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Lower Churchill Management Corporation
350 Torbay Road, Suite 2
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Attention: Scott O'Brien

Subject: Lower Churchill, Phase 1 Development
Agreement LC-G-002
Engineering Procurement and Construction Management (EPCM) Services
Muskrat Falls – Partial Impoundment during Construction

Dear Scott:

We refer to our discussion regarding the above mentioned and write to present an overview of the reasons behind the need for partial impoundment during construction at Muskrat Falls and confirm our recommendation with regard to an impoundment at El. 25.0 m during the fall of 2016.

Topic Overview

Natural Conditions at Muskrat Falls

In natural conditions, the Churchill River downstream of Lake Winokapau remains open most of the time in winter due to its steep slope and high flow velocity. The water surface remains in contact with cold air and large quantities of frazil ice are generated along the river reach. This frazil ice accumulates downstream of Muskrat Falls where the flow velocity drops leading every year to the creation a major ice dam at that location. This phenomenon was recognized at the early stages of the Muskrat Falls project back in the 80's:

"The severe ice conditions at Muskrat Falls site became the governing factor in determining the height of the downstream cofferdams and has caused a great deal of concern in the planning and design of the river diversion program." (Cheung and Guillaud, 1981).

The following presents a summary of the natural conditions at site.

<u>Downstream of Muskrat Falls - Water level</u>

- Open water season : El. 3.0 to 6.0 m;
- Winter season : El. 10.0 to 20.0 m;
- Spring : El. 4.0 to 7.0 m;

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Average to maximum seasonal variation: El. 10.5 to 17.0 m.

Upstream of Muskrat Falls – Water level

- Open water season : El. 16.5 to 19.0 m;
- Winter season : El. 16.5 to 20.0 m;
- Spring : El. 18.5 to 21.5 m;

Average to maximum seasonal variation: El. 2.5 to 5.0 m.

As it may be seen from the ranges above, the significant variation in the downstream water level in winter from one year to another constituted a major challenge in designing and planning the construction of the Lower Churchill Project.

Rational for Partial Impoundment at Muskrat Falls during Construction

The ice jam downstream the project site is a direct consequence of the generation of frazil ice in the river. It is recognized by the industry that the best approach in minimizing the frazil ice generation consists of raising the water level upstream of the critical location and reducing the flow velocity allowing the formation of a thermal ice cover. The result is twofold: first isolate the cold air from the water surface; and second create a storage capacity for the deposition of frazil ice transported from farther upstream. Using this approach at Muskrat Falls, it will be possible to:

- Avoid uncertainties related to ice accumulation downstream of the falls, which occurs in natural conditions and which would otherwise raise the downstream water level.
- Keep the winter downstream water level as low as possible to minimize the size of the cofferdam protection;
- Make the cofferdam protection of the downstream side of the project feasible and cost effective;
- Allow construction of North Dam independent of the season;
- Compress the schedule for completion of the works.

Ice Studies

Over the years, several ice studies were performed to determine the optimum water level to minimize the reservoir impoundment and the construction cost and to maximize the efficiency of the proposed approach (see attachment 1). The first numerical analysis was performed by the LaSalle Consulting Group in 1998. Since 2007, Hatch has performed various ice studies to improve the knowledge of the river conditions during the winter time and to optimize the solution to be implemented during the construction. The main outcomes of these studies are:

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- Apply a well-known approach of reducing frazil ice accumulation and prevent the formation of ice dams by creating a reservoir upstream of the critical location;
- Propose an head pond water level of 25 m to obtain the optimal balance between minimizing the reservoir impoundment level and the temporary structures and reducing or eliminating the ice accumulation immediately downstream of the falls;
- Demonstrate theoretically and from benchmark with other projects that the approach provides control and predictability in the forecasted ice conditions.

Impact on the Design Parameters of the Project

The partial impoundment of the reservoir and the control of the ice accumulation downstream of the project had a major impact in designing the main components of the projects temporary and diversion works and in planning the construction, such as:

- Type of spillway;
- Number of spillway bays;
- Width of spillway bays;
- Height of spillway gates;
- Lower cord elevation of spillway downstream temporary bridge;
- Sequence of construction of spillway rollways;
- Upstream cofferdams crest elevation;
- Downstream cofferdams crest elevation;
- Upstream riprap protection of North Spur;
- Downstream riprap protection of North Spur.

At the same time, operational constraints were defined due to the partial impoundment, i.e.

- Never lower the head pond below elevation 24 m, once raised (for environmental considerations);
- Minimize the reservoir water level fluctuations to prevent landslides and landslide generated waves.

Conclusions

The approach in managing the ice conditions at the Muskrat Falls site during construction, by creating an upstream reservoir, was first proposed back in the early 80's, then thoroughly studied at the end of the 90's and more recently since 2007. Although considering different layouts for the Muskrat Falls development, these studies all recognized the unconditional need of well thought ice management strategy, which would provide predictable conditions at the site under construction. The latest ice studies addressed the layout of the present project and concluded that a partial impoundment to elevation 25.0 m (about 8 m rise of the

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water level in natural conditions) would achieve the goal of significantly reducing the frazil ice that in natural conditions creates ice jam downstream of the site and by that limiting the variation in the winter downstream water elevation. This in turn allows for a reliable and safe design based on the results of ice studies forecasting the ice conditions. Failure to consider this established ice management strategy could lead to an exposure to several risks the most important of which during the winter 2016/17 would be the flooding of the powerhouse excavation and later in 2017/18, the delay in the construction of the spillway rollways and therefore a delay in the final impoundment to full supply level. Since the construction works were designed for head pond water level 25.0 m, there would also be a risk in damaging the structures already built that would eventually require repairs. Finally, should the temporary head pond be drawn down to the natural conditions following a partial impoundment, this could trigger landslides of the reservoir rim that is already recognized as unstable. It may also lead to landslide generated waves that, due to the short warning time and the unpredictability of the intensity, could endanger the safety of the people working at the site.

Recommendation

Considering the thorough approach in establishing the strategy for ice management during construction at Muskrat Falls and the potential risks related in case of failure to apply and follow it, SNC-Lavalin maintains the recommendation to impound and keep the head pond water level at elevation 25m as planned. This would allow for significantly more predictable winter hydraulic conditions, which served as a basis for the design of the temporary and permanent structures of the site and would therefore reduce exposure to adverse and unpredictable conditions that may lead to a safety risk for the people present at site, damage to the already existing geotechnical structures and/or flooding of the powerhouse excavation and the North Dam area.

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Michel Tremblay
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c.c.: R. Power, L Clarke, P. Cattelan, S. Guérette

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Attachment 1

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