Presentation on Quick Clay and the North Spur
Dr. Stig Bernander
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Points from Presentation	ENVC Comment
• North Spur has landslide scars indicative of "quick clay"	• The presence of "quick clay" in the North Spur area was initially identified back in the 1960's. It has been confirmed in more recent geotechnical field studies (*Bank Stability and Fish Habitat 2010 Field Investigation Reports*, AMEC, 2011).
• Liquefaction of "quick clay" can lead to landslides	• The CDA *Technical Bulletin: Geotechnical Considerations for Dam Safety* provides several recommendations for approaches to reduce the risk of soil liquefaction which have been included in the design of the North Spur including: o Reducing the slope of the embankment (planned) o Adding a berm at the toe (planned) o Reducing the internal water pressure (planned) o Replacing liquefiable zone with denser material (planned) o Adding drainage (planned) o Adding reinforcement such as piles, caissons, cellular cofferdams or slurry walls o Unsaturate the zone susceptible to liquefaction (being done) • Over $1 billion in total project costs for the LCP at Muskrat Falls is for North Spur stabilization work
• Dr. Bernander does not contend that the North Spur containment is impossible, but that there are possible hazards related to failure of sensitive clays on the North Spur	• Dr. Bernander admitted during the presentation that he had not seen the conceptual design for the North Spur and could not comment on its effectiveness. Dr. Bernander's opinion is based on his research in Europe with no first-hand knowledge about the sources, causes and types of previous land-slides in North Spur area.
• Dr. Bernander discussed possible slope	• It is expected that the reservoir

stability problems relating to the reservoir impoundment	impoundment for Muskrat Falls will have a *long-term* stabilizing effect on bank stability in the area (*Bank Stability and Fish Habitat 2010 Field Investigation Reports*, AMEC, 2011; *Bank Stability Study*, AMEC, 2009). • Information from the NALCOR studies indicates that the most critical time for landslide events is generally associated with initial filling of the reservoir and for a period of up to two years after completion, and that most landslides occur at pre-existing landslide features (*Bank Stability and Fish Habitat 2010 Field Investigation Reports*, AMEC, 2011).
• Dr. Bernander discussed possible slope stability problems relating to construction	• NALCOR will have consultation with and planned oversight of contractors concerning best management practices and work procedures to meet design objectives during the construction phase (e.g., avoiding human activity such as pile driving that could induce landslides, having a geotechnical expert on-site during construction, instrumentation to monitor groundwater, etc.). Design includes temporary works for interim slope stability.
• Dr. Bernander mentions NALCOR reports provided offers little geotechnical information	• NALCO has provided ENVC several reports relating to geotechnical aspects of the project, and we are waiting on a couple more
• NALCOR used the Limit Equilibrium Stability Analysis method or Plastic Equilibrium (PLE) Analysis method, which Dr. Bernarder indicated is not applicable to “quick clay” formations. This approach has been wrongly applied in engineering practice throughout the 20th century.	• Guidelines prepared by the Canadian Dam Association (CDA) have been used as a basis for the geotechnical design. These guidelines are used as the current accepted best practice for dam design across Canada. PLE is the accepted method for determining slope stability and factors of safety for embankment slopes subjected to normal operating conditions according to the CDA Dam Safety Guidelines. • This is a static load assessment method. • The North Spur engineering design has

	also been reviewed by independent third parties including MWH International, and a Cold Eye Review undertaken by Hatch. Opinion from these reviews is that the current design is adequate.
• According to Dr. Bernander downward progressive slides occur when the disturbing agent is located up slope (eg. overburden pressure at the top of the slope). Upward progressive slides (including spreads and earth flows– or retrogressive slides) occur when the disturbing agent is located down slope (eg. excavation, toe erosion). • Dr. Bernander is sceptical of the assertion that there have been no downhill progressive failures along the Churchill River valley- site visit of area looking at landslide scars indicates downhill landslide formation (according to Dr. Bernander). • For landslides in sensitive clays, the triggering agent is normally related to human activities such as construction including placing of fill/soil/sand/rock; road embankments; pile driving; blasting. • Groundwater saturation during rainy periods can act to increase the load triggering landslides.	• According to experts in the field that have been consulted on this issue (by NALCOR), there have been no documented cases of a downward progressive failure trigger as proposed by Dr. Bernander reported in the eastern Canadian Clay formation. The identified trigger for all landslides on the Churchill River area has been toe erosion, confirming an upward progressive failure. (*Landslide Generated Waves in the Muskrat Falls Reservoir*, SNC Lavalin, 2013).
• Dr. Bernander recommended the use of Finite Differences Method (FDM) Progressive Failure Model (PFM) for areas with sensitive clays or "quick clay" formations. This method can be used for retrogressive landslides as well as progressive landslides.	• This method is not specifically mentioned in the CDA Dam Safety Guidelines. However, the guidelines do recommend for large dams or dams with complex foundation conditions the use of more sophisticated methods based on the Finite Elements Method (FEM) or the Finite Differences Method (FDM) (ie. non-static assessment). From NALCOR's *Design Criteria- Geotechnical*: o "The stability of the soil slopes whether excavated slopes, cofferdams or the North Spur must be verified using limiting

	equilibrium or other appropriate methods by application of recognized software such as G-Slope, Slope-W or finite element software. The analyses will be under total or effective stress conditions as appropriate and utilizing circular or non-circular methods as applicable (Bishop's simplified, Janbu or Morgenstern Price)." o Non-static assessments appear to have been used in determining the factors of safety with seismic loading, but not in other cases. This should probably be clarified with NALCOR.
• Dr. Bernander made repeated use of examples of landslides in Norway and Sweden which he has studied extensively	• Dr. Bernander is not as familiar with Eastern Canadian Clay formations, however, he does comment that retrogressive landslides tend to be more common in highly over-consolidated clays as is typical in Quebec.
• In examining past landslides: o PFM analysis can be used to explain historical landslides in sensitive clays o PFM analysis indicates that even an insignificant additional load could trigger a landslide o The PLE method gives false safety factors and predicted landslide configurations very different from that of real landslides	• Slope stability analysis on selected landslides in the Churchill River valley used PLE analysis methods (from MF1602 – *Bank Stability and Fish Habitat 2010 Field Investigation Reports*, AMEC, 2011).
• The Progressive Failure analysis method was developed by Dr. Bernander and his colleagues.	• Dr. Bernander and colleagues' model for progressive failure has primarily been developed for failures, where the disturbing agent is located up slope (downward progressive failure). In eastern Canada clay deposits, the majority of large slides (as flow slides and spread failures) are triggered by erosion at the toe of the slope, generating an upward progressive

	failure. • Dr. Bernander is the developer of PFM approach for non-static assessment of downhill land-slide formation. In our opinion, he is promoting the use of his own research and his own work.