cannot claim that the study gives an entirely accurate analysis**. We simply bring to light the fact that there is a problem which should be studied in more a depth*.

- Section 6.3 - *For those reasons, the landslides analysis performed on the North Spur with Stig Bernander's method are not supposed to give exacts odds for progressive failure. Yet, as the values are really low, we can say that it still represents a warning of an existing risk of landslide*.

- Section 7 - *The software has been used to assess the risk of a progressive landslide encountered on the Muskrat Falls construction project. On the basis of the outcome of this study, **we can affirm that the North Spur does not form a safe and reliable part of the impoundment** wall. **For assumed material properties and geometries of failure**, the critical load are below 1000 kN/m whereas a rise of the water level with 21 m will give an increased load of* $Nq = 0{,}5\ \gamma_w\ Hd^2 =$

> *$0{,}5 \cdot 10 \cdot 21^2$ = 2420 kN/m which is more than twice what the ridge can stand* ***with the assumed properties***.

It should be noted that there is no universally-adopted method for analysing the stability of potential landslides of the progressive failure type. The IE's opinion is that Dury's thesis does not add any new research or information to demonstrate that stability analyses of the North Spur based on Bernander's interpretation and method are "better" than those performed by Nalcor. In addition, because Dury's analysis includes several simplifications and assumptions that are critical to the outcome, it is not really possible to draw reliable conclusions from the reported results.

It is also noted that the thesis is Master's level. According to the details on the last page, the author has completed an undergraduate degree and a one-year Masters degree, with no post-graduate work experience. On that basis, the author would not be considered an expert regarding landslides and analysis of their stability (and there is no evidence that he claims to be an expert).

In summary, the IE considers that the overall design, review and due diligence process for the North Spur was consistent with what is expected for a major hydroelectric project.